QM

Biomass DH Plants

Planning Handbook

Developed by the Working Group
QM for Biomass DH Plants

3rd completely revised edition
C.A.R.M.E.N. e.V. Straubing 2022

QM Holzheizwerke is a **quality management system** for hot water heating systems using biomass. The **output of these systems ranges from about 100 kW upwards and targets** the heat supply of individual buildings or local and district heating networks. This quality management system focuses on the professional design, planning and execution of heat generation systems and district heating networks. Important quality criteria are high operational reliability, precise control, low emissions and economical operation of the whole system.

This quality management system was initially developed in Switzerland in 1998. In 2004, the international **working group QM Holzheizwerke (Quality Management for Biomass District Heating Plants - QM for Biomass DH Plants)** was founded in order to jointly offer quality standards for biomass district heating plants.

This **planning handbook** describes the project process and shows how the quality objectives for a heat generation plant and heating network can be achieved by means of professional planning and execution.

The Planning Handbook is part of the **QM Holzheizwerke series of publications,** of which the following volumes have been published to date:

Volume 1: Q-Guidelines (with Q-plan)
ISBN 978-3-937441-91-7

Volume 2: Standard hydraulic schemes - Part I
ISBN 978-3-937441-92-4

Volume 3: Sample tender for biomass boilers
(Swiss version for one biomass boiler)
ISBN 978-3-937441-87-0

Volume 3: Sample tender for biomass boilers
(Swiss version for two biomass boilers)
ISBN 978-3-937441-88-7

Volume 4: Planning Handbook
ISBN 978-3-937441-96-2

Volume 5: Standard hydraulic schemes - Part II
ISBN 978-3-937441-95-6

The series of publications can be obtained directly from the website of the QM Holzheizwerke working group (www.qmholzheizwerke.ch). Other documents, software tools and FAQs as well as information about current developments on the topic of energy from biomass can also be found on this website. Some volumes of the series have been translated into English, Italian and partly other languages with the support of the EU-Interreg project ENTRAIN (freely available, see www.qm-biomass-dh-plants.com).

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Series of publications QM Holzheizwerke Volume 4

Developed by the Working Group Quality Management
for Biomass District Heating Plants

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translated with support from

CE-INTERREG-Project ENTRAIN

Working Group QM for Biomass DH Plants

For Switzerland:
Holzenergie Schweiz with financial support from the Swiss Federal Office of Energy
www.qmholzheizwerke.ch
www.holzenergie.ch

For Austria:
AEE INTEC - Institute for Sustainable Technologies
www.klimaaktiv.at/qmheizwerke

For Germany:
Baden-Württemberg: HFR - University of Applied Forest Sciences Rottenburg
Bavaria: C.A.R.M.E.N. e.V.
www.qmholzheizwerke.de

For Italy:
APE FVG - Agenzia per l'Energia del Friuli Venezia Giulia
www.ape.fvg.it

International:
Quality Management for Biomass District Heating Plants
www.qm-biomass-dh-plants.com

These websites provide information and publications on the topic of biomass utilisation for heat supply. Software tools can also be downloaded from here.

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ISBN 3-937441-90-5 QM Holzheizwerke series of publications

Volume 4: Planning Handbook

Foreword

On behalf of the Swiss Federal Office of Energy and several Swiss cantons, a quality management (QM) system for larger biomass district heating (DH) plants was developed by Swiss experts in 1998 and subsequently expanded and successively becoming QS-Holzheizung. Based on this, in 2004 representatives from Switzerland, Austria, Baden-Württemberg, Bavaria, Rhineland-Palatinate (no longer active) and from 2020 also Italy joined forces to form the **QM Holzheizwerke working group** in order to jointly create quality standards for biomass district heating plants and offer these under the name QM Holzheizwerke. The focus is on the professional design, planning and execution of heat generation plants and heating networks. Important quality criteria are high operational safety, precise control, good air-hygienic properties and economical fuel logistics. The goal is efficient, low-emission and economical operation of the entire plant.

QM Holzheizwerke (QM for Biomass DH Plants) is designed for hot water and hot water heating systems based on biomass (wood chips, bark, shavings, pellets, etc.) in the **output range from about 100 kW upwards to** supply heat to individual buildings or local and district heating networks. Plants for electricity generation are not taken into account, but it is recommended to consider QM for Biomass DH Plants analogously or as far as possible also for such plants.

This **Planning Handbook is part of the QM Holzheizwerke series of publications**. It explains the project process and shows how the quality objectives for a heat generation plant and heating network can be achieved by means of professional planning and execution. It is aimed in particular at investors, plant operators and planners, but also provides important basic information for training and further education, research and development, as well as for funding agencies and decision-makers in politics and administration. The Planning Handbook is divided into four parts and a supplementary appendix. In the first, introductory part, the basic ideas for rational energy use in the sense of QM for Biomass DH Plants and the first steps of project development are explained. Part two covers the technical and economic fundamentals for the planning, construction and operation of biomass DH plants. The third part describes step by step the planning process all the way to the commissioning and acceptance of the plant. Finally, the fourth part provides know-how on the operation, management, optimisation and modernisation of plants. In the appendix, further information, calculations and aids are summarised and the most important technical terms are explained in a glossary.

In order to take into account the continuous development of technology and know-how, the 3rd edition of the Planning Handbook has been completely revised, updated and supplemented by the team of the QM Holzheizwerke working group. The basis for this is the present state of the art. Currently emerging "new system concepts" such as multi-boiler systems with equipment in series, flue gas condensation in combination with heat pumps or the interaction of biomass DH plants with various other centrally or distributed integrated renewable heat sources (solar thermal energy, geothermal energy, waste heat, heat pumps, etc.) are also covered.

In order to increase readability and to enable a broader, also international application, generally valid formulations were preferred and country-specific information and text sections were largely omitted. As far as possible, the Planning Handbook refers to internationally valid standards and guidelines. Country-specific standards, laws and regulations are not explicitly referenced. These are part of the annex (for Switzerland, Austria and Germany).

The different price ranges in the various countries can only be taken into account to a limited extent in the case of **cost information.** Here the specific explanations for illustrations and information must be observed and, if necessary, the price range must be checked and adjusted according to national conditions.

The contents of this Planning Handbook have been compiled to the best of our knowledge and corrected with all due care. Nevertheless, the authors cannot assume any liability or guarantee for the completeness, topicality, correctness and quality of the information provided. The Planning Handbook is not a substitute for detailed and project-specific planning by specialists and the examination of and compliance with the applicable standards and legal regulations. Liability claims against the authors relating to material or immaterial damage arising from the use of the Planning Handbook are excluded.

The team of authors of the QM Holzheizwerke working group would like to thank the first authors of the Planning Handbook, on whose valuable and comprehensive work the current new edition is based. In addition, we would like to thank the many experts in the industry for their valuable feedback and active participation in the course of the consultation process.

Special thanks also go to the pioneers of the QM Holzheizwerke working group Ruedi Bühler, Hans Rudolf Gabathuler and Franz Promitzer for their commitment to developing and establishing quality standards for biomass district heating plants.

The editing and new edition of the QM Holzheizwerke Planning Handbook was made possible by the financial and personnel support of the following institutions, for which we would also like to express our sincere thanks!

- Schweizer Bundesamt für Energie
- Österreichisches Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie im Rahmen der Klimaschutzinitiative klimaaktiv
- C.A.R.M.E.N. e.V., Bayern
- Holzenergie-Fachverband Baden-Württemberg e.V.

QM Holzheizwerke working group, 28 January 2022

Overview

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Part 1 - Rational use of energy

1 Biomass as an energy source

1.1 Introduction

Forests are valuable ecosystems - habitats as well as working spaces offering utilisation, protection and recreation. In addition, forests reduce CO_2 and using wood as a raw material makes an important contribution to the reduction of greenhouse gases. Forestry and the timber industry are important economic sectors in Central Europe and shape our cultural landscapes. It is essential that forestry occurs sustainably and in harmony with nature. Only this way can we profit from its ecological, economic and social benefits in the long term.

Wood is one of the most important renewable raw materials. The properties of wood make it ideal for a wide range of uses: for buildings, paper, everyday objects - wood plays a major role in engineering and design.

Why energy from biomass?

Economically sensible

- Diversification of the energy supply
- Independence in times of crisis
- Increased guarantee of supply
- Revenues for forestry and timber management
- Regional added-value and creation of jobs

Environmentally compatible

- Renewable and CO_2-neutral
- High efficiency and low emissions
- Short and low-risk transport routes
- Easy preparation and storage
- Storable and available at any time
- Combinable with other regional renewable heat sources

Comfort through biomass district heating

- Proven technology with guaranteed supply
- No maintenance and low space requirement for customers

Log wood has been used for thousands of years for heating, cooking, crafts, steam generation, etc. In recent decades, wood has also gained great importance as an energy source in the form of wood chips and pellets for individual and district heating systems. With resource conservation and waste in mind, mainly biomass as well as by-products of wood processing, which would otherwise be discarded, are used for the production of wood chips and pellets. No additional CO_2 is produced when wood is burned, as only the CO_2 stored during growth is released into the atmosphere.

1.2 Importance of energy from biomass

1.2.1 Origin

The wood demand of the EU and its member countries are covered primarily by our forests and to a lesser extent by recycled waste wood and wood imports. Industrial wood processing involves mainly sawmills, the board and paper industry and downstream operations (carpentry, joinery, furniture manufacturing, etc.). It has priority over wood used for energy. Biomass is obtained from weak wood, damaged wood (e.g. from storm damage or bark beetle infestation), waste wood, but also timber from short rotation plantations or (private) small forests. The remaining wood share for energy use is made up of wood scraps unsuitable for industry (bark, crosscut wood, sawdust, chips, even lye waste from pulp production). Overall, the share of energy use of the total wood supply in the EU is around 60 %. Figure 1.1 gives an overview of the timber flow in the EU in 2015. For sustainable use, regional wood with the shortest possible transport distance is important. Accordingly, the available fuels and their origin depend on regional framework conditions and supply chains.

1.2.2 Use

Heat accounts for more than 50 % of energy demand in the EU. Within the heat sector, households and industry each account for around 40 %, with the remainder divided between the service sector, agriculture and others [1].

Energy from biomass plays a key role in the energy transition - especially in heat generation. But interest in the use of wood and other solid biomass to generate electricity, fuels or chemical products is also on the rise. Around 17 % of the EU's energy demand is covered by renewable energy (Figure 1.2). Here, the share of bioenergy, including energy from wood, energy crops and biogenic waste, is around 60 %. Most of the bioenergy is used to provide heat (74.6 %). The remainder is used for the production of electricity and fuels.

For **heat generation** in detached houses and apartment buildings, manually fed combustion systems (logs, wood briquettes, etc.) or automatic pellet or wood chips heating systems are usually used. The latest, tried-and-tested firing and boiler technologies with high efficiency and low emissions are available from a large number of manufacturers. Biomass district heating systems consisting of a heating plant, a heat distribution network and a heat transfer station can supply heat (heating, hot water, process heat) to heating networks ranging from a few buildings to large cities. The heat is provided by the combustion of wood chips, bark, etc. in fully automated biomass firing and boiler systems that are adapted to the respective fuel used. Individual biomass furnaces are also used in large-scale plants for process heat and steam generation in industry or, as combined heat and power (CHP) plants, also for electricity production. By-products from the wood processing industry (e.g. sawmill by-products, lyes) are often thermally utilised right on site. Surpluses from electricity and heat production can in turn be fed into existing energy grids.

Electricity can be generated from biomass by means of combustion (steam turbines, ORC) or gasification (gas engines) in a fixed-bed or fluidised-bed process. While electricity generation was originally designed primarily for larger plants (plants from 400 kW upwards), biomass gasification plants in the small and micro power sector are now also ready for the market. Operation only brings ecological and economical benefits if heat generated during the production of electricity is used at a high annual thermal and electrical utilisation rate.

The product gas derived from biomass gasification can be used not only for the combined production of electricity and heat, but also for the production of fuels and other chemicals or fed into natural gas grids in processed form. Depending on the plant concept and mode of operation, in addition to gas from biomass, charcoal or pyrolysis oil can also be produced as usable by-products or biochar as a CO_2 sink.

Whatever the product range and configuration of current and future biomass utilisation plants, heat will always be a by-product that must be taken advantage of to ensure that plants operate in a resource-saving and efficient manner.

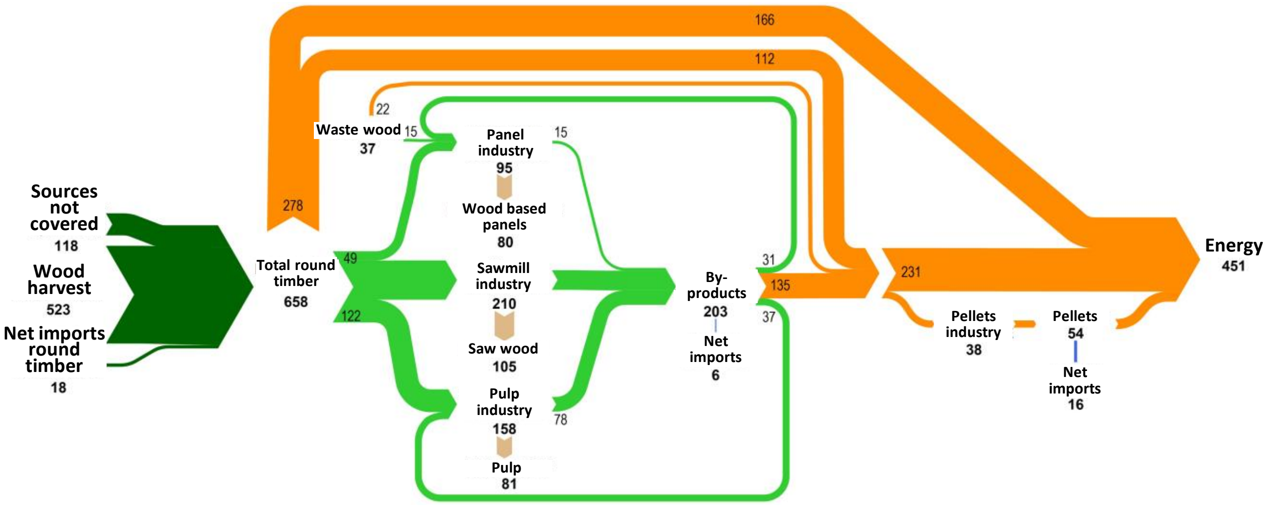


Figure 1.1 Timber flow diagram for the forest-based sector of the EU-28 countries in million harvested solid cubic metres (2015); basic data for the figure taken from ([2], [3]).

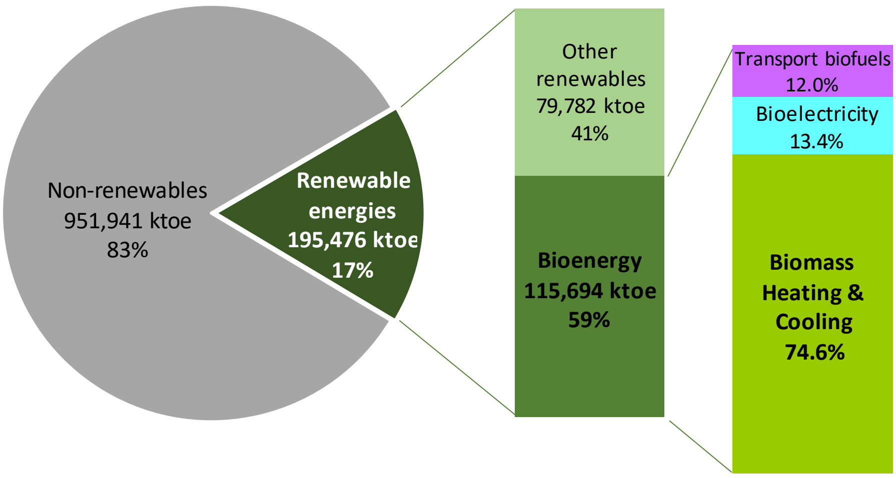


Figure 1.2 Share of renewable energies in the EU's gross energy demand in kilotonnes of oil equivalent (ktoe) and percent as well as breakdown of the contribution of bioenergy (2016); base data for the figure taken from [4].

1.3 The role of energy from biomass in the energy system

1.3.1 Significance in international comparison

In 2017, the global average consumption of primary energy was around 60 kWh per day and person; within the EU countries, this value was significantly higher in 2018 at 100 kWh ([1], [5] - [7]). Even though the share of renewable energy has steadily increased over the past years, around 85 % of the EU's total energy supply is still covered by non-renewable resources (Table 1.1). In most countries, energy from biomass as part of bioenergy represents the largest share of renewables (solid primary biomass). It plays an important role in the transformation towards a renewable energy supply, especially in the heat sector, as its properties are most similar to those of fossil fuels (high heat density, storability, flexibility). Within the EU, Finland, Sweden, Latvia, Estonia and Austria have the largest shares of bioenergy in relation to the number of inhabitants [4].

Table 1.1 Composition of energy sources for total energy supply worldwide [5], in the EU and in selected countries (2018) [1]; data for Switzerland from [8].

* Sum value for wind power, solar energy and other

Total energy supply 2018	World	EU-28	EN	AT	CH	IT
Total [TWh]	**166,098**	**18,742**	**3,543**	**386**	**304**	**1,781**
Non-renewable energy sources	**86.2 %**	**85.0 %**	**85.9 %**	**69.9 %**	**78.8 %**	**80.9 %**
Renewable energy sources	**13.8 %**	**15.0 %**	**14.1 %**	**30.1 %**	**21.2 %**	**19.1 %**
Bioenergy	9.3 %	9.0 %	8.5 %	16.7 %	7.4 %	8.7 %
Solid (incl. wood)	-	*6.2 %*	*4.0 %*	13.9 %	3.8 %	5.6 %
Hydropower	2.5 %	1.9 %	0.5 %	9.8 %	12.3 %	2.7 %
Wind power		2.0 %	3.1 %	1.6 %	0.04 %	1.0 %
Solar energy	2.0 %*	0.9 %	1.5 %	0.9 %	0.9 %	1.4 %
Other		1.2 %	0.5 %	1.1 %	0.6 %	5.2 %

But energy from biomass occupies a special position not only technically, but also economically. While other renewable technologies can largely rely on direct and free energy sources (wind, sun, water, ambient or geothermal heat), the provision of wood fuels requires additional activities such as cultivation, harvesting, processing and transport. The longer supply chain creates permanent regional jobs in the fuel supply sector. In a global comparison of the effect of renewable energy sources on jobss , energy production from solid biomass ranks sixth with 787,000 jobs generated in 2018 [9]. In the EU, energy production from solid biomass ranked first in 2018. With 360,600 jobs in the solid biomass sector (out of a total of 1.5 million jobs in the renewable energy sector), a turnover of 31.8 billion euros was generated [10].

1.3.2 Potential in future energy systems

In numerous studies and energy strategies, bioenergy (solid, liquid and gaseous) is assigned a key role as a substitute for fossil energy sources. This is mainly due to the energy content, the storage capacity and the flexible availability as well as the generally local application of biomass. From today's perspective, it seems unlikely that biomass will be able to completely cover the world's energy needs without conflicting with other priorities such as biodiversity, sustainability, the demand for land, water and food. Nevertheless, biomass will be a mainstay of our future energy supply. Currently, the global share of bioenergy is about 15,447 TWh/a (corresponds to 9.3 % of the total energy supply, see Table 1.1). According to a comparative literature study by Faaij et al [11], the global bioenergy potential for 2050 is estimated at a maximum of 139,000 TWh/a, whereby the energy demand will also increase to the range of 222,000 to 417,000 TWh/a by then. The European potential for 2050, on the other hand, is estimated at a maximum of up to 8,300 TWh/a. These figures should be seen as indicative and may vary depending on regional availability.

Even if wood is used more in the future for the production of fuel, wood gas or chemical raw materials (keyword “bioeconomy”), biomass remains an essential component of renewable electricity and heat supply. However, since the biomass potential will not be sufficient for a complete renewable energy supply, great importance must be attached to efficient biomass DH plants and a resource-conserving and sustainable use of wood as an energy source. In the case of combined heat and power plants for the production of electricity and heat, complete heat utilisation and thus heat output optimised operation is indispensable.

To achieve a fully renewable heat supply, it will also be essential to use other regional and renewable heat sources (solar thermal, geothermal, waste heat and ambient heat with/without heat pumps). Biomass DH plants and local heating networks are an ideal starting point for integrating these heat sources and making them usable. Since this in any case leads to more complex plant configurations and interactions between different heat sources, it is all the more important to pay great attention to comprehensive and detailed planning with special consideration of the requirements of the individual heat generators and their efficient and low-emission interaction.

1.4 Promoting measures for energy from biomass

In order to promote a rapid switch to a fully renewable energy supply and to compensate for unfavourable framework conditions (e.g. lack of or too low CO_2 prices), biomass based energy production plants are promoted in many countries. The most common support measures within the EU are [12]:

- Investment subsidies (non-repayable grants, concessionary loans)
- Feed-in tariffs (fixed prices)
- Feed-in premiums (mark-ups on market prices, operating cost subsidies)
- Tax exemptions or relief
- Tax refund
- Legal regulations (e.g. CO_2 emissions trading, targets for renewable share, CO_2 pricing)

In the electricity sector, mainly feed-in tariffs and feed-in premiums are applied, but increasingly also one-off payments, while investment subsidies dominate in the heating sector. In contrast, tax incentives are used rather less frequently. Since the Paris Climate Agreement of 2015, legal requirements for the promotion of renewable energy have also been increasingly adopted. These include the phase-out of heating oil, natural gas and coal or requirements for a share of renewable energy in residential construction. In total, the bioenergy sector received around €14 billion in support from the EU and its member states in 2018 (€73 billion in total for renewable energy sources) [13]. About 8% of the total EU energy funding is spent on biomass, while still more than 30% (or €50 billion) of funding goes to fossil fuels.

Depending on the country, funding is provided for the construction, expansion and optimisation or refurbishment of biomass heating plants and the associated local and district heating networks, as well as for individual commercial and private biomass plants. The funding rates for investment subsidies are often in the range of 20 to 40 %. Common funding requirements with a focus on the heating sector are:

- Minimum share of renewable energy sources in the overall system
- Efficiency of boiler, heating network and overall system (e.g. benchmarks for boiler efficiency, heat distribution losses)
- Sufficient connection density of the distribution network
- Maximum permissible return temperature
- Minimum CO_2 savings
- More stringent emission requirements than prescribed by law
- Energy source change from fossil to renewable
- Combination with thermal building renovation
- Quality Management for Biomass District Heating Plants (www.qm-biomass-dh-plants.com)
- Other quality assurance requirements

Current and detailed information on funding opportunities and funding procedures should be obtained from the relevant national and regional funding agencies.

The introduction of national/international CO_2 prices, as already implemented in individual countries, is an effective complement and alternative to subsidies to push the switch to a sustainable renewable heat supply based on biomass and other renewable energy sources.

2 QM for Biomass DH Plants

2.1 Origin and objective

Switzerland, Baden-Württemberg, Bavaria and Austria have jointly created quality standards for biomass DH plants and have been offering them under the name “QM Holzheizwerke” since 2004. The focus is on the professional design, planning and execution of the heat generation plant and the heating network. Important quality criteria are high operational safety, precise control, good air-hygienic properties and economical fuel logistics. The goal is energy-efficient, environmentally friendly and economical operation of the entire plant.

QM for Biomass DH Plants is a project-related quality management system. It ensures that quality is defined and checked in a time-limited project in which several companies are involved.

2.2 Why QM for Biomass DH Plants?

Wood heating systems, especially those with heating networks, are long-term undertakings with high investment costs and long depreciation periods. The risks are correspondingly high. It is often difficult to foresee the development of demand because construction activity - both in new buildings and in the renovation sector - is subject to strong fluctuations. Forecasts about the future energy situation, which is currently undergoing a change towards renewable, fossil-free heat generation, are just as tricky.

Professional project management is therefore an indispensable prerequisite for successfully realising and operating a larger wood-fired heating plant with a heating network. Integral components of project management are quality management, set out in the form of a document in which the quality requirements and responsibilities are defined (Q-plan), and the assessment of economic viability, for example with a business plan, before the plant is realised. This ensures that plants are built which achieve a high annual efficiency at low investment costs, can be operated with low maintenance and emissions, and offer a high level of supply security.

Accordingly, QM for Biomass DH Plants is ideal for accessing links to subsidies for biomass DH plants and heating networks. Only a targeted linking of subsidies with quality requirements ensures a target-oriented and long-term sustainable use of subsidies. In Austria, for example, the application of QM for Biomass DH Plants is mandatory in order to receive investment subsidies. The application of QM for Biomass DH Plants in combination with subsidies was described by the EU Court of Auditors as a “particularly recommendable procedure” [14].

QM for Biomass DH Plants provides various quality assurance procedures (Figure 2.1) that can be used for the construction of a new heating plant, a heating network, the replacement of boilers in a heating plant or the expansion of a heating network, depending on the size and complexity:

- **QMstandard®**
  The standard procedure covers the entire planning and implementation process with five milestones (MS1 to MS5).
- **Simplified version of QMstandard®**
  Under certain conditions, the simplified version includes only three of five milestones within the planning and realisation.
  When replacing a biomass boiler or expanding a heating network, simplified requirements can also be applied within individual milestones.
- **QMmini® (qm:kompakt** - qm compact**)**
  This greatly simplified procedure runs in two phases and can only be used for systems without an additional fossil boiler in the specified output range according to Figure 2.1.

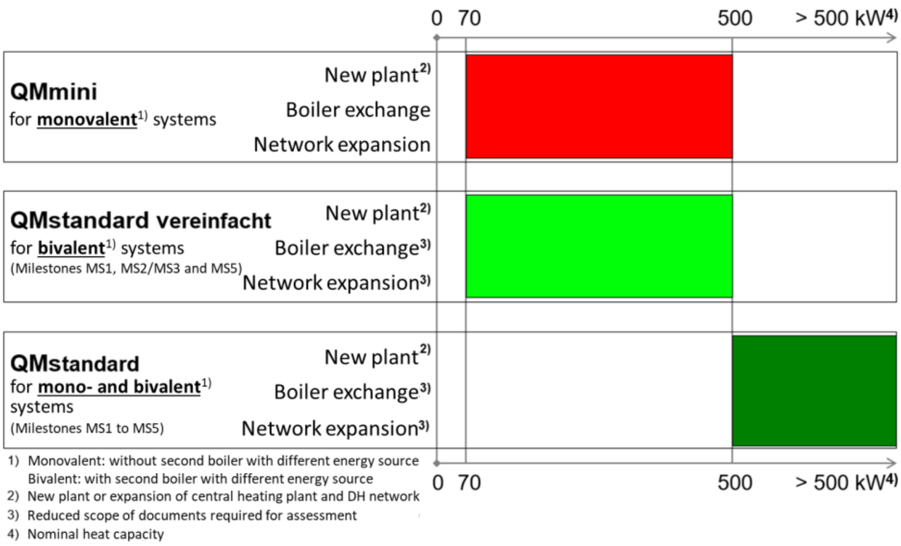


Figure 2.1 Scope of application of QMstandard® and QMmini® in Switzerland.

Based on empirical values, QM for Biomass DH Plants has defined quality requirements (**Q-requirements**). The most important of these are related to the demand assessment and appropriate system selection, the design of the heat generation and the district heating network, the fuel assortment and operational optimisation.

The implementation of a systematic **operational optimisation** after the commissioning of the plant is an integral, mandatory part of the quality assurance with QM for Biomass DH Plants. In the first year of operation, the most important operating data must be recorded and evaluated for different operating states. They form the basis for proving whether the plant meets the agreed quality requirements (Q-requirements) (see chapter 16).

2.3 QMstandard®

2.3.1 Most important project participants

The most important people involved in quality assurance with the QM for Biomass DH Plants procedure are:

- The **client** or an authorised representative determines the quality standard and is responsible for the economic viability of the project.
- The Quality manager (**Q-manager)** ensures that the quality management system "QM for Biomass DH Plants" is defined, implemented and maintained. With this objective, the Q-manager advises the building owner and the main planner. The activities include quality planning, quality checks and quality control.
- **The main planner** is responsible to the client for the quality of the overall system (biomass heating plant and heating network) within the scope of the planning services specified in the engineering contract. A main planner must be designated for project planning in accordance with the QM for Biomass DH Plants.

2.3.2 Tasks and responsibilities

In the usual course of a project, the following tasks are performed by the **client** or the client´s representative:

- Appointment of the Q-manager and commissioning of the main planner. Establishment of QM for Biomass DH Plants - as early as possible.
- Organisation of the project with clear organisational structures as well as precisely defined responsibilities and competences in all task areas.
- Regulation of the organisation and legal form of the sponsorship (operating company) of the wood-fired heating plant.
- Proof of economic viability, for example with the help of a business plan.
- Securing funding.
- Approval of the documents submitted by the project participants.
- Procurement of the necessary official permits and transit rights.

The **Q-manager´s** tasks:

- All administrative work in connection with QM for Biomass DH Plants: setting up the QM system in cooperation with the client and the main planner, organising the necessary meetings, preparing the documents required by QM for Biomass DH Plants.
- Quality planning: Unambiguous definition of the quality requirements in the quality plan (Q-plan) in cooperation with the client and the main planner; ensuring that the Q-requirements listed in the Q-plan comply with the recognised rules of technology.
- Quality check: Check at each milestone whether all documents and data are available and whether the quality requirements agreed in the Q-plan are within the agreed tolerance.
- Quality control: Ensure that quality deviations are identified and corrected in good time; if quality deviations are identified, the Q-manager must work with the client and the main planner to find solutions.

The Q-manager does not assume any legal responsibility for the realised system. This is the responsibility of the main planner and the manufacturers within the scope of their commissions and in the final responsibility towards the building owner.

The **main planner** is responsible to the client for the quality of the biomass heating plant within the scope of the planning services specified in the engineering contract. The required quality is specified in the Q-Plan of QM for Biomass DH Plants in six sub-areas:

- Demand assessment and appropriate system selection
- Heating network
- Heat generation
- Plant documentation
- Acceptance
- Operational optimisation

2.3.3 Planning process with milestones

Figure 2.2 gives an overview of the process of QM for Biomass DH Plants and the planning steps. The procedure and planning steps are described in detail in the quality guidelines (Q-Guidelines) (see chapter 2.3.4 and [15]).

The Q-manager is appointed by the client and assumes responsibility for the implementation of QM for Biomass DH Plants. The main planner is also appointed by the client and is responsible for the overall planning of the plant. Together they record the quality requirements in the Q-plan main document (milestone MS1). The planning process is divided into five project phases. QM for Biomass DH Plants is already established at the preliminary study stage with Milestone 1, so that quality planning (Q-planning) can begin as early as possible. Milestones 2, 3 and 4 are then used for quality checks (Q-checks) and quality control (Q-control) during the course of the project. This ensures that quality deviations are detected and corrected in time. The conclusion of QM for

Biomass DH Plants is Milestone 5 after at least one year of operational optimisation.

In detail, the procedure and the application of QM for Biomass DH Plants in individual countries can be adapted to the framework conditions there, so that a conformity with the respective customary planning and funding procedures is given. This can mean, for example, adapting the areas of application and designations of QMstandard, its simplified version, QMmini or adapting or supplementing individual documents or quality criteria. Country-specific adaptations are not discussed in detail here. The respective national contact points of QM for Biomass DH Plants can provide more detailed information.

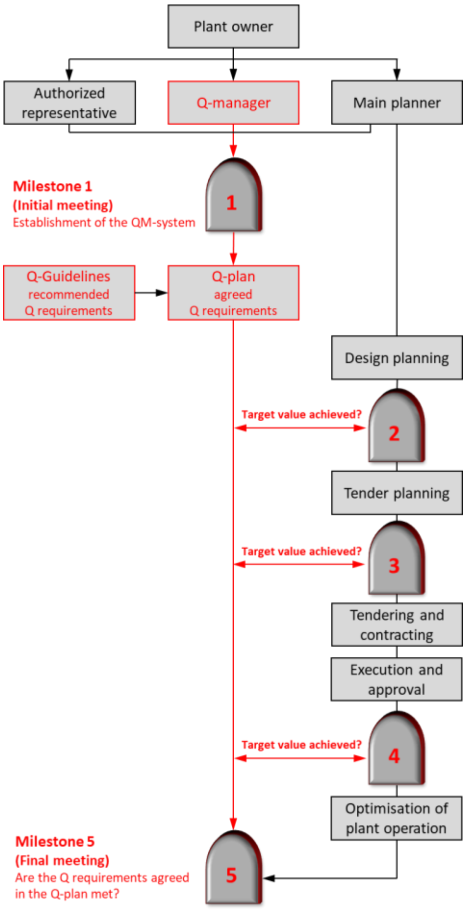


Figure 2.2 Process of QM for Biomass DH Plants.

2.3.4 Q-plan

QM for Biomass DH Plants should require as few documents and administrative effort as possible. The central document is the Q-plan, consisting of two parts:

- the main document that is created during the establishment of QM for Biomass DH Plants in Milestone 1. Here, the quality requirements and responsibilities are agreed and defined on a project-specific basis before the plant is realised.
- the additional document with an EXCEL table, which is created by QM for Biomass DH Plants when each further milestone is reached. The supplementary document is used for quality checks and quality control during the course of the project.

2.3.5 Q-Guidelines

An integral part of the Q-plan are the Q-Guidelines [15]. It describes the process of QM for Biomass DH Plants. In addition, it describes in detail the quality requirements that must be met today in the planning and construction of a wood-fired heating plant with a heating network. The Q-Guidelines and Q-plan (main document) have the same structure, so that both documents can be used in parallel in a very simple and practical way:

A. Project participants
B. Establishment of QM for Biomass DH Plants
C. Project schedule with milestones
D. Services provided by the client
E. Services and Q-requirements Main planner
F. Fuel definition

In the annex, the Q-Guidelines contain the following further information:

- Special regulations for Austria
- Maximum flow velocities for capillary tubes
- Graphics:
  - Heat distribution losses as a function of connection density
  - Specific costs of heat generation
  - Specific costs of heat distribution
- Q-requirements for heat generation (tabular overview)
- Minimum daily heating load for low-load operation
- Checklists for milestones MS1 to MS5 according to QMstandard. Further checklists for boiler replacement and for network expansion.
- Q-plan main and additional document (sample)

2.3.6 Tools for planners

QM for Biomass DH Plants provides further tools for planners. The most important are:

- **Standard hydraulic schemes:** Collection of proven solution concepts for heat generation variants. They contain detailed documents such as principle schemes with designation and positions of measuring points, hydraulic design of the boiler circuits, a functional description of the various control circuits with control diagram, a measuring point list for optimising operation and specifications for data recording. They also contain information on the design of the capillary and the control of the capillary pumps. Word documents for the individual standard hydraulic schemes are available to the planner, which are filled in and adapted according to the project.
- **Sample tender** for systems with one or two biomass boilers: The planner can use a Word document as a tender template, which contains the essential elements of a tender and which can be completed and adapted according to the project.
- **Planning Handbook**: The present handbook provides a detailed description of the planning process

and the state-of-the-art biomass DH plants with district heating networks. Furthermore, it describes the requirements for the optimal operation and provides basic knowledge for all important aspects of planning and for the most important plant components.

- **Checklists** for milestones MS1 to MS5 according to QMstandard (Q-Guidelines [15]): They describe the documents to be submitted for the respective milestone. Checklists for new installations, for boiler replacement and for network expansion.
- Excel tool for **demand assessment and appropriate system selection**: In the tool, the basic customer data (annual heat demand, power demand, energy reference area) are checked for plausibility. The climatic conditions of the plant location as well as the length and heat losses of the district heating pipeline are specified. On this basis, the tool enables an initial design of heat generation and heat distribution at the beginning of the project and checks compliance with the most important Q-requirements. As the planning progresses, the data is updated in the further milestones (see chapter 11).
- **Excel tool "Erneuerung Holzenergieanlagen" (refurbishment of biomass district heating plants)**: The consultation tool "Erneuerung Holzenergieanlagen" is an Excel file [16]. The most important system-specific data for the assessment can be entered here. After the input, the user receives a rough analysis through an automatic data evaluation with benchmarks. With the tool it is possible to give recommendations and to refer to further tools and information. It is freely available to planners, consultants and plant operators.
- Excel tool **Economic Profitability Calculation**: This tool is used to create a budgeted balance sheet and budgeted income statement over a plant operating period of 25 years. The tool can be used to determine tariff models and cost development over the project duration, economic bottlenecks and the success of the project at an early stage (see chapter 10).
- **FAQs:** The QM for Biomass DH Plants working group provides further specific information on frequent technical questions (FAQs) on its website [17].

Quality assurance with QM for Biomass DH Plants requires the exchange and constant updating of information and documents in the course of the project. In the simplest case, this can be done by e-mail and paper. A helpful alternative can be a simple cloud solution with a standardised folder structure and specific access rights where the QM-relevant documents of a project are saved.

Database as a tool for the project process

In Austria, due to the large number of QM projects, a database with a web interface was developed to handle the entire QM process. This ensures that all project participants as well as federal and provincial funding agencies have access to the same information and documents:

- Central access point for all project participants (client, planning companies, Q-managers, funding agencies, higher-level QM management)
- Specific access rights per project
- Allocation of roles and specific authorisations according to the Q-Guidelines for the client, the main planner and the Q-manager.
- Complete mapping and documentation of the QM process incl. read-only formatting at milestone completion
- Upload and download function for all documents
- Automatic notifications for milestone completions
- Upload and automated evaluation of annual operating reports
- Higher-level evaluation of the quality progress of the recorded biomass DH plants and heat networks
- Direct link to funding processing
- Important data basis for funding agencies, political and administrative authorities

2.4 QMmini

2.4.1 Scope of application

QMmini was developed as a supplement to QMstandard for systems in the output range between about 100 kW and 500 kW and has been offered since 2011. In order to be able to achieve the same quality objectives more easily, the scope of application is not only restricted in terms of output, but also limited to simple systems with monovalent installations, i.e. installations with one or more biomass boilers. QMmini can also be applied to existing systems, e.g. when replacing an existing biomass boiler or when expanding the existing heating network.

Figure 2.1 shows the scope of application and the demarcation between QMmini and QMstandard.

2.4.2 Procedure

QMmini runs in two phases. In phase 1, the design of the plant is reviewed in the project form QMmini. In phase 2, analogous to milestone MS5, various documents and information on the operational behaviour of the plant are analysed and recorded in the final QMmini message.

2.4.3 Documents and tools

QMmini provides the following tools for planners and installers in Switzerland for download:

- Project procedure for quality support QMmini
- Guidelines for quality support QMmini
- Project form QMmini with example (Excel-based).

In Austria, a similar procedure for "local heating systems" below 400 kW is offered under the term qm:kompakt.

3 Project development

3.1 From the idea to the kilowatt hour

Every biomass district heating project starts with an idea. This can have a number of triggers:

- Good examples
- Climate policy objectives
- Upcoming replacement of fossil heating systems (e.g. in public buildings)
- Sales problems for low-quality biomass fuels
- Political mandate
- Spatial planning requirements (e.g. energy master plan)
- Trade associations, energy agencies, planning offices

Experience shows that the path “from the idea to the kilowatt hour of heat or electricity” is long, and often only a few ideas result directly in the construction of a plant. Sometimes an idea needs several attempts until the time is ripe for project implementation. The challenge is, to have a simple concept at an early stage, which enables a decision to be made between further development and abandonment of the project. If the decision is then made in favour of further development of the project, the complex planning phase begins. The challenge here is to successfully complete the path without later abandoning the project. An overview of the project development process according to QM for Biomass DH Plants can be found in the Q-Guidelines [15].

Between the idea and the commissioning of the plant, the focus is on discussing and answering **technical and economic** questions. Especially in the early project phase, however, it is always about **non-technical** aspects as well. Every major biomass district heating project triggers interpersonal processes. Whether it is the establishment of an operating company or the acquisition of heat customers. These processes can sometimes be just as challenging and decisive for the success of the project as the choice of the right plant technology.

The early project phase is crucial for the establishment of QM for Biomass DH Plants. The earlier the standards and recommendations of QM for Biomass DH Plants are incorporated into the project, the easier their implementation will be later on.

Various people and stakeholders are involved in the development of a biomass district heating project (see Figure 3.1). They not only have dissimilar interests, but also different perspectives and expectations. It is crucial to bring them together constructively.

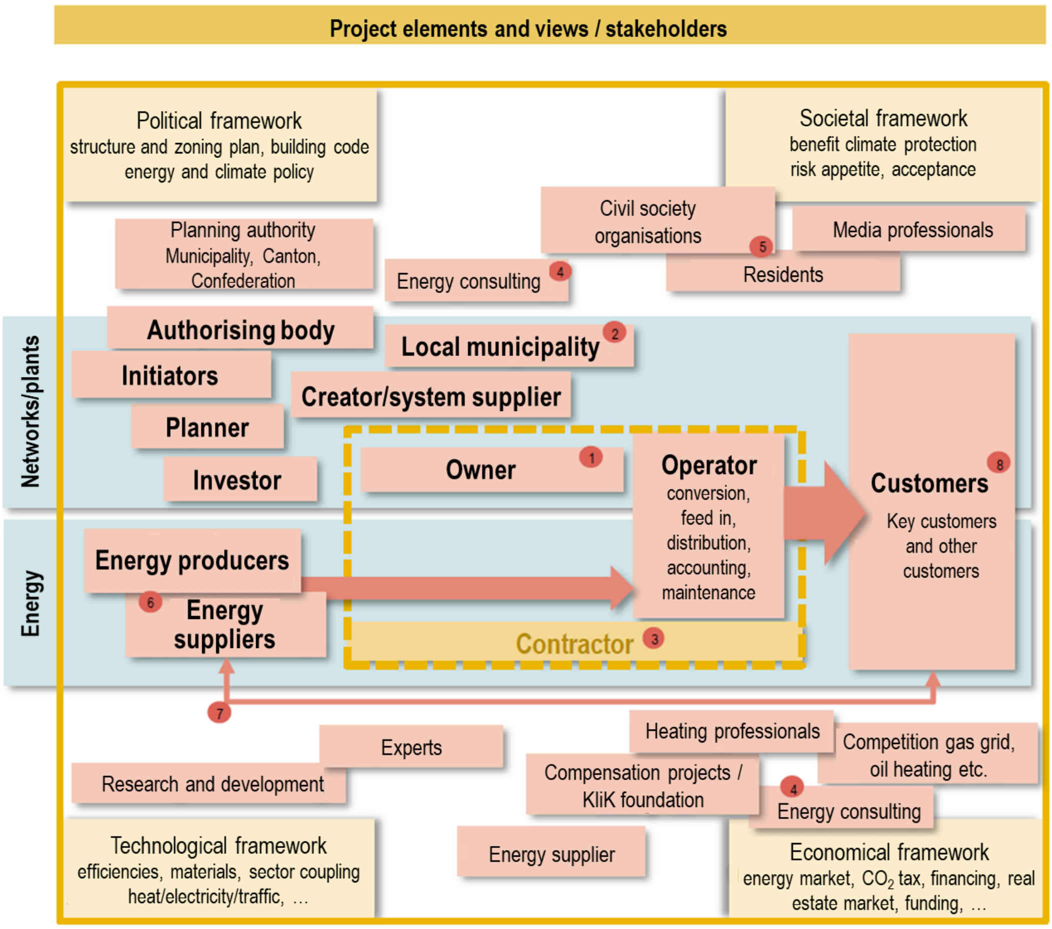


Figure 3.1 Project elements and perspectives of the different stakeholders [18].

3.2 Feasibility study

The basis for the fundamental decision as to whether an idea should be pursued or discarded is usually a feasibility study (other terms are preliminary study, rough analysis, preliminary planning, project and planning preparation, etc.). The feasibility study serves to create a reliable basis for deciding whether or not to implement a project.

Since biomass district heating plants are long-term infrastructure projects with a high initial investment, the feasibility study is of great importance and should accordingly be prepared comprehensively and by experts. It does not include detailed or implementation planning and can in no way replace it.

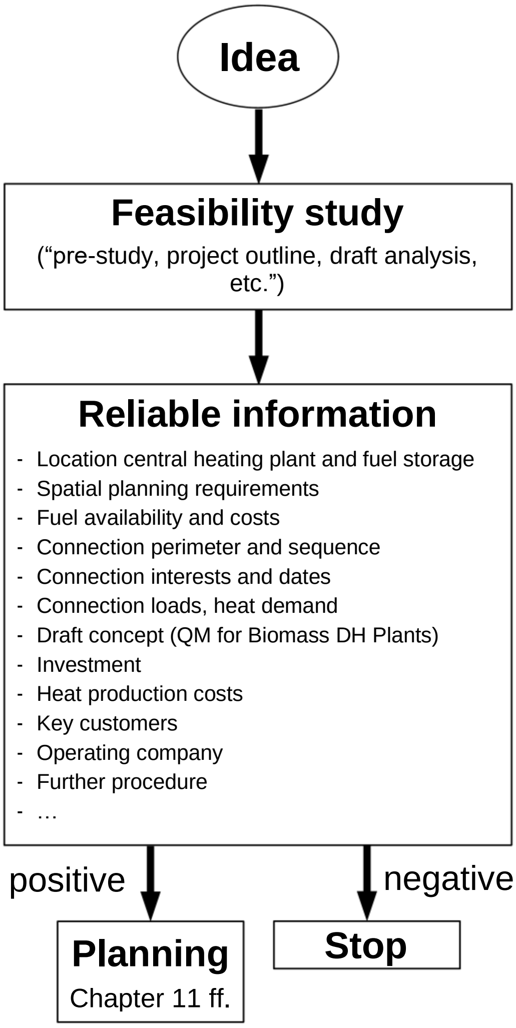


Figure 3.2 Integration of the feasibility study into the project development.

The feasibility study is usually carried out still without an operating company (sponsorship) and no project guarantee. Therefore, its financing is often a challenge. If municipalities or energy supply companies are involved in the project idea, they sometimes take over the financing. There is also the possibility of using low-cost consultants from professional associations, energy agencies, etc. to support the early project development phase. Sometimes planning offices are the initiators of a project idea and make advance payments. Depending on the country-specific framework conditions, participation or funding by the federal government, federal states/cantons or other agencies in the financing is also possible.

Figure 3.2 shows which questions need to be clarified in a feasibility study so that a decision is possible. However, these must always be defined on a case-by-case basis. The project development and the subsequent planning process can be supported by an accompanying risk analysis in order to be able to identify and consider potential risks at an early stage.

3.2.1 Location of central heating plant and fuel storage

Due to intensive construction activity and the expansion of residential areas, it is becoming increasingly difficult to find suitable locations for heating plants and fuel storage facilities. Ideal locations are therefore commercial and industrial areas, existing expanding centres or merging two or more existing heating plants. For the acceptance of further project development, it is advantageous if several locations are evaluated as part of the feasibility study. The evaluation of possible locations for the heating plant and fuel storage is therefore one of the first and most important tasks in the context of project development and should be tackled as early as possible. Today it must be kept in mind that more and more locals are making use of their right to appeal a decision The larger the plant is to be, the more important this aspect is. If no site can be found, the clarification of the other questions may become obsolete. The most important criteria for the site evaluation are:

- Space conditions and existing infrastructure (electricity, water, sewage, telecommunications, etc.)
- Suitable access for fuel delivery (e.g. avoiding access through residential areas, schoolyards, etc.).
- Security of supply for fuel and operating material
- Topography (e.g. unfavourable at the foot of inhabited slopes)
- Wind direction
- Ownership
- Proximity to the supply area (avoidance of long district heating pipes)

3.2.2 Requirements for spatial planning

As part of the site evaluation, the conformity of the planned site with the country and site-specific framework conditions of spatial planning must also be examined. Sites in an agricultural zone or forest require country-specific approval and rezoning procedures. The time required for this must be taken into account for project development.

3.2.3 Fuel availability

Regionality is an important argument for the development of biomass district heating projects. Therefore, the regional fuel availability and security of supply must be clarified at an early stage. This includes in particular the quality and the costs. It is often advisable to sign preliminary contracts with potential fuel suppliers. In the case of large biomass DH plants, it is advisable to verify the fuel supply (see chapter 4).

3.2.4 Connection perimeter and connection interest

With the help of the heat procurement density or the connection density (see chapter 12), an initial, provisional connection perimeter can be defined easily. Ideally, this is grouped around established large consumers interested in a connection (key customers), who form the framework of the heating network. The interest among the key customers is determined by means of a survey, if it is not already known. The most important information is:

- Basic interest in connection
- Expected connection time
- Average previous final energy demand
- Age of the existing heating system
- Planned extensions or renovations of building services.

The question about the basic interest in connection is initially asked without specifying binding heating prices, as these can only be determined in detail once the project has reached a certain stage of development. The answers are therefore non-binding and not very reliable. The decision to connect depends primarily on the heat production costs. These are determined by the number of properties to be connected as well as the connected load and the connection date. Therefore, key customers are extremely important. The detailed procedure is also listed in the Handbook on Planning of District Heating Networks [19].

The results of the survey can be used to determine initial reference values for connected load and energy demand and to draw up an initial demand assessment (see chapter 11).

3.2.5 Draft concept

It is advisable to draw up an initial draft concept for the plant at a very early stage. This ensures that, on the one hand, the standards and requirements of QM for Biomass DH Plants and, on the other hand, the respective legal regulations (e.g. air pollution control, ash disposal) are taken into account right from the start.

3.2.6 Investment and heat production costs

The investment and heat production costs are estimated on the basis of quotations, experience and reference values. The heat production costs enable the non-binding connection interests registered in the first heat demand survey to be substantiated with costs in order to query the interest of potential heat customers again.

An informative meeting with potential customers has proven to be a good idea. People who have taken part in the survey subsequently expect information on the results. At the same time, such events serve to acquire additional customers.

The heat costs should already be given in the form of a three-part heat tariff (see chapter 10.5) and compared to the costs of other types of heating.

3.3 Other aspects

3.3.1 Funding

Investments are often financed by one-off connection fees, by own funds, by subsidies and by loans. Ideally about 25 % of the investment costs are covered by one-off connection fees. In the case of financial support from the public sector, the conditions of the bank loans become significantly more favourable. Financing through provident foundations (e.g. pension funds) "green" or sustainable forms of investment (funds, bonds, etc.) or citizen participation models can also be interesting.

3.3.2 Operating company

In principle, the following company forms are suitable as operating companies:

- Private company
  - Sole proprietorship
  - Partnerships (e.g. civil law partnership)
  - Corporations (e.g. public limited company, limited liability company)
  - Cooperatives
- Public enterprise
  - Form not governed by private law (e.g. municipal own business)
  - Private law form (e.g. purely public limited company)

The most suitable form of company depends on various factors (financing, structure of the customers, role of the public sector, etc.) and must always be clarified on a case-by-case basis. If it is not possible to form a separate operating company, contracting is an additional alternative.

3.3.3 Success factors and "stumbling blocks"

The most important **success factors** during the early phase of project development are, according to the report "Sozioökonomische Aspekte thermischer Netze" [18]:

- Professional project development and feasibility study
- Consideration of socio-economic aspects
- Identification and classification of stakeholders with regard to motivation, scope for action and decision-making mechanisms
- Early clarification of responsibilities
- Communication of clear benchmarks from the outset (e.g. target values for connection density, heat production costs, required connection progress, etc.).
- Key customers
- Visits to existing, similar examples by authorities, residents and other interested parties
- Person who drives the project
- Step by step expansion of the headquarters and the district heating network
- Support from public authorities
- Emphasising benefits for the forest (supporters)
- Early, transparent information
- Emphasising benefits of biomass: renewable, CO_2-neutral and climate-friendly, regional value and others

The most important **"stumbling blocks"** during the early phase of project development are, according to the report "Risiken bei thermischen Netzen" [20]:

- Insufficient or delayed information
- Overestimation of the connection potential
- Objections and complaints
- Time pressure (road works, key customers, etc.)
- Reduction to single aspect (e.g. fine dust emissions)
- Fear of dependence
- Communication of bad examples
- Negative press

Part 2 - Basics

4 Energy from biomass

4.1 Introduction

Fuel quality is a significant aspect of biomass heating plants. Not only fuel costs, but also the quality of the wood used has an impact on the operating and maintenance costs as well as the efficiency of the plant and the generation of air pollutants. Quality parameters are therefore increasingly important points in supply contracts between plant operating companies and fuel suppliers.

In addition to anthropogenic influences (e.g. contamination with mineral material such as gravel or soil from storage sites), it is mostly natural parameters that are decisive for the quality of biomass. The naturally determined fuel composition affects three essential aspects in the operation of biomass heating plants. The net calorific value (NCV) [MJ/kg] is largely determined by the combustible wood components carbon and hydrogen. It decreases with increasing water and ash contents. Ash content and composition influence fouling and slagging processes as well as corrosion and thus have an impact on maintenance costs.

Nitrogen oxide and dust emissions are directly linked to fuel quality. Other exhaust gas components (e.g. CO_2 or CO) do not depend directly on the fuel used [21]. The following chapter is intended to enable plant operators to assess fuel qualities.

4.2 Elementary composition of wood fuels

Wood as a fuel consists largely of the main elements carbon, hydrogen and oxygen (Table 4.1). Depending on the type of fuel, nitrogen and sulphur can also occur in concentrations > 1 %. The calorific value is essentially determined by the contents of carbon and hydrogen. Oxygen bound in the fuel supports the oxidation process. Sulphur contributes to the calorific value of a fuel and is oxidised to SO_2 or SO_3. After combustion, it can react further to form other compounds. Sulphur oxides (SO_x) are undesirable emission components because they pollute the air. Nitrogen bound in the fuel is the essential factor in the formation of unwanted nitrogen oxide emissions (NO_x) for wood firing systems.

Secondary elements are the decisive ash formers. The ash content of a fuel influences the calorific value and, in conjunction with the plant technology, has an impact on dust emissions. In addition, ash content and ash composition are significant influencing variables with regard to fouling and slagging of the plant. Special attention is paid to elements potassium, sodium, chlorine and sulphur. The two elements potassium and sodium contribute to lowering the ash softening point. They influence corrosion processes, fouling (e.g. on heat exchanger pipes) and slagging due to the formation of alkali chlorides. Undesirable compounds such as hydrogen chloride (HCl) and dioxins and furans (PCDD/F) can be formed from the chlorine bound in the fuel. Chlorine and sulphur compounds have a corrosive effect.

Trace elements are found in wood fuels mainly in the form of heavy metals that are absorbed from the environment during the growth of trees. These can be present in fuels in very different concentrations and have a toxic effect. After combustion, the heavy metals (which are vapourised in the flue gas) condense or ad/absorb onto ash, with few exceptions. They are thus bound in the ash and can be removed from the natural cycle (e.g. by landfilling or processing). In the case of wood fuels, heavy metals influence the ash quality, especially with regard to their recyclability (see chapter 9).

4.3 Reference states

Biogenic solid fuels consist of combustible and non-combustible substances. Non-combustible components comprise the water and ash components of the fuel, while the organic component releases energy in oxidation processes. While organic matter as well as mineral and ash contents usually lie within a certain range of values depending on site conditions and wood species, the water content can vary greatly. In order to be able to compare fuel analyses, reference states are defined (Figure 4.1).

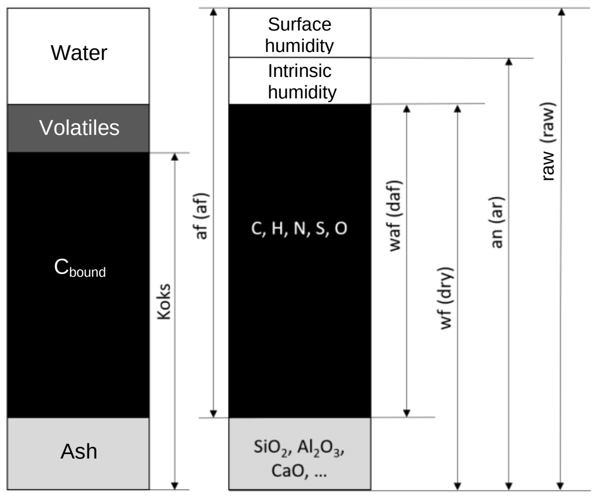


Figure 4.1 Reference states of solid fuels.
raw: raw state
an (ar): analysis moist
wf (dry): water-free
af (af): ash-free
waf (daf): water- and ash-free

Table 4.1 Elemental composition of energy wood.

Category	Main elements	Secondary elements	Trace elements
Elements:	Carbon C Oxygen O Hydrogen H Nitrogen N	Phosphorus P Potassium K Sodium Na Sulphur S Calcium Ca Silicon Si Magnesium Mg Chlorine Cl	Boron B Copper Cu Iron Fe Manganese Mn Zinc Zn Lead Pb Chromium Cr Arsenic As Cadmium Cd Other elements
Scale:	> 1 % or > 10,000 mg/kg	0.01 - 1 % resp. 100 - 10,000 mg/kg	< 0.01 % resp. < 100 mg/kg
Influence on:	Energy content	Ash quantity/behaviour, emissions, corrosion	Ash utilisation, emissions

For example, the net calorific value for a fuel sample in the anhydrous state is NCV_{wf} = 19 MJ/kg. When delivered to the heating plant, the same sample in its raw state would have a net calorific value of NCV_{raw} = 8.2 MJ/kg with a water content of 50 % and an ash content of 0.5 %. Five reference states are distinguished for the precise specification of analysis results for biogenic solid fuels and for their comparison [22]:

- Raw state - raw (raw)
- Analysis moisture - am (as received): sample in air-dry state
- Anhydrous - wf (dry, d): specification refers to dry fuel
- Ash free (af): specification refers to the ash-free fuel.
- Water and ash free - daf (dry, ash free): specification refers to the water and ash free fuel.

A **conversion of analysis results** related to different fuel states is possible with the following three formulas.

$$X_{wf} = \frac{x_i}{1 - \gamma_{H_2O,1}}$$

$$X_{af} = \frac{x_i}{1 - \gamma_{A,1}}$$

$$X_{daf} = \frac{x_i}{1 - \gamma_{A,1} - \gamma_{H_2O,1}}$$

X_i	Parameter in reference state i
γ_{Xi}	Mass fraction of the fuel parameter X in the reference state i [kg/kg] (A … Ash)

The **net calorific value** takes into account the enthalpy of vaporisation of the water contained in the fuel (2.441 MJ/kg H_2O).

$$NCV_{daf} = \frac{NCV + 2.441 * \gamma_{H_2O}}{1 - \gamma_A - \gamma_{H_2O}} \left[\frac{MJ}{kg}\right]$$

4.4 Important parameters

4.4.1 Water content and wood moisture

Wood fuels always contain a certain amount of water, which varies widely depending on the type of wood, time of harvest, storage location and duration and has a considerable influence on the quality of wood combustion. The water content is composed of the surface moisture of the wood (caused, among other things, by external influences such as precipitation) and the intrinsic moisture (stored water in cell walls, cell cavities and cell interstices).

The water content is indicated either as water content or wood moisture content (also wood humidity). These specifications differ in their different reference values. In accordance with DIN EN ISO 17225, they are given in mass percent (wt-%) [23]. The **water content M** is the most important quality parameter for wood fuels. It describes the water m_w in the moist fuel in relation to its total mass, which is composed of the mass of the anhydrous fuel m_B and the water mw contained in it.

$$\gamma_{H_2O} = \frac{m_w}{m_B + m_w}$$

$$M = \frac{m_w}{m_B + m_w} * 100$$

γ_{H2O}	Mass fraction of water in the fuel [kg/kg].
M	Water content [wt-%]
u	Wood moisture [wt-%]
m_w	Mass of water in the fuel [kg]
m_B	Mass of anhydrous (biomass) fuel [kg]

In contrast, the **wood moisture u** describes the amount of water m_w bound in the fuel, related to the anhydrous amount of fuel m_B. Values > 100% are therefore possible for u.

$$u = \frac{m_w}{m_B} * 100$$

In the field of energy use, the indication of the water content has become widely accepted. The indication of the wood moisture content is rather uncommon outside traditional forestry. The wood moisture can be calculated from the stated water content and vice versa (Table 4.2).

Table 4.2 Conversion of water content M - wood moisture u.

Water content M [%]	Wood moisture content u [%]
0	0
20	25
25	33
40	67
50	100
60	150

4.4.2 Ash content

Ash content is the amount of ash that remains when the fuel is completely burnt. The ash contained in a fuel consists of its inorganic portion, mainly the minor elements listed in chapter 4.2 such as silicon, potassium or sodium. The ash also contains a large proportion of the trace elements or heavy metals which are deposited on the ash after combustion. For example, if the iron concentration in a fuel is 50 mg/kg (wf), an ash content of the fuel of 0.5 % (wf) (i.e. 5 g of ash per 1 kg of anhydrous fuel) increases the iron concentration in the ash (assuming that the iron is completely present in the ash as Fe_2O_3) to 10,000 mg/kg (chapter 9).

The ash content A is calculated from the mass of the ash m_a in the fuel in relation to the mass of the fuel used $m_{B,i}$ (specifying the reference state i).

$$\gamma_{Ash} = \frac{m_A}{m_{B,i}}$$

$$A = \frac{m_A}{m_{B,i}} * 100$$

γ_{Ash}	Mass fraction of ash in the fuel [kg/kg].
A	Ash content [wt-%]
m_A	Mass of ash in the fuel [kg]
$m_{B,i}$	Mass of the fuel in the reference state [kg].

4.4.3 Net and gross calorific value

The heat released during the (complete) combustion of wood fuels is given as net calorific value (NCV) or gross calorific value (GCV). The gross calorific value (also "higher heating value") describes the absolute amount of energy released during combustion of a specified amount of fuel [MJ/kg]. In addition to the sensible heat released, this value also includes the energy that is in the form of water vapour in the flue gas (latent heat) and can be made usable through condensation ("condensing technology"). In biomass combustion systems, the water usually escapes with the flue gas in the form of steam. The enthalpy of vaporisation of the water released during condensation can therefore not be utilised. The energy content of wood is therefore usually given as the net calorific value (also "lower heating value"). This value indicates the energy content of a fuel [MJ/kg] minus the amount of energy contained in the flue gas in the form of water vapour. It is linearly dependent on the water content of the fuel (Figure 4.2). Table 4.3 illustrates the influence of the water content on the calorific value.

The calorific value is determined calorimetrically in the laboratory according to EN ISO 18125:2017-08 [24]. During wood combustion, water vapour is produced on the one hand from the water contained in the fuel and on the other hand from the reaction of the hydrogen bound in the fuel with oxygen. To calculate the net calorific value (NCV) from the gross calorific value (GCV), the amount of energy released during the condensation of this water vapour is subtracted from GCV.

$$NCV = GCV - h_V * \gamma_W \left[\frac{MJ}{kg}\right]$$

$$\gamma_W = \frac{M_{H_2O}}{M_{H_2}} * \gamma_{H_2} + \gamma_{H_2O} \left[\frac{kg}{kg}\right]$$

$$NCV = GCV - 2.441 * \left(8.937 * \gamma_{H_2} + \gamma_{H_2O}\right) \left[\frac{MJ}{kg}\right]$$

γ_W	Specific water content of the exhaust gases during complete combustion [kg/kg].
h_V	Evaporation enthalpy of water h_V = 2.441 MJ/kg
M_i	Molar mass of the fuel parameter i [kg/kmol].
γ_i	Mass fraction of the fuel parameter i [kg/kg]

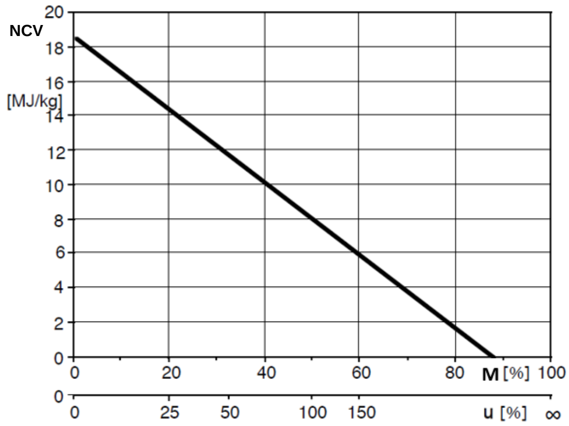


Figure 4.2 Net calorific value (NCV) of wood as a function of water content M and wood moisture u.

Table 4.3 Calorific value of wood as a function of water content M for different tree species and units of measure. Assumption for calorific value in kWh/kg (anhydrous reference basis): 5.2 for softwood and 5.0 for hardwood [25].

Water content M in [wt-%]		0	5	10	15	20	25	30	35	40	45	50	55	60
Tree type/density[1)]	Unit of measurement	Net calorific value as a function of the water content M												
	kWh/kg	5.20	4.91	4.61	4.32	4.02	3.73	3.44	3.14	2.85	2.55	2.26	1.97	1.67
Spruce	kWh/fm	1,971	1,957	1,942	1,925	1,906	1,885	1,860	1,832	1,799	1,760	1,713	1,656	1,584
379 kg_{wf}/fm	kWh/rm	1,380	1,370	1,360	1,348	1,334	1,319	1,302	1,282	1,259	1,232	1,199	1,159	1,109
	kWh/LCM	788	783	777	770	763	754	744	733	720	704	685	662	634
	kWh/kg	5.20	4.91	4.61	4.32	4.02	3.73	3.44	3.14	2.85	2.55	2.26	1.97	1.67
Pine	kWh/fm	2,241	2,226	2,209	2,189	2,168	2,144	2,116	2,083	2,046	2,001	1,948	1,883	1,802
431 kg_{wf}/fm	kWh/rm	1,569	1,558	1,546	1,533	1,518	1,500	1,481	1,458	1,432	1,401	1,364	1,318	1,261
	kWh/LCM	896	890	883	876	867	857	846	833	818	801	779	753	721
	kWh/kg	5.00	4.72	4.43	4.15	3.86	3.58	3.30	3.01	2.73	2.44	2.16	1.88	1.59
Beech	kWh/fm	2,790	2,770	2,748	2,723	2,695	2,664	2,627	2,586	2,537	2,480	2,411	2,326	2,221
558 kg_{wf}/fm	kWh/rm	1,953	1,939	1,923	1,906	1,887	1,864	1,839	1,810	1,776	1,736	1,687	1,628	1,555
	kWh/LCM	1,116	1,108	1,099	1,089	1,078	1,065	1,051	1,034	1,015	992	964	930	888
	kWh/kg	5.00	4.72	4.43	4.15	3.86	3.58	3.30	3.01	2.73	2.44	2.16	1.88	1.59
Oak	kWh/fm	2,855	2,835	2,812	2,786	2,758	2,726	2,689	2,646	2,596	2,537	2,467	2,380	2,273
571 kg_{wf}/fm	kWh/rm	1,999	1,984	1,968	1,951	1,931	1,908	1,882	1,852	1,817	1,776	1,727	1,666	1,591
	kWh/LCM	1,142	1,134	1,125	1,115	1,103	1,090	1,075	1,058	1,038	1,015	987	952	909
	kWh/kg	5.00	4.72	4.43	4.15	3.86	3.58	3.30	3.01	2.73	2.44	2.16	1.88	1.59
Poplar	kWh/fm	1,765	1,752	1,738	1,723	1,705	1,685	1,662	1,636	1,605	1,569	1,525	1,472	1,405
353 kg_{wf}/fm	kWh/rm	1,236	1,227	1,217	1,206	1,193	1,179	1,163	1,145	1,123	1,098	1,067	1,030	983
	kWh/LCM	706	701	695	689	682	674	665	654	642	627	610	589	562

[1)] Values for kg (wf) per fm without drying shrinkage (density) [26].
The heating values for the cubic metre (rm) were calculated as a flat rate of 0.7 fm/rm and for the loose cubic metres (LCM) of wood chips as 0.4 fm/LCM (for particle size class P16S).

4.4.4 Volume specifications

As shown in 4.4.3, the calorific value is related to the mass of the fuel and strongly dependent on the water content. However, weighing delivered fuel quantities is often not possible for smaller plants because the infrastructure is missing or too expensive. Therefore, it is common practice, especially for smaller plants, to estimate fuel quantities on a volume basis and to bill them in this way. There are different volume specifications from the forestry and timber industry that are commonly used in connection with wood (see Table 4.4).

Table 4.4 Room dimensions for energy wood [27].

Volume specification	Definition	Unit
Solid cubic metres	Standing timber stock, 1 m³ corresponds to 1 m³ of solid wood mass, in the case of layered wood without spaces between.	fm, m³
Cubic metre	Layered wood; corresponding to 1 m³ including the spaces in between (around 0.8 fm)	rm
Loose cubic metres (bulk cubic metres)	Loosely offloaded quantity of wood; used for logs, wood chips, shavings or similar (approx. 0.4 fm)	LCM (German: Srm)

An important parameter is the **bulk density** of a fuel [kg/LCM]. This is mainly influenced by the physical density [kg/m³], which strongly depends on the type of wood and water content. The bulk density also takes into account the lumpiness of the processed fuel. In the case of wood chips and shredded material, this decisively influences the spaces in a fuel fill. The density or bulk density together with the calorific value determine the volume-related energy density [MJ/m³] or [kWh/m³] of a fuel (see Table 4.5). This is an important parameter for estimating storage and transport costs. The fuel mass m can be calculated from the fuel density ρ and the volume V ($m = V * \rho$).

However, the bulk density is considered to be a very imprecise quantity, as it depends on many factors. It is generally true that non-uniform fuel dimensions reduce the bulk density. The homogeneity of wood chips is influenced by both the fuel preparation process and the feedstock. Processing by means of shredders or slow-running chippers leads to elongated, inhomogeneous dimensions with many splinters and frayed fractures. The bulk density of such material is lower than wood processed by high-speed drum chippers, whose chips tend to have smoother edges and a higher proportion of fines. While chips from logs have uniform dimensions, thinning residual wood or landscape maintenance wood contains different degrees of fine and coarse knots, which also leads to very different dimensions In addition, it should be noted that compacting the bulk material, for example by using uniform particle sizes (fewer air gaps) or jogging the particles during transport, reduces the bulk volume.

For the conversion of solid cubic metres (unchipped wood) into bulk cubic metres (wood chips), an average loosening factor of 2.8 can be used. A procedure for determining the bulk density is described in the standard EN ISO 17827 [28].

In summary, determining the volume delivered is very simple and cheap. However, volume is not well suited for indicating energy contents or fuel prices. Due to fluctuating densities, bulk densities and water contents of the fuel, such information is very inaccurate. A precise indication of relevant parameters is only possible on the basis of the fuel mass and depending on the respective reference state or water content. While a calculation by volume is suitable for designing the fuel storage area and estimating transport quantities, it has proven to be inadequate for billing (Section 4.7).

Table 4.5 Bulk density and energy content of various fuels.

Energy source	Water content [wt-%]	Bulk density [kg/LCM]	Energy content [kWh/rm]	Volume per energy content [m³/MWh]
Wood chips (HH)[1)]	30	250 - 330	900 - 1,100	1.10 - 0.90
Wood chips (WH)[1)]	30	160 - 230	600 - 800	1.70 - 1.25
Bark (HH)	50	500	1,000	1.00
Bark (WH)	50	320	750	1.33
Sawdust (HH)	40	230 - 270	650 - 750	1.50 - 1.33
Sawdust (WH)	40	150 - 190	450 - 550	2.20 - 1.80
Sawdust	15	170	717	1.39
Wood shavings	15	90	380	2.63
Briquettes	2	900 - 1,500	4,500 - 7,500	0.17
Pellets	2	670	3,000 - 3,500	0.30
Hard coal	-	870	8,300	0.12
Heating oil extra light[2)]	-	840	10,000	0.10

[1)] HH: hardwood, WH: softwood; [2)] LCM equals m³

4.5 Fuel supply for automatic wood firing systems

4.5.1 Overview

Wood used for energy supply (with the exception of short-rotation crops) accumulates as a residue or co-product from wood processing or also during forest management (e.g. tree thinning). The various sources, processing and utilisation paths are shown in Figure 4.3 DIN EN ISO 17225 [23] “Biogenic solid fuels - Fuel specifications and classes” has been successively expanded since 2014 and contains classifications of various wood fuels:

- Part 1: General requirements
- Part 2: Classification of wood pellets
- Part 3: Classification of wood briquettes
- Part 4: Classification of wood chips
- Part 5: Classification of lump wood
- Part 6: Classification of non-wood pellets
- Part 7: Classification of non-wood briquettes
- Part 8: Classification of thermally treated and pressed biomass fuels (withdrawn)
- Part 9: Classification of coarse shredded wood and wood chips for industrial use

The material flow of wood used for energy supply can be assigned to three raw material sources: (1) forestry (2) the cultivation of wood in short rotation plantations (SRC), (3) the accumulation as residual material in landscape management (LMW). While conifers in particular are put to material use after harvesting, various categories of wood for energy are produced in the forest and during wood processing. Various processing steps produce intermediate products that are used as fuel within the wood processing industry to cover its own energy needs. In addition to this internal use, wood from forestry is processed into end products and supplied to end customers in the form of logs, pellets and chipped and shredded material. SRC wood is usually chipped directly after harvesting and delivered to (large) consumers in the form of wood chips. A similar recovery path exists for landscape maintenance wood, which is usually gathered at collection points after maintenance measures and supplied as shredded material for energy recovery. After being removed from the cycle of material use, waste wood is sent to suitable plants for energy recovery (see Figure 4.3).

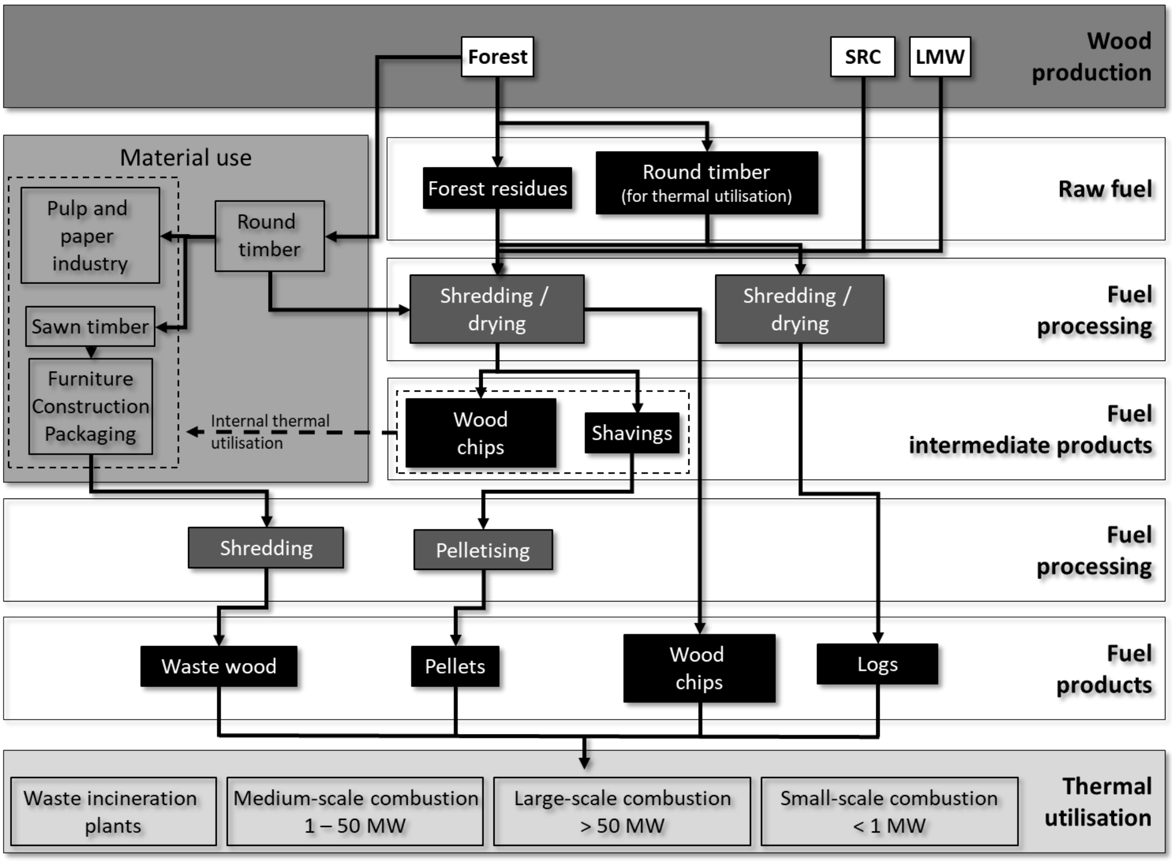


Figure 4.3 Material flow diagram from wood.

4.5.2 Assortments of wood

Forest residues and round timber: The use and maintenance of forests produces so-called forest residues, which are energetically utilised. This is residual wood from thinning, and secondly residues from the extraction of trunk wood for the use of wood as a material (mostly crown-end wood). Due to their small diameters, both assortments often have high bark contents and, especially in the case of coniferous forests, higher needle contents, and thus place increased demands on the plant technology. Furthermore, round timber from the targeted removal of weak logs is energetically utilised. In most cases, tree components with high ash contents such as needles, twigs and branches stay behind, resulting in a high-quality fuel.

Fuel from short rotation coppice (SRC): In short rotation coppice plantations, fast-growing woods such as poplar or willow are usually cultivated with the aim of energy recovery. Harvesting mainly takes place in winter, i.e. when the trees are free of leaves. The water content of wood chips from SRC tends to be higher than the that of freshly harvested wood chips from forest residues and round timber. SRC wood also has relatively low raw densities; this and the high water content should be taken into account especially in volume-based accounting. The ash content of SRC wood chips is generally comparable to that of forest residues due to the increased content of bark and fine branches in both assortments. Likewise, the calorific value (anhydrous reference basis) is comparable to that of forest residues. Burning freshly harvested SRC wood chips is not recommended, especially in smaller furnaces, as manufacturers often specify the use of fuels with lower water contents (max. 30 to 35 %). The desired water content can be achieved by (natural) drying or mixing the SRC wood chips with drier fuels [29].

Landscape maintenance wood (LMW): Landscape maintenance wood comes from the maintenance of hedges and embankments along traffic areas (roads, railways and waterways), power lines and green spaces in urban areas. The composition can be very different, for example, in addition to softwood (e.g. alder, poplar and willow), hardwood (e.g. maple, hazel, hornbeam) also accumulates. In the municipal sector, garden and park waste as well as shrub cuttings are collected separately through pick-up or delivery systems. This green waste contains (especially in summer) a high proportion of herbaceous material that is suitable for recycling through composting or fermentation. The woody portion, which accumulates more in winter, is important for thermal recycling [30]. Specialist literature often points to partially increased contents of pollutants such as ash, heavy metals or chlorine in landscape maintenance wood as fuel, which can entail increased requirements for approval procedures and plant technology [31]. Scientific studies have shown an influence of winter salt spreading on roads or fertilisation of adjacent agricultural land. However, the measured chlorine contents in landscape wood are comparable to those in forest chips. In addition to the location, the decisive factor is therefore which parts of a tree are processed into wood chips. Increased ash and chlorine contents were found especially in finer branches that have a high bark content compared to the wood [32].

Waste wood: Wood used for material purposes becomes waste wood at the end of its useful life. This waste wood comes from different sources and is recycled in stages. For this purpose, it is collected and processed at suitable sites. Here, the material flows are divided up with regard to their further utilisation: Uncontaminated waste wood that is suitable for material utilisation is reused as a secondary raw material. Excess quantities or contaminated waste wood that is no longer suitable for material use is fed into energy recovery [33]. Materials collected under the term "waste wood" are characterised by their inhomogeneity, especially with regard to foreign matter content and impurities. The classification of waste wood according to its origin, composition and contamination with hazardous substances makes it possible to divide it into different categories (Table 4.6).

Table 4.6 Cataloguing of waste wood according to the European List of Waste [34] and lists on the transport of waste from the Federal Department of the Environment, Transport, Energy and Communications [35].

Waste category (chapter of the list)	Waste code	Description
wastes from wood processing and the production of panels and furniture, pulp paper and cardboard	03 01 01	waste bark and cork
	03 01 04*	sawdust, shavings, cuttings, wood, particle board and veneer containing hazardous substances
	03 01 05	sawdust, shavings, cuttings, wood, particle board and veneer other than those mentioned in 03 01 04
	03 03 01	waste bark and wood
packaging (including separately collected municipal packaging waste)	15 01 03	wooden packaging
	15 01 10*	packaging containing residues of or contaminated by hazardous substances
construction and demolition wastes (including excavated soil from contaminated sites)	17 02 01	wood, instead of this code 17 02 97 or 17 02 98 is used in Switzerland
	17 02 04*	glass, plastic and wood containing or contaminated with hazardous substances
	17 02 97	CH: waste wood from construction sites, demolitions, renovations and conversions
	17 02 98*	CH: problematic waste wood
wastes from the mechanical treatment of waste	19 12 06*	wood containing hazardous substances
	19 12 07	wood other than that mentioned in 19 12 06
municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions	20 01 37*	wood containing hazardous substances
	20 01 38	wood other than that mentioned in 20 01 37
	20 03 07	bulky waste

* wastes classified as hazardous according to the European List of Waste [34]

Table 4.7 Exemplary classification of waste wood in Germany and Switzerland.

<table>
<tr><th colspan="2">Germany</th><th colspan="3">Switzerland</th></tr>
<tr><th>Category</th><th>Description according to Altholzverordnung (AltholzV) – Waste Wood Ordinance</th><th>General description</th><th colspan="2">Luftreinhalteverordnung (LRV) - Ordinance on Air Pollution Control</th></tr>
<tr><td rowspan="3">A I</td><td rowspan="3">Naturbelassenes oder lediglich mechanisch bearbeitetes Altholz - Natural or only mechanically processed waste wood</td><td>Naturbelassenes Waldholz - Natural forest wood</td><td>Naturbelassenes Holz (stückig und nicht stückig) Bst. a+b</td><td rowspan="4">Holzbrennstoffe
Anhang 5, Ziffer 31, Absatz 1</td></tr>
<tr><td>Restholz aus Sägereien - Waste wood from sawmills</td><td>Unbehandeltes Altholz Bst d 1</td></tr>
<tr><td rowspan="2">Restholz aus Zimmereien, Schreinereien - Waste wood from carpentries, Joineries</td><td>Unbehandeltes Altholz Bst d 1</td></tr>
<tr><td rowspan="2">A II</td><td rowspan="2">Verleimtes, gestrichenes, beschichtetes, lackiertes oder anderweitig behandeltes Altholz ohne halogenorganische Verbindungen in der Beschichtung und ohne Holzschutzmittel. - Glued, painted, coated, lacquered or otherwise treated waste wood without halogen-organic compounds in the coating and without wood preservatives.</td><td>Restholz Bst c</td></tr>
<tr><td>Behandeltes Altholz ohne Holzschutzmittel, halogenorgansicher Beschichtung oder PCB - Treated waste wood without wood preservatives, halo-organic safe coating or PCBs</td><td>Altholz Bst a</td><td rowspan="4">Übrige Brennstoffe aus Holz, gelten nicht als Holzbrennstoffe
Anhang 5, Ziffer 31, Absatz 2</td></tr>
<tr><td>A III</td><td>Altholz mit halogenorganischen Verbindungen in der Beschichtung ohne Holzschutzmittel. - Waste wood with halogen-organic compounds in the coating without wood preservatives</td><td>Behandeltes Altholz mit halogenorgansicher Beschichtung, ohne Holzschutzmittel - Treated waste wood with halogen-organic coating, without wood preservatives</td><td rowspan="3">Problematische Holzabfälle Bst b</td></tr>
<tr><td>A IV</td><td>Mit Holzschutzmitteln behandeltes Altholz […] sowie sonstiges Altholz, das […] nicht den Kategorien A I - A III zugeordnet werden kann, ausgenommen PCB-Altholz. - Waste wood treated with wood preservatives [...] and other waste wood which [...] cannot be assigned to categories A I - A III, with the exception of PCB waste wood (which contains polychlorinated biphenyls and is covered by the relevant Waste Ordinance).</td><td rowspan="2">Beh. Altholz mit Holzschutzmittel - Treated waste wood with wood preservative
Mit PCB behandelte Holzabfälle – Waste wood treated with PCB</td></tr>
<tr><td>PCB-Altholz – PCB-waste wood</td><td>Altholz, das PCB im Sinne der PCB/PCT-Abfallverordnung ist und nach deren Vorschriften zu entsorgen ist, insbesondere Dämm- und Schallschutzplatten, die mit Mitteln behandelt wurden, die polychlorierte Biphenyle enthalten. - Waste wood that is PCB within the meaning of the PCB/PCT Waste Ordinance and must be disposed of in accordance with its provisions, in particular insulation and soundproofing boards that have been treated with agents containing polychlorinated biphenyls.</td></tr>
</table>

In Germany, in addition to cataloguing according to waste codes, there are classifications in waste wood categories (Table 4.7). In Switzerland, waste wood is not considered wood fuel, but waste according to the Ordinance on Air Pollution Control (LRV) [36]. Waste wood AI and AII according to the classification of waste wood in Germany correspond to the waste wood permitted under the LRV, which may be burned in wood-fired furnaces (Table 4.7). For the thermal recovery of contaminated assortments (e.g. residues of PVC-coated or pressure-impregnated wood), country-specific regulations must be observed with regard to plant technology and emission protection measures. The term industrial wood or sawmill residue refers to a by-product from the wood-processing industry that is exclusively admitted in its natural form as wood fuel. In Austria, waste wood is also classified as waste and not as fuel, but by-products from the wood-processing industry can be used as fuel. The thermal utilisation of waste wood takes place almost exclusively in special waste wood or waste incineration plants as well as in industrial plants for the utilisation of biogenic residues (e.g. paper and board industry). However, co-firing of untreated waste wood in biomass district heating plants is possible with the appropriate official permit.

4.5.3 Fuel preparation

Mechanical shredding**:** Mechanical shredding can be carried out according to two basic principles (see Figure 4.4).

- Cutting process with sharp tools (drum or disc chipper) for the production of wood chips; the wood chips have good flow behaviour and form a homogeneous fuel; used in particular for the production of forest chips, in sawmills and wood-processing plants. Wood chips according to ISO 17225-4 must be produced with cutting tools.

- Crushing process with blunt tools (slow-running chippers with ripper teeth, hammer mills, screw chippers, etc..) for the production of shredded fuel. Shredded material wedges easily, has poor flow behaviour and is particularly inhomogeneous. The tool is less sensitive to impurities and is therefore mainly used in the landscape maintenance sector.

Drying and storage: The storage of fuels is an important part of the supply chain. Firstly, natural drying processes that take place during storage can improve quality due to decreasing water content. Storage also plays a major role in keeping fuel supplies in line with demand. In principle, there are various possibilities: Storage before or after chipping, natural or technical drying, storage outdoors or in warehouses. The possible applications as well as the advantages and disadvantages of the respective methods are described below [37].

Figure 4.4 Differentiation between wood chips (cut with sharp tools, left) and shredded wood (chopped with blunt tools, right).

After harvesting, the wood to be chipped can be left in the form of piles for several weeks to months in a suitable storage area. This pre-drying allows water contents to fall from < 50 % to < 30 %. An ideal storage place for pre-drying should be well ventilated and sunny, close to the forest, have a dry, permeable subsoil and be accessible all year round.

The natural drying of wood chips piles takes place by convection. Self-heating in the pile creates a temperature difference to the surroundings. As a result, warm air rises from the pile and transports the moisture away, cooler and drier air flows in laterally. The size and shape of the wood chips pile play an important role. The shape should be roof profile-like ("pointed cone"). This favours convection (chimney effect) and precipitation water cannot collect in hollows on the surface of the windrow. In addition, covering with a diffusion-open fleece offers protection against precipitation, but allows evaporation from the inside. The heap height should not exceed four metres to avoid the risk of fire through spontaneous combustion. Technical drying, on the other hand, is much faster, but more cost-intensive. Waste heat from power plants such as biogas CHPs or solar drying with air collectors [38] can be used for drying.

Often, wood chips are produced from freshly harvested wood material with a high water content > 50 % and stored for a longer period of time in a covered or uncovered temporary storage or at the heating plant before use. Various problems can occur when storing fresh wood chips with a high water content:

- Biological processes heat up the wood chips pile, ignition is possible.
- Water condenses on the top of the fill and mould develops which can be harmful to health.
- Degradation processes and wood-decomposing fungi reduce organic matter (decreasing density and increasing ash content); fuel parameters may deteriorate (e.g. accumulation of nitrogen).

These dangers can be reduced by drying the material quickly to water contents < 30 % and storing in suitable storage conditions. Coarse and sharp-edged wood chips with a low proportion of fines are ideal. This provides sufficient spaces for air circulation and moisture removal. The storage period should not be too long, a guideline is three months. An appropriate sequence should be followed for storage and use ("first in - first out" principle).

For outdoor storage, ensure that the ground is dry and that the location is as sunny and wind-exposed as possible. In contrary to an unpaved surface, a paved surface can be driven on all year round by heavy goods vehicles. Gravelled pitches have proven to be effective, as they do not seal the surface. However, there is a possibility here and on other unpaved sites that the fuel may be contaminated by build-up of mineral soil or humus and stones. When stored in buildings such as wood chips bunkers or warehouses, the fuel is protected from precipitation. Good air circulation must be ensured to counteract the formation of condensation water and the resulting mould.

Pressing/pelleting: The solid fuel wood pellets are produced by pressing dry natural sawdust or wood shavings with or without the addition of additives. DIN EN ISO 17225-2 contains requirements for raw material and pellet properties (diameter and length, water content, ash content and melting behaviour, mechanical strength, fines content, additives, calorific value, bulk density, element content), classified according to use in commercial and domestic (A1, A2, B) and industrial applications (I1, I2, I3).

Although pellets are a very dry fuel, processes take place during storage that lead to so-called outgassing and self-heating of the fuel. Extract substances contained in the wood (resins, fats and free fatty acids) reach the fuel surface due to high temperatures during drying or due to the effect of pressure during pelleting and thus come into contact with atmospheric oxygen. This sets off oxidation reactions that lead to the release of volatile organic hydrocarbons (VOC), carbon monoxide (CO) and carbon dioxide (CO_2). The resulting organic compounds such as butyric acid and aldehydes can cause odour nuisance. The odourless gases CO and CO_2 can lead to oxygen deficiency in insufficiently ventilated storage rooms, and there is a risk of suffocation and poisoning for personnel. In combination with self-heating of the fuel (both by exothermic oxidation reactions and by adsorption heat, which occurs when pellets absorb moisture from the air), the presence of flammable gases such as CO can lead to spontaneous combustion, especially in very large storage rooms. Pellet storage areas should therefore always be sufficiently ventilated (see chapter 14.2.9 and 19). Outgassing decreases with increasing fuel age and storage time. Other influencing variables are the mechanical load during filling (shortest possible paths to prevent abrasion of fine material) and the temperature during storage (the cooler, the lower the activity) [39].

4.5.4 Quality parameters

Wood fuels show great differences in quality due to different raw materials and differences in the manufacturing process. Low-emission, trouble-free and energy-efficient operation of wood-fired systems is only possible with the use of a suitable fuel adapted to the system (chapters 5and 13). For example, small-scale combustion systems (standard series devices) in particular require consistently homogeneous qualities with low water content, ash content and fines content. An accurate assessment of fuel quality is also essential with regard to billing. Table 4.8 provides an overview of essential quality parameters that can be used to assess fuels “at first glance”.

Table 4.8 Typical characteristics for assessing fuel quality.

Quality parameters	“Good” quality	“Poor” quality
Water content	low	high
Ash content	low	high
Calorific value	high	low
Particle shape	sharp-edged	rough
Fine fraction	low	high
Excess lengths	low	high
Impurity content	low	high

Table 4.9 contains typical value ranges of important fuel parameters for wood and bark of deciduous and coniferous trees as well as for waste wood. The tree species willow and poplar are exemplary for wood from short rotation or landscape maintenance wood (SRC and LMW). It should be noted that the values listed cover large fluctuation ranges. The typical value is a statistically determined reference point. The actual fuel composition may deviate from it and depends, for example, on the respective location. Planners, suppliers and plant operating companies must therefore determine individual values for a design. Online databases such as Phyllis2 [40] or FRED of the Bavarian State Office for the Environment [41] contain additional data on various fuels.

Table 4.9 Typical fuel parameters of wood and bark - Part I main elements [23], [33], [42].

Parameter	Unit (Reference state: wf)		Wood (without bark, leaves, needles)		Bark		SRC and LMW		Waste wood
			Softwood	Hardwood	Softwood	Hardwood	Pasture	Poplar	
Ash-content	wt-%	Value range	0.1 - 1.0	0.2 - 1.0	< 1 - 5	0.8 - 3.0	1.1 - 4.0	1.5 - 3.4	0 - 2
		Typical value	0.3	0.3	1.5	1.5	2.0	2.0	
Calorific value	MJ/kg	Value range	18.5 - 19.8	18.4 - 19.2	17.5 - 20.5	17.1 - 21.3	17.7 - 19.0	18.1 - 18.8	18 - 20.2
		Typical value	19.1	18.9	19.2	19	18.4	18.4	
Carbon C	wt-%	Value range	47 - 54	48 - 52	48 - 55	47 - 55	46 - 49	46 - 50	n.a.
		Typical value	51	49	52	52	48	48	
Hydrogen H	wt-%	Value range	5.6 - 7.0	5.9 - 6.5	5.5 - 6.4	5.3 - 6.4	5.7 - 6.4	5.7 - 6.5	n.a.
		Typical value	6.3	6.2	5.9	5.8	6.1	6.2	
Oxygen O	wt-%	Value range	40 - 44	41 - 45	34 - 42	32 - 42	40 - 44	39 - 45	n.a.
		Typical value	42	44	38	38	43	43	
Nitrogen N	wt-%	Value range	< 0.1 - 0.5	< 0.1 - 0.5	0.3 - 0.9	0.1 - 0.8	0.2 - 0.8	0.2 - 0.6	n.a.
		Typical value	0.1[1)]	0.2[1)]	0.5	0.3	0.5	0.4	
Sulphur S	wt-%	Value range	< 0.01 - 0.02	< 0.01 - 0.05	< 0.02 - 0.05	< 0.02 - 0.20	0.02 - 0.10	0.02 - 0.10	n.a.
		Typical value	< 0.02	0.02	0.03	0.03	005	0.03	
Chlorine Cl	wt-%	Value range	< 0.01 - 0.03	< 0.01 - 0.03	< 0.01 - 0.05	< 0.01 - 0.05	0.01 - 0.05	< 0.01 - 0.05	0.02 - 0.20
		Typical value	0.01	0.01	0.02	0.02	0.03	< 0.01	
Fluorine F	wt-%	Value range	< 0.0005	< 0.0005	< 0.0005 - 0.002	n.a.	0 - 0.01	n.a.	n.a.
		Typical value	< 0.0005	< 0.0005	0.001		0.003		
Aluminium Al	mg/kg	Value range	30 - 400	< 10 - 50	400 - 1,200	30 -100	3 - 100	n.a.	n.a.
		Typical value	100	20	800	50	50	10	
Calcium Ca	mg/kg	Value range	500 - 1,000	800 - 20,000	1,000 - 15,000	10,000 - 20,000	2,000 - 9,000	4,000 - 6,000	n.a.
		Typical value	900	1,200	5,000	15,000	5,000	5,000	
Iron Fe	mg/kg	Value range	10 - 100	10 - 100	100 - 800	50 - 200	30 - 600	n.a.	n.a.
		Typical value	25	25	500	100	100	30	
Potassium K	mg/kg	Value range	200 - 500	500 - 1,500	1,000 - 3,000	1,000 - 3,200	1,700 - 4,000	2,000 - 4,000	n.a.
		Typical value	400	800	2,000	2,000	2,500	2,500	
Magnesium Mg	mg/kg	Value range	100 - 200	100 - 400	400 - 1,500	400 - 1,000	200 - 800	200 - 800	n.a.
		Typical value	150	200	1,000	500	500	500	
Manga-nese Mn	mg/kg	Value range	40 - 200	n.a.	9 - 840	n.a.	79 - 160	n.a.	n.a.
		Typical value	100		500	190	97	20	
Sodium Na	mg/kg	Value range	10 - 50	10 - 200	70 - 2,000	20 - 1,000	10 - 450	10 - 60	n.a.
		Typical value	20	50	300	100	n.a.	25	
Phospho-rus P	mg/kg	Value range	50 - 100	50 - 200	20 - 600	300 - 700	500 - 1,300	800 - 1,100	n.a.
		Typical value	60	100	400	400	800	1,000	
Silicon Si	mg/kg	Value range	100 - 200	100 - 200	500 - 5,000	2,000 - 20,000	2 - 2,000	n.a.	n.a.
		Typical value	150	150	2,000	2,500	500		
Arsenic As	mg/kg	Value range	< 0.1 - 1.0	< 0.1 - 1.0	0.1 - 4.0	0.1 - 4	< 0.1	< 0.1 - 0.2	0.39 - 15.4
		Typical value	< 0.1	< 0.1	1.0	0.4	< 0.1	< 0.1	
Cadmium Cd	mg/kg	Value range	< 0.05 - 0.50	< 0.05 - 0.50	0.2 - 1.0	0.2 - 1.2	0.2 - 5	0.2 - 1	n.a.
		Typical value	0.1	0.10	0.5	0.5	2	0.5	
Chrome Cr	mg/kg	Value range	0.2 - 10.0	0.2 - 10.0	1 - 10	1 - 30	0.3 - 5	0.3 - 2	0.1 - 5.3
		Typical value	1.0	1.0	5	5	1	1	
Copper Cu	mg/kg	Value range	0.5 - 10.0	0.5 - 10.0	3 - 30	2 - 20	2 - 4	2 - 4	3.4 - 668.4
		Typical value	2.0	2.0	5	5	3	3	
Mercury Hg	mg/kg	Value range	< 0.02 - 0.05	< 0.02 - 0.05	0.01 - 0.1	n.a.	< 0.03	< 0.03	0.02 - 36.1
		Typical value	0.02	0.02	0.05	< 0.05	< 0.03	< 0.03	
Nickel Ni	mg/kg	Value range	< 0.1 - 10.0	< 0.1 - 10.0	2 - 20	2 - 10	0.2 - 2	0.2 - 1.0	n.a.
		Typical value	0.5	0.5	10	10	0.5	0.5	
Lead Pb	mg/kg	Value range	< 0.5 - 10.0	< 0.5 - 10.0	1 - 30	2 - 30	0.1 - 0.2	0.1 - 0.3	9.3 - 3,314.3
		Typical value	2.0	2.0	4	15	0.1	0.1	
Vanadium V	mg/kg	Value range	< 2	< 2	0.7 - 2.0	1 - 4	0.2 - 0.6	n.a.	n.a.
		Typical value	< 2	< 2	1.0	2	0.3		
Zinc Zn	mg/kg	Value range	5 - 50	5 - 100	70 - 200	7 - 200	40 - 100	30 - 100	n.a.
		Typical value	10	10	100	50	70	50	

[1)]The typical nitrogen content varies depending on the wood species: spruce 0.1, silver fir 0.17, beech 0.22 [43]. n.a. = not available.

The **water content** is the most important parameter in terms of fuel quality. The water content is an essential factor for the storability and stability of the finished fuel and the necessity of drying (target water content < 30 - 35 %) or, at best, blending. It directly influences the calorific value, since the water contained in the fuel must first be evaporated during combustion using thermal energy. Without condensing technology, this heat energy cannot be recovered by condensing the steam. Furthermore, the water content has an influence on the CO and dust emissions released during combustion, as well as the accumulation of ash. The mass of the water itself and shrinkage effects during drying influence the bulk density of the fuel.

The typical water content of freshly harvested round timber (heartwood and sapwood) as well as fresh forest chips is 45 - 55 %, with material from SRC often > 55 %. Through technical or natural drying, significantly lower water contents of 15 - 35 % can be achieved. Wood chips with a water content < 15 % can usually only be produced by means of technical drying. A particularly dry fuel, on the other hand, is wood pellets, which have a standard water content < 10 % Depending on the combustion technology used, certain water contents in the fuel must not be exceeded (chapter 5). For boilers in the small to medium output range, relatively high demands are placed on the fuel by the manufacturers and the legislation, and the water content ranges defined in accordance with the type test must be met (e.g. for micro appliances/pellet stoves < 15 to 20 %, for series appliances < 35 %). For larger heating (power) plants, reliable operation is also possible with water contents > 35 % and even freshly chopped wood ([37], [44]).

The **ash content** of a fuel has an influence on particle emissions and slag formation during combustion as well as on the disposal costs for the total amount of ash produced during plant operation. High ash contents facilitate wear and corrosion of plant components. Depending on its chemical composition, ash is recycled, for example, as a fertiliser component or as an aggregate in cement production. If no material recycling path is possible (e.g. due to excessive heavy metal contamination), the ash must be disposed of in suitable landfills [44].

As shown in Table 4.9, the ash contents vary between 0.1 and 5 % depending on the type of wood and bark content. DIN EN ISO 17225-4 defines four classes for wood chips (A1 to B2) with permissible ash contents of < 1 % to < 3 %. Higher ash contents are usually due to higher proportions of bark and needles. For example, the smaller the diameter of a tree or the higher the proportion of twigs, the higher the ratio of bark to wood. Another influencing factor is contamination with inorganic materials (e.g. soil or stones).

Typical **calorific values** for bark or wood (anhydrous reference basis) are between 17.1 and 21.3 MJ/kg (Table 4.9), with bark covering a much wider range of variation. The calorific value of softwoods tends to be higher than that of hardwoods due to slightly higher C contents. However, this aspect is of secondary importance compared to other parameters. Due to the increased concentrations of ash-forming minor and trace elements, the ash content of bark is usually significantly higher than in the associated wood. It follows that the calorific value of bark can be both above and below the calorific value of the corresponding wood [21]. Very high ash contents, for example due to mineral impurities or lignin degradation by special fungi, reduce the calorific value [44].

The **particle size** significantly influences the flow properties as well as the storage and drying behaviour of the fuel. The particle size is significantly influenced by the production and preparation steps, but also depends on the type of wood and the selected assortment. Small particles or a high proportion of fine material can restrict ventilation and lead to dust emissions during bunker filling. In addition, a high proportion of fines has a negative influence on the combustion quality. The steady air supply in the fuel bed is impeded, resulting in the formation of hotspots. This leads to increased wear in the grate area and the fireclay as well as an increased dust content due to trace substances in the flue gas, which are no longer incorporated into the ash. Large, overlong or fringy (= not sharp-edged) particles facilitate blockages in conveyor systems such as transport screws and can cause bridging in the storage area. High-quality wood chips are relatively homogeneous, have a low proportion of fines, a short maximum length and sharp edges [37].

The foreign content is the percentage of foreign material in the fuel. In addition to metal parts, stones and waste (coarse foreign matter), this category includes in particular adhering humus and mineral soil (fine foreign matter). If the coarse foreign matter is unintentionally chopped along with the fuel, the chipper itself, components of the conveyor system or the heating system can be damaged, sometimes considerably, by the foreign matter. Adhering soil leads to increased wear on the chipper blades and increases the ash content. During combustion in the heating (power) plant, an increased ash content due to foreign substances, altered ash melting behaviour and possibly increased heavy metal content of the fuel or ash lead to increased disposal costs, corrosion and slagging of the plant components [44].

In order to be able to take the different compositions of fuels and the resulting combustion properties into account in the best possible way when selecting firing and flue gas technology, QM for Biomass DH Plants has drawn up a fuel classification (see Table 4.10 and Table 4.11).

Table 4.10 Part I - Classification of fuels and particle sizes of QM for Biomass DH Plants based on the specifications according to EN ISO 17225-1, the classification of particle sizes have been supplemented with the S classes of EN ISO 17225-4.

Fuels	Short designation	**Particle size** mm (see Table 4.11) P	**Water content** Mass-% as delivered M	**Nitrogen content** Mass % on anhydrous Reference basis N1[1]	**Fines content < 3.15 mm** Mass-% as delivered F	**Ash content with foreign content** Mass % on anhydrous Reference basis A	**Energy content** Regarding Hu moist Fluctuation range kWh/LCM
Quality wood chips from forest residue (round) wood (WS)[1][9] and industrial residue wood (IS)[1][9]	fine WS-P16S-M20 IS-P16S-M20	16S	15 - 20	0.1 - 0.5 (0.2)	F05	A1.0	Softwood (WH): 700 – 900 Hardwood (HH): 1,000 - 1,200
	rough WS-P31S-M20 IS-P31S-M20	31S	15 - 20	0.1 - 0.5 (0.2)	F05	A1.0	WH: 630 - 850 HH: 950 - 1,150
Wood chips from forest residues (WS)[1] and industrial residues (IS)[1][2]	WS-P31S-M35 IS-P31S-M35	31S	20 - 35	0.1 - 0.5 (0.2)	F10	A3.0	WH: 600 - 800 HH: 900 - 1,100
	WS-P31S-M50 IS-P31S-M50	31S	30 - 50	0.1 - 0.5 (0.2)	F10	A3.0	WH: 550 - 750 HH: 850 - 1,050
	WS-P31S-M55+ IS-P31S-M55+	31S	30 - 60	0.1 - 0.5 (0.2)	F10	A3.0	WH: 500 - 700 HH: 800 - 1,000
	WS-P45S-M35 IS-P45S-M35	45S	20 - 35	0.1 - 0.5 (0.2)	F10	A3.0	WH: 550 - 750 HH: 850 - 1,050
	WS-P45S-M50 IS-P45S-M50	45S	30 - 50	0.1 - 0.5 (0.2)	F10	A3.0	WH: 500 - 700 HH: 800 - 1,000
	WS-P45S-M55+ IS-P45S-M55+	45S	30 - 60	0.1 - 0.5 (0.2)	F10	A3.0	WH: 450 - 650 HH: 750 - 950
	WS-P63-M50 IS-P63-M50	63	30 - 50	0.1 - 0.5 (0.2)	F10	A3.0	WH: 450 - 650 HH: 750 - 950
	WS-P63-M55+ IS-P63-M55+	63	30 - 60	0.1 - 0.5 (0.2)	F10	A3.0	WH: 400 - 600 HH: 700 - 900
Poplar and willow from forest and landscape	PWW	31S 45S 63	30 - 60	0.2 - 0.8 (0.3)	F10 F10 F10	A5.0	450 - 700 400 - 650 350 - 600
Poplar and willow from short rotation areas	PWK	31 45 63	30 - 60	0.5 - 3.0 (0.5)	F25	A10.0	400 - 650 350 - 575 300 - 500
Wood from landscape maintenance	LH[1]	31 45 63	30 - 60	0.4 - 1.0 (0.5)	F25	A10.0	400 - 800 350 - 750 300 - 700
Thinning residues from coniferous and deciduous trees Ø <80 mm and crown wood	DH	31 31 45 45 63 63	30 - 60	0.4 - 1.0 (0.6)	F25	A10.0	WH: 400 - 650 HH: 650 - 900 WH: 350 - 600 HH: 600 - 850 WH: 300 - 550 HH: 550 - 800
Sawdust	SP	< 4	35 - 50	0.1 - 0.3 (0.1)	-	A3.0	WH: 450 - 550 HH: 650 - 750
Bark crushed[8] max. coarse fraction 5 %	RZ	45 45 63 63	30 - 65+	0.3 - 0.9 (0.5)	F05 F05 F05 F05	A10.0	WH: 700 - 850 HH: 950 - 1,150 WH: 650 - 800 HH: 900 - 1,100
Bark uncrushed[8]	Ruz	n.V.	30 - 65+	0.3 - 0.9 (0.5)	F05	A10.0	-
Residual wood from wood processing[10]	RHH	n.V.	n.V.	n.V.	n.V.	n.V.	-
Waste wood[4][10]	AH	45 63	< 30	0.5 - 1.5 (0.8)[12]	F10 F10	A10.0	550 - 750 500 - 700
Pellets[5]	PEL	n.V.	-	-	-	-	-

Table 4.11 Part II - Classification of fuels and particle sizes of QM for Biomass DH Plants based on the specifications according to EN ISO 17225-1, the classification of particle sizes was supplemented with the S classes of EN ISO 17225-4.

The classification is based as far as possible on the fuel standard ISO 17225, deviations are mentioned.

1) Must not contain poplar and willow unless contractually agreed; bark content adhering to the wood chips maximum 20 % anhydrous by weight.
2) According to CEN/TS 14588. Wood chips produced as a by-product of the wood processing industry, with or without bark. In Switzerland, only untreated wood chips from sawmill residues are considered as wood chips from industrial residues (IS).
3) Water content classification does not comply with fuel standard ISO 17225.
4) DE: Waste wood category A I and A II; AT: Waste wood sector concept wood Q3 and Q4; CH: Waste wood is not considered as wood fuel (Ordinance on Air Pollution Control: Annex 5, Number 3, Paragraph 2, Letter a)
5) Observe pellet standards according to ISO 17225-2
6) Variation range is determined by different bulk density:
   - Chipping logs from a pile results in a higher bulk density than chipping whole trees with branches
   - The size distribution of the wood chips in the main proportion of 60 % influences the bulk density (a higher proportion of fine wood chips increases the bulk density)
   - The fuel preparation process, chipping or shredding, has a major influence on the bulk density (shredded fuel has a lower bulk density than chipped fuel).
   fuel has a lower bulk density than chopped fuel).
7) with needles, leaves and twigs
8) The numerical values (P class) of mass refer to the particle sizes (mass fraction at least 95 %) that fit through the specified sieve opening sizes of round openings (ISO 17827-1). If a sample meets the criteria of more than one class, it shall be assigned to the lowest possible class. The coarse fraction shall be ≤ 5 % by weight as delivered.
9) For quality wood chips (coarse and fine), additionally tightened requirements of the country-specific standards must be observed.
10) For residual wood from wood processing RHH and waste wood AH, the chemical composition shall be determined on the basis of fuel analyses according to EN ISO 17225-1 Table 5b, page 24 and Annex B, Table B.1, page 43. For waste wood, in addition to the maximum ash content, the maximum foreign content (m. % on an anhydrous basis) of sand, stones and glass shall also be determined.
11) For the nitrogen content, a range of values and a typical value are given in parentheses. The typical value is important for the design of the denitrification.
12) The nitrogen content of waste wood depends on the composition (proportion of natural waste wood and board material [MDF, chipboard, plywood, etc.]). For pure board material, a maximum nitrogen content of 6 % can be expected.

n.V.: by arrangement, to be determined on a case-by-case basis
WH: softwood (softwood: spruce, fir, pine, Douglas fir, larch; softwood: maple, cherry, alder)
HH: Hardwood (Hardwood: oak, beech, elm, sweet chestnut, ash, robinia, hornbeam (hail beech), hazel, birch, walnut, fruit trees [except cherry]).
The following applies to all fuels: $_{Hu}$ > 1.5 kWh/kgdamp

Classification of particle sizes of wood chips and coarse shredded wood					
Particle size	Main share* min. 60 %/95 %[1]	Fine material share* < 3.15 mm	Coarse fraction*	Maximum length of the particles	Cross-section of the oversized particles
P16S	3.15 mm - 16 mm	F15	> 31.5 mm, ≤ 6 %	≤ 45 mm	< 2 cm²
P31S	3.15 mm - 31.5 mm	F10	> 45 mm, ≤ 6 %	≤ 150 mm	< 4 cm²
P31	3.15 mm - 31.5 mm	F25[2]	> 45 mm, ≤ 6 %	≤ 200 mm	< 4 cm²
P45S	3.15 mm - 45 mm	F10	> 63 mm, ≤ 10 %	≤ 200 mm	< 6 cm²
P45	3.15 mm - 45 mm	F25[2]	> 63 mm, ≤ 10 %	≤ 350 mm	< 6 cm²
P63	3.15 mm - 63 mm	[3]	> 100 mm, ≤ 10 %	≤ 350 mm	< 8 cm²
P100	3.15 mm - 100 mm	[3]	> 150 mm, ≤ 10 %	≤ 350 mm	< 12 cm²

1) The numerical values of the mass are related to the particle sizes (mass fraction at least 60 %) that fit through the specified sieve opening size of round openings (ISO 17827-1). For bark and shredded bark, the main fraction including fines shall have a mass fraction of 95 %. For wood chips and coarse shredded wood for use in domestic and small commercial fireplaces, S classes shall be used. The lowest possible property class shall be indicated.
2) with needles, leaves and twigs
3) Fines content varies depending on fuel
4) Recommendation in deviation from the standard: For fuel transport and fuel feeding system with screw conveyors

* Particle size in mass % in the as-delivered state

4.5.5 Supply strategies

The individual processing steps for the provision of wood fuel include the harvesting of the wood (felling, limbing, back limbing), shredding (chipping), transport to the silo or intermediate storage and, if necessary, intermediate storage, reloading and transport. The cost is primarily dependent on the volume to be processed and not on the weight. Therefore, the prices per energy content for coniferous wood are usually about 10 - 15 % higher than for hardwood. The choice of supply strategy depends in particular on the respective local framework conditions (location and accessibility, fuel market and demand, existing logistics, fuel supply companies and infrastructure, etc.) and must be adapted to the respective requirements.

If the wood is processed into chips while still in the forest (from round timber piles or freshly cut) and transported from there to the consumer, this is called a **direct supply chain**. The fact that there is no intermediate storage makes this the most cost-effective supply option. However, it requires precisely planned and reliable fuel logistics, and care must be taken to ensure that security of supply is guaranteed even under extreme conditions such as winter weather and road conditions. In addition, it should be noted that the wood chips fresh from the forest can have a water content of up to 60 %.

In contrast to the procedure described above, in an **indirect supply chain** the energy wood is temporarily stored in the form of chips or round timber in a warehouse or storage yard directly at the heating plant or at external locations after it has been removed from the forest. Temporary storage favours an uninterrupted supply, allows for more flexibility in delivery and fuel purchasing, and enables specific coordination of the fuel mix used depending on the operating condition and season. Particularly at high altitudes with limited access to the forest or the heating plant in winter, intermediate storage directly at the heating plant is necessary to ensure security of supply. During storage, the fuel is pre-dried and the high flexibility in fuel purchasing can result in price advantages. However, the supply costs increase due to higher investment and manipulation costs. Certain fuels according to Table 4.10, such as quality wood chips or dried, screened fuels, can usually be supplied only via an indirect supply chain. This must be taken into account when selecting the fuel or boiler and discussed with the fuel supplier (see chapter 13).

With a combination of the two variants (**mixed supply chain**), intermediate fuel storage facilities can be dimensioned smaller and thus save costs. At the same time, a high security of supply is guaranteed. If the construction of an intermediate storage facility is necessary, it should be examined whether, in order to use synergies, the largest possible storage yard can be set up to supply several wood firing systems. In addition to wood chips, round timber can also be stored in a pile and chipped as needed.

Mixed assortments: Assortments with unfavourable properties can also be used by mixing with higher qualities. For example, combinations of bark with a high water content and dry residual wood or of landscape maintenance wood with a tendency to slagging and low-ash wood chips are suitable. Mixed fuels are generally cost-effective and are becoming increasingly important. To ensure smooth plant operation, permissible fuel mixtures must be determined with the boiler manufacturer depending on the boiler utilisation. The water content of the fuel mixture is a particularly important criterion for both nominal output and low-load operation (heat input < minimum output of the firing system).

4.6 Analytics

As a standard method for determining the **water content,** gravimetric measurement of the fuels by means of drying at 105 °C according to DIN EN ISO 18134-1 [45] and DIN EN ISO 18134-2 [46] (simplified method) is usually used. The water content can be calculated via the loss of mass of the fuel during drying until the weight is constant. This method is recognised and precise, but also time-consuming and labour-intensive. In practice, both fuel supply companies and heating plant operators often need to determine the water content as quickly as possible, for example, for transparent billing when buying and selling or for assessing the quality of a delivery. A variety of rapid determination devices are available on the market for this purpose. The devices determine the water content of the fuel in different ways - gravimetrically, electrically or via infrared radiation. Furthermore, the way in which the measurement is carried out differs, for example in the form of manual measurement on extracted samples or automatic measurement in the fuel flow. Rapid measurement methods do not achieve the accuracy of a determination in a drying oven. They are therefore not suitable for billing purposes. However, they provide sufficiently accurate values for the qualitative assessment of a fuel batch [47].

The **ash content** of biomasses is determined according to the standard DIN EN ISO 18122 [48]. In the laboratory, a sample is heated (burnt) at 550 °C in a muffle furnace with a prescribed heating rate in an oxidising atmosphere. The combustion residue is back weighed, and the ash content is calculated from the mass ratio of ash and fuel.

The **calorific value is** determined in the laboratory according to the standard EN ISO 18125:2017-08 [24] in a bomb calorimeter. Here a weighed quantity of the analysis sample of a fuel is burnt in oxygen under high pressure at specified conditions.

4.7 Fuel supply contract and billing

4.7.1 Fuel supply contract

The fuel supply contract is concluded between the heating plant operating company and the fuel supply company and is intended to guarantee the uninterrupted supply of fuels suitable for the heating plant. Basic points must be specified in the contract:

- Definition of the fuel assortments
- Delivery quantities and proportions of the assortments, delivery modalities
- Fuel price, price adjustment (indexation) and billing method
- Term of contract and cancellation conditions, place of jurisdiction

When buying and selling wood fuel, the traded energy quantity is decisive. However, this depends on various fuel parameters (density, bulk density, water content, type of wood). Depending on the structure of the fuel supply (one or several suppliers) and the existing infrastructure at the heating plant, different billing methods (by volume, weight or amount of heat generated) come into question.

4.7.2 Billing according to volume

Billing by volume is widely used. The price for a delivery is determined on the basis of guideline values for the energy content per bulk cubic metre for different wood assortments as a function of the water content. However, this is the most inaccurate method, as the energy contents of the delivered fuels can vary greatly due to fluctuating (solid) densities, bulk densities and water contents. For example, a cubic metre of beech chips contains almost 50 % more energy than a cubic metre of spruce chips. An important differentiation criterion when billing by volume is therefore the different densities of hardwood and softwood. Softwoods such as spruce, fir, pine, Douglas fir, larch (generally softwood) as well as the softwoods cherry and alder have lower (energy) densities than hardwoods (generally hardwood: maple, oak, beech, elm, sweet chestnut, ash, robinia, hornbeam, hazel, birch, walnut, fruit trees - except cherry).

However, the bulk density of the fuel has an even greater influence than the fluctuating solid density when trading with wood chips. This is essentially determined by particle size, fines content and external influences such as compaction through vibration during transport. DIN EN ISO 17225-1 specifies bulk densities for wood chips between 150 kg/LCM and 450 kg/LCM. Based on this range of variation, Figure 4.5 shows the range in which the energy content per unit volume (depending on the water content of the fuel) can lie, as well as price ranges for volume-based billing of wood chips, based on an exemplary average price of 30 €/MWh [49]. Insufficient knowledge regarding the water content or bulk density of the fuel can easily lead to significant price deviations. Therefore, this billing method is not recommended or only recommended if the fuel parameters are known with sufficient accuracy.

Advantage of billing by volume:

- Simple determination of the volume

Disadvantage of billing by volume:

- Great uncertainty regarding the energy content

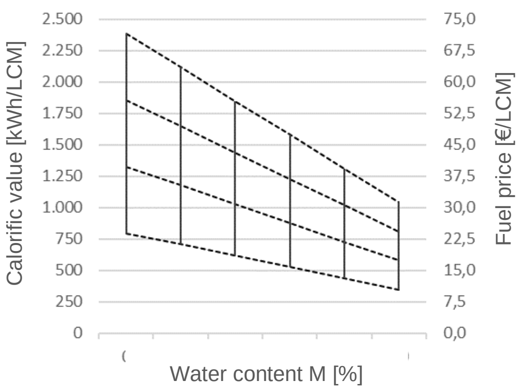


Figure 4.5 Volume-related calorific value and guide values for fuel prices of wood chips as a function of water content for bulk densities between 150 kg/rm (bottom) and 450 kg/rm (top); basis of calculation 30 €/MWh.

4.7.3 Billing according to weight

In the case of billing by weight, which is common for larger plants, the water content of the fuel is taken into account. The price for a delivery is determined on the basis of the energy content per tonne of water-free fuel. For example, forest-fresh wood chips with a water content of 50 % have a calorific value of 2.3 kWh/kg (Figure 4.6). For a delivery of 20 tonnes, this corresponds to an energy quantity of 46 MWh. For an average price of 30 €/MWh, this results in a price of 1,380 € for a truck load of 20 tonnes.

While the water content has a considerable influence on the amount of energy traded, the mass-related heating values between softwood and hardwood differ only slightly. Due to the higher content of resins and lignin, the calorific value of softwoods slightly exceeds the calorific value of hardwoods (by mass). As a natural fuel, however, these values are subject to natural fluctuation (Table 4.9, Figure 4.6).

The weight is usually determined by weighing the truck before and after unloading. When using weight sensors integrated in the truck, sufficient accuracy must be guaranteed by the supplier. For a representative determination of the water content of a delivery (chapter 4.6), either several samples or a representative composite sample should be analysed.

Advantages of billing by weight:

- Independent of wood type and bulk density
- High accuracy regarding the energy content

Disadvantage of charging by weight:

- Measurement of weight and water content necessary

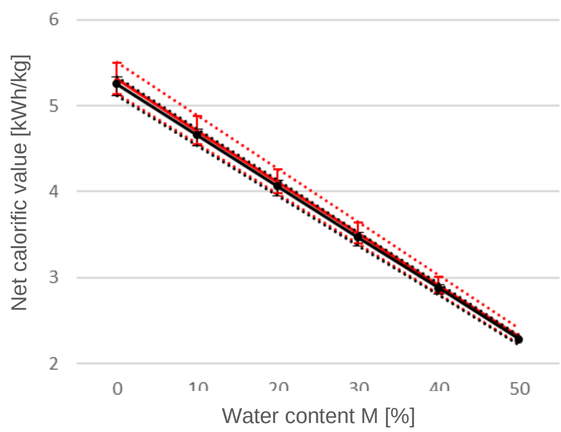


Figure 4.6 Mass-related net calorific value of softwood (red) and hardwood (black) as a function of water content.

4.7.4 Billing according to the amount of heat generated

Billing according to the amount of heat generated requires a heat meter in the primary circuit of the boiler that can record the amount of heat released in the system. This must be installed professionally and in accordance with the technical guidelines of the heat meter and must be flawless (see also chapter 7.4.3). However, there is a difference between the energy content of the fuel and the measured amount of energy, which is caused by system-related losses. Accordingly, the contracting parties must specify the procedure for billing in the supply contract. For example, a fuel price in € per MWh of generated heat is agreed for a defined annual utilisation rate of the plant (e.g. 85 %). The annual utilisation rate is determined using a formula that takes into account the boiler efficiency and standby losses (chapter 20.12). If the actual annual efficiency deviates from the agreed value, the fuel price is adjusted linearly.

This type of billing assumes that the total fuel used (in a heating circuit equipped with a heat meter) is purchased from a single company. With a corresponding supply contract, a periodic reading of the amount of heat produced is then sufficient for billing. However, other or modified methods (e.g. with additional quality criteria or the use of several supply companies) can also be applied.

Billing according to the amount of heat generated offers a low risk for the operating company of heating plants, as losses due to fluctuations in calorific value, for example due to storage-related substance degradation, are the fuel supplier´s responsibility. The fuel supply company should therefore ensure suitable storage conditions at the plant or just-in-time provision.

Advantages of billing according to heat quantity:

- Independent of water content
- Independent of wood type and bulk density

Disadvantages of billing according to heat quantity:

- Dependent on the annual utilisation rate of the system
- Estimation of the annual degree of utilisation necessary

5 Plant components of heat generation

5.1 Areas of application

Automatic wood-fired boilers are offered in a wide performance range (Figure 5.1). The spectrum ranges from heating a single-family house to power plant boilers with more than 100 MW of firing thermal output. The most common applications for biomass DH plants are in the medium output range between 200 kW and 2 MW, where both wood chips from the forest and residual wood from wood processing are used as fuel. The basic principles, areas of application and most common designs of the most important firing types are described below. The fuel used and the combustion technology are mutually dependent. Therefore, for the selection and operation of automatic wood furnaces, the assessment of the wood assortment according to the technical criteria of the plant is decisive. These include the size of the pieces, the permissible proportion of overlengths, bark and fines, and the water content (chapter 4). Table 5.1 provides an overview of the most important types of wood combustion systems, their usual output ranges and fuels. chapter 13 goes into more detail on the selection of suitable combustion technology depending on the available fuel.

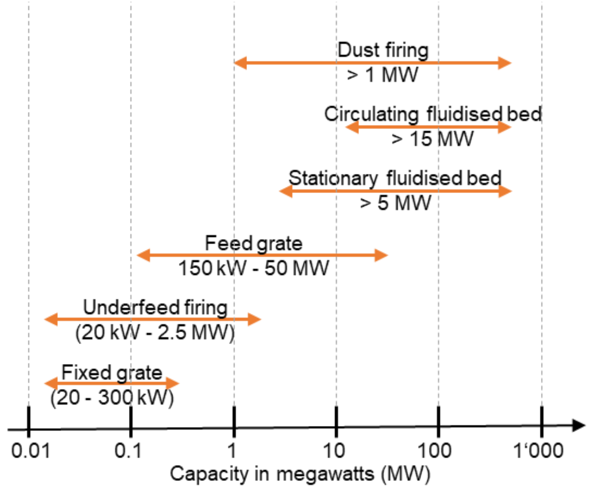


Figure 5.1 Areas of application of the most important types of biomass combustion systems.

Table 5.1 Areas of application of the most important types of biomass combustion systems.

Type	Power range	Fuels	Water content [%]	Ash content [% wf]
Fixed grate	20 - 300 kW	Wood chips	10 - 35	
Underfeed firing	20 kW - 2.5 MW	Wood chips, sawdust, pellets, max. dust content 50 %.	5 - 50*	< 2
Feed grate	150 kW - 50 MW	Pellets, wood chips and most biomasses, max. dust content 50 %.	5 - 60	< 50
Stationary fluidised bed	from 5 MW from 20 MW	Different biomasses Diameter < 10 mm Diameter < 80 mm	5 - 60	< 10
Circulating fluidised bed	15 MW - 100 MW	Different biomasses Diameter < 10 mm	5 - 60	< 10
Dust firing	1 MW - 100 MW	Different biomasses Diameter < 5 mm	usually < 20	< 2

* Mostly up to M35, with sufficiently long uncooled burnout zone up to M50 possible.

5.2 Fundamentals of combustion

During combustion in energy plants, the energy bound in the fuel should be completely released. This requires complete combustion. Combustion plants should therefore be designed and laid out in such a way that complete combustion is possible even with fluctuating fuel qualities. It is then the task of the plant operator to operate the plant in such a way that complete combustion is realised so that the organic fuel components are converted as efficiently as possible into CO_2 and H_2O. The combustion process of solid fuels can be subdivided into the following sub-processes (Figure 5.2):

- Heating and drying
- Degassing and pyrolysis
- Combustion of the volatile fuel components
- Burnout of the solid fuel components

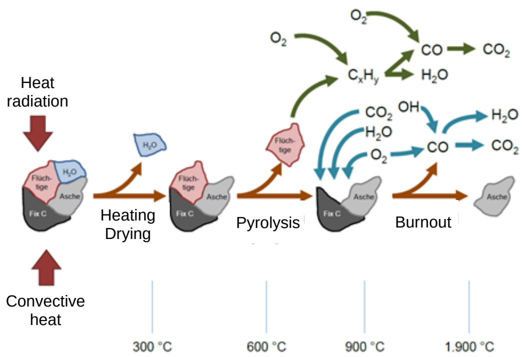


Figure 5.2 Simplified combustion process diagram.

Depending on the type of combustion, the sub-processes shown do not necessarily have to take place one after the other, but can also overlap to some extent. At the beginning of the combustion process, the water contained in the fuel is evaporated, i.e. the fuel is heated and dried in the process. During the further heating of the fuel, pyrolysis begins, whereby the highly volatile fuel components escape and pass into the gas phase. This produces a combustible gas mixture, so that combustion begins when the appropriate ignition temperature is reached. In the further course, the remaining solid fuel components also react with the available oxygen from the combustion air. In this chemical transformation of the organic fuel components, a distinction is made between homogeneous (both reaction partners gaseous) and heterogeneous (reaction between solid and gaseous phase) reactions. The heterogeneous combustion of solid fuels is much more complex and demanding than the homogeneous combustion of gaseous fuels, such as natural gas.

5.3 Combustion technologies

5.3.1 Overview

In the following, the most common firing technologies in biomass heating (power) plants are explained, which can basically be divided into fixed-bed, fluidised-bed and dust firing systems (Figure 5.3).

The heat required for drying and degassing is supplied in different ways during heating operation, depending on the type of firing. In dust firing, the entering fuel particles are brought into contact with hot flue gases. In fluidised bed furnaces, the heat is transferred by solid particles in the fluidised bed. In these cases, the heat transfer is convective. In grate firing systems, heat is primarily supplied by the radiation emitted by the surrounding combustion chamber walls. When starting up the furnace, either electric hot air blowers (fuels with low water content < 35 %, plants in the lower output range up to 900 kW) or gas-fired pilot burners (higher output ranges > 900 kW, max. fuel moisture approx. 55 %) are used to ignite the fuel.

A fundamental distinction must be made between standard series units and individually adapted industrial boilers. With increasing deterioration of the fuel quality, i.e. wetter material, more irregular and coarser pieces, clogging with needles, bark and leaves, as well as possibly higher foreign matter content, more robust and more complex technology must be used. This complex technology is technically feasible for smaller plants to a limited extent. In addition, the necessary technology leads to higher specific investment costs (€/kW installed capacity).

While the specific investment costs for series units are relatively low, these plants require high fuel quality. Standard series units are suitable for dry fuels, for example wood chips with water content < 35 %, and are usually available up to a capacity of 500 kW, rarely up to 1,500 kW. The dry, free-flowing fuel can be transported to the boiler by low-cost silo discharge systems. Such devices are not suitable for forest-fresh wood chips. Experience has shown that there is a risk of chimney fires, emission limits being exceeded, increased soiling and plant wear, odour nuisance and problems with wood chips discharge from the silo if the fuel is too moist. Firing systems for forest-fresh wood chips have also developed further in the low output range > 150 kW. Although the specific investment costs for the boiler are higher here (up to 50 % for the same boiler output), such industrial boilers have significantly greater fuel flexibility. Higher capital costs can be compensated by lower fuel costs, especially in combination with long operating times.

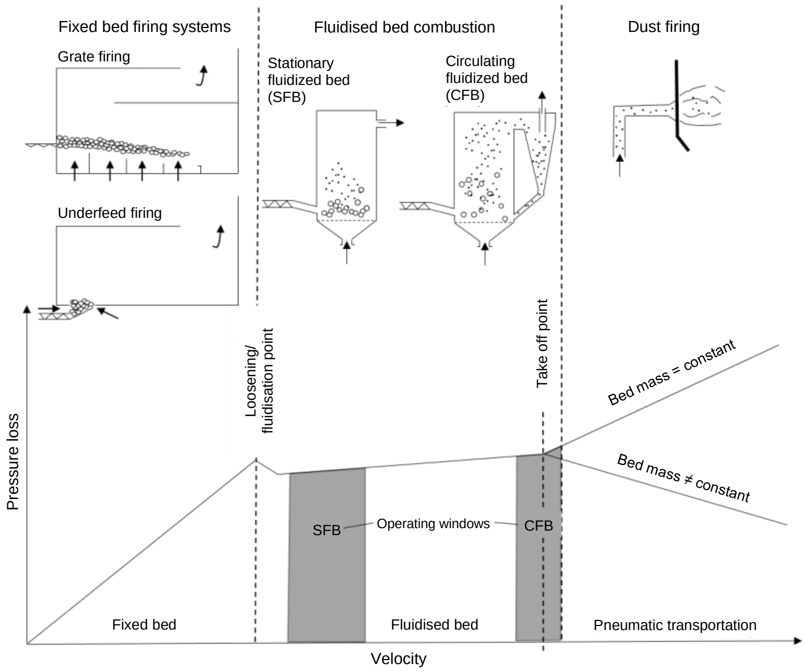


Figure 5.3 Overview of firing technologies. Classification according to the flow rate of the fuel gas through the plant and the type of fuel transport.

5.3.2 Fixed-bed firing systems

In **underfeed firing** (Figure 5.4), the fuel is fed from below into a fire trough (retort) by means of a screw conveyor. There, the fuel is dried and degassed and the charcoal burns off. To ensure complete oxidation of the combustible gases, secondary air is added and mixed with the hot combustion gases before they enter the hot afterburner chamber. In the downstream heat exchanger, heat is released from the hot flue gases and the flue gas is cleaned. The grate ash usually has to be de-ashed manually, but there are also furnaces on the market with automatic de-ashing systems that have a movable afterburner grate and a de-ashing screw. The nominal boiler output of underfeed firing systems is limited upwards to about 2.5 MW_{th}. They are particularly suitable for fine-grained wood fuels such as sawdust, pellets or wood chips (maximum grain size 50 mm) with a water content of 5 - 50 %. The design of the combustion chamber and afterburner chamber must be adapted to the water content. With fuels rich in ash, problems arise with regard to ash discharge from the hot combustion chamber. In addition, sintered or melted ash layers on the fuel surface can block the release of combustion gases from the ember bed for a short time, resulting in unsteady combustion conditions at each combustion gas breakthrough. The investment costs of underfeed furnaces are lower than those of grate furnaces. Continuous fuel input and a stable, quiet fuel bed enable simple and good output control and low-emission low-load operation. However, this type of construction is being used less frequently.

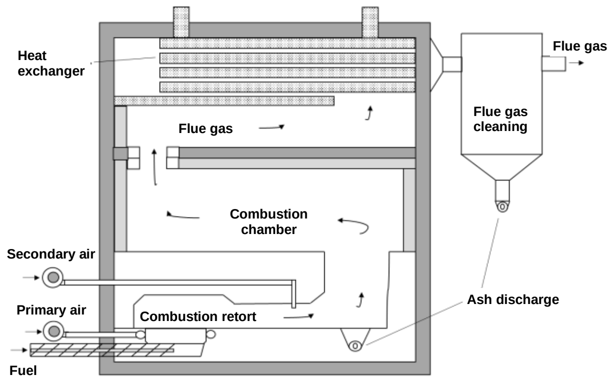


Figure 5.4 Functional principle of an underfeed firing system.

In fully automatic wood firing systems, grate firing systems with **tilting grates** are often used (Figure 5.5). These can consist of one to three rotatable elements. There is no active movement of the fuel on the grate. The fuel is pushed onto the grate in the closed state (1), which forms the basis for a quiet ember bed. After a certain period of operation (e.g. 8 hours), the fuel supply is stopped. Then the entire grate or an element of it is tilted to the side and opened (2). The ash falls down. A residual glow zone remains on the grate area that was not tilted. This saves energy for reigniting after closing the grate. A tilting grate with two elements is also called a step-breaking grate. Opening both elements allows complete cleaning of the combustion chamber.

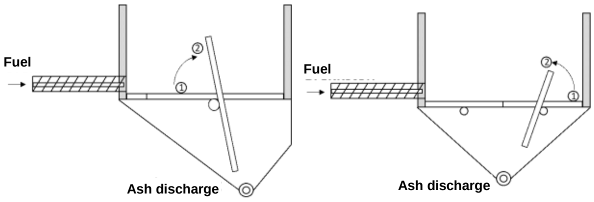


Figure 5.5 Functional principle of fuel loading and ash removal for tilt grate (left) or step crusher grate (right); (1) closed position, (2) open position.

In a **feed grate firing system** (Figure 5.6), the fuel is pushed horizontally onto the grate (screw conveyor or hydraulic insert) and conveyed further through the combustion chamber by the movement of the grate elements. Ash removal takes place at the end of the grate. Part of the combustion air is supplied as primary air through the grate, which can be divided into several zones. Within the first zone, fuel drying takes place, followed by degassing in the middle zone (this is the main combustion zone) and charcoal burnout in the last zone. A zonally controlled primary air supply through the grate enables adjustment to the burn-off behaviour of the fuel, continuous partial load operation and the setting of a reducing atmosphere in the primary combustion zone. The secondary air is mixed above the grate or, more advantageously for NO_x reduction, with spatial separation in the secondary combustion zone with the combustible gases for burnout in the subsequent combustion chamber.

The grate fulfils the functions of fuel transport as well as stoking and circulation to homogenise the fuel bed and improve air passage. To ensure a uniform primary air supply to the various grate zones, it is necessary to have the most homogeneous fuel allocation possible on the grate. Therefore, a correct adjustment of the feed rate of the individual grate elements is crucial for efficient operation in order to ensure a uniform, slow grate movement. Inhomogeneous occupancy can lead to slagging, the whirling up of unburnt particles and high fly ash contents. This necessitates a higher air surplus to achieve complete combustion (streaking). Excessive movement frequencies of the grate elements lead to unburnt carbon in the ash or insufficient fuel occupancy of the grate. Infrared light barriers distributed over the various grate zones are used to control the height of the embers and regulate the feed rate.

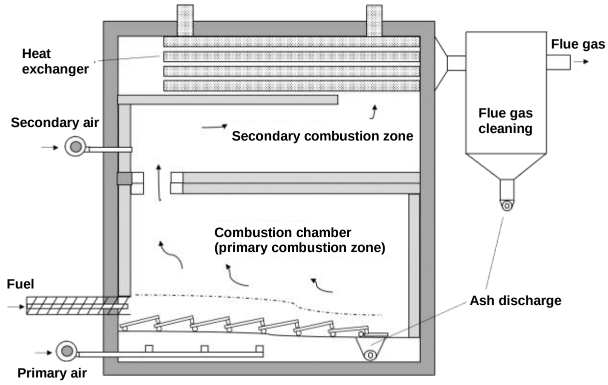


Figure 5.6 Functional principle of a feed grate firing system.

Grate firing systems are suitable for fuels with high ash content, varying lumpiness and high water content. Part of the energy released during combustion is needed to evaporate the water contained in the fuel. A radiation cover over the fuel ensures a high degassing temperature. For the use of fuels with > 50 % water content, the furnace must have an uncooled burnout flue. Feed grate furnaces are mainly realised according to the counter-flow principle. This allows targeted flue gas recirculation. In the case of fuels with high water contents, the hot combustion gases are also fed back over the grate covered with fresh fuel, so that pre-drying of the fuel takes place in the first zone of the grate. In this way, fuels with a water content of up to 60 % can be used. In addition, two further types of combustion chamber geometries are distinguished on the basis of the direction of movement of fuel and gases: co-current and medium-current (Figure 5.7).

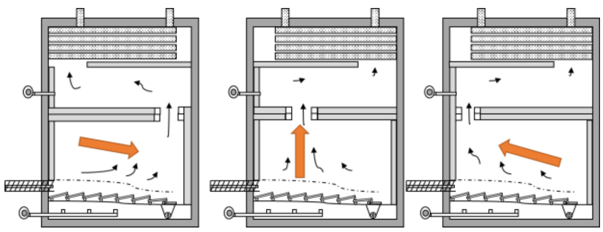


Figure 5.7 Construction principles of grate furnaces; direct current (left), medium current (middle) and counter current (right).

With the help of fans, primary combustion air is supplied from below through the grate and the fuel bed and secondary air in the post-combustion zone. The air supply at the various points is supported by an exhaust gas fan, which ensures a negative pressure in the entire system. A homogeneous lumpiness of the wood chips with a low proportion of fines is important for a uniform air supply and low-emission combustion. In biomass DH plants, the inclined and horizontal moving grates are the most common. The grate is composed of alternating fixed and movable grate elements. The fuel is transported by periodically moving the movable grate elements back and forth. This mixes unburnt and burnt fuel particles, renews the surface of the fuel bed and achieves homogeneous fuel coverage of the grate. The horizontal moving grate has inclined grate elements. Their movement results in a very homogeneous grate covering and widely prevents slag formation due to local overheating. One advantage over the inclined moving grate is the more compact design.

For fuels with a low ash melting point and for very dry fuels, grate cooling (by water or air) is often necessary. Another means of controlling the combustion chamber temperature or the temperature of the fuel bed on the grate is flue gas recirculation. To avoid the formation of slag in the fuel bed, the use of primary flue gas recirculation should be considered. In this case, part of the CO_2-rich and oxygen-poor flue gas flow is fed into the fuel bed together with the combustion air. The mixing ratio is determined by the desired sub-stoichiometric combustion air ratio (air deficiency). Overheating in the combustion chamber, which causes slag formation and high wear on the combustion chamber lining, can be prevented by secondary flue gas recirculation. In this process, part of the CO_2-rich and oxygen-poor flue gas flow is fed into the combustion chamber separately or together with the secondary air. The temperature of the fuel bed or burnout zone can thus be lowered by up to 200 K reducing maintenance and servicing.

5.3.3 Fluidised bed combustion

In a fluidised bed combustion system, there is no fixed fuel bed. The fuel, together with hot bed material, a granular inert material, usually sand and ash, is fluidised by rapidly inflowing primary air (usually with a recirculation gas component). The particles are thus in a fluidised state. The bed material fulfils the function of heat transfer. It absorbs the released combustion heat and releases it again throughout the fluidised bed. The good mixing and the very homogeneous temperature distribution create good conditions for the thermal conversion of the fuel. Due to the high air velocities, there is a higher pressure drop in the fluidised bed, which requires higher outputs of the blowers used (about 100 mbar more compared to grate firing). During the start-up of the furnace, the bed material must first be heated to around 600 °C usually with the help of a gas or oil-fired start burner before fuel can be added to the combustion chamber.

Fluidised-bed furnaces are suitable for fuels with different water and ash contents. The combustion temperature must be kept below the fuel-dependent ash softening temperature, as the tendency to slagging, corrosion and agglomeration of the bed material increases with rising temperature. To separate sulphur and chlorine, it is suitable to introduce additives (e.g. limestone) directly into the combustion chamber. In this way, the release of pollutants such as SO_x and halogen compounds can be avoided without major equipment expenditure. Due to relatively low combustion temperatures, practically no thermal NO_x is formed. The formation of NO_x from the nitrogen contained in the fuel can be controlled by a low excess of air (air staging) [50]. Fluidised bed combustion systems are therefore well suited for the energetic utilisation of biogenic residues.

A distinction is made between stationary and circulating fluidised bed furnaces. At gas velocities of 1 to 2 m/s, the bed material forms a **stationary fluidised bed**. Above this layer, the fuel is fed into the combustion chamber, falls onto the fluidised bed and degasses there. Complete oxidation of the combustible gases released in the process takes place in the free space above with the addition of secondary air. No special fuel preparation is required; grain sizes < 10 mm are sufficient. Due to the bed dimensions, this technology is suitable for plants up to 80 MW. At higher gas velocities (5 to 10 m/s), bed material is increasingly discharged from the fluidised bed. After exiting the combustion chamber, it is separated again and recirculated (**circulating fluidised bed**, Figure 5.8). Compared to the stationary fluidised bed, this technology offers the advantage that the solids are mixed more intensively when additives are added, which reduces additive consumption.

For economic reasons, the circulating fluidised bed in particular is only used from a plant size of 30 MW upwards.

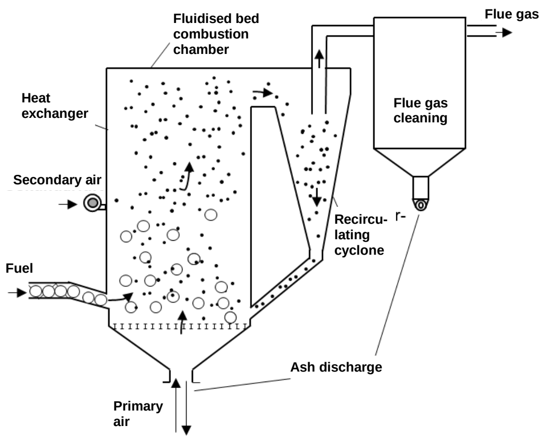


Figure 5.8 Operating principle of a circulating fluidised bed combustion system.

5.3.4 Dust firing

Fuels with a dust content > 50 %, as typically produced in the wood-processing industry, are no longer suitable for use in an underfeed or grate firing system. This would require processing by briquetting or pelletisation (chapter 4.5). The fuel can also be used directly in a dust firing system. This firing technology can be combined with others (e.g. a grate or fluidised bed firing) and enables fuel staging (chapter 5.6).

In injection or dust firing systems, the dusty fuel (maximum particle size 10 to 20 mm, water content < 20 %) is pneumatically introduced into the combustion chamber. In this process, the carrier air acts as primary air. Fuel particles begin to degas immediately after entering the furnace. Combustion of the volatile components takes place by adding secondary and tertiary air.

A dust firing system is often designed in the form of a swirl burner (Figure 5.9). Here, primary, secondary and tertiary air jets are blown concentrically through annular nozzles into the combustion chamber. The primary air stream and the fuel nozzle are located in the centre of the flame; a primary combustion zone is formed here. Towards the outside, air staging is achieved by faster-flowing secondary and tertiary air streams, which suck in the exhaust gases and oxidise them as they proceed (Figure 5.10).

Due to the favourable mixing of fuel and air as well as the small grain size of the fuel particles, a high burnout quality with low CO emissions is achieved (complete combustion). The fuel supply is continuously adjustable up to a partial load of about 25 % of the nominal load without any significant influence on the combustion characteristics. Another advantage of this technology is low NO_x values due to air staging and low required excess air. Because of the high combustion temperature and thus high energy density on the walls of the combustion chamber, the possibility of cooling by water or flue gas recirculation should be provided. High thermal load and erosion can lead to rapid wear of the fireclay ([51], [52]).

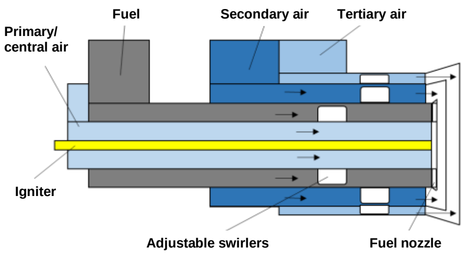


Figure 5.9 Section through a swirl burner.

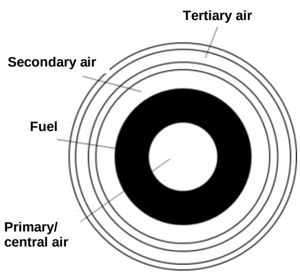


Figure 5.10 Principle of air staging within the flame of a swirl burner (front view of air and fuel nozzles).

5.4 Heat transfer in the boiler section

The heat released in the combustion chamber is transferred via a heat exchanger from the hot flue gases to a circulating heat transfer medium, usually liquid or vapour water, in CHP plants or for process heat also thermal oil. High heat transfer is crucial for high boiler efficiency (chapter 20.11). To ensure this, operational deposits on the heat exchanger surfaces must be removed at regular intervals (see chapter 5.5).

Depending on the respective requirements, different types of construction, operating principles (co-current, counter-current or cross-current) and superstructures (horizontal or vertical) are used. In biomass boilers, the fire tube boiler (flue gas flow inside the tube) and the water tube boiler (flue gas flow outside the tube) are widely used. If the heat transfer medium is inside the heat exchanger tube, which is in contact with the hot flue gas on the outside, it is called a water tube boiler. The water tube boiler is the predominant design for steam generation. In a fire tube boiler, the hot flue gas is passed through tubes around which the heat transfer medium flows. With water as the heat transfer medium, this type of construction is also known as a shell boiler and is mainly used for hot water production. The fire tubes usually contain so-called turbulators. These spiral-shaped components swirl the exhaust gases (increase the flow turbulence), thus improving the heat transfer to the heat exchanger tube. Turbulators also serve as cleaning devices (chapter 5.5).

A drop in temperature below the dew point of the exhaust gas results in condensation of potentially corrosive gas components. Both the water content and the sulphur and chlorine content in the fuel are important here. Regardless of the sulphur or chlorine content, the water vapour partial pressure and thus the dew point in the exhaust gas increases with increasing water content of the fuel. The acid dew point in the flue gas increases both with increasing sulphur and chlorine content and with increasing water vapour content, depending on the water content in the fuel and the excess air. For fuels with increased sulphur or chlorine contents (e.g. waste wood, wood from landscape maintenance, especially from road embankments, residual wood from wood processing), the acid dew point rises significantly above that of water vapour to > 100°C up to 200 °C [53].

If the exhaust gases are cooled below the respective acid dew points, sulphuric or hydrochloric acid occurs, which is responsible for corrosion damage (surface corrosion, pitting corrosion). However, the decisive factor for avoiding corrosion problems is not only the exhaust gas temperature, but also the temperature of the surfaces with which the exhaust gases come into contact. To minimise problems with corrosion on the heat exchanger surfaces in the boiler, boiler manufacturers prescribe a minimum inlet temperature of the water into the boiler. The higher the water content, the higher the minimum inlet temperature should be. The minimum boiler return temperature is ensured by appropriate admixing of the flow to the return (boiler return temperature protection) via a hydraulic admixing circuit in the boiler circuit (controlled 3-way valve) (see chapter 7.2). At the same time, the minimum and maximum flow rates specified by the boiler manufacturer must be adhered to in order to ensure a complete and even flow and to avoid local overheating.

In plants using fuel assortments with critical sulphur and chlorine contents, it may be necessary to raise the boiler inlet temperature to > 80 °C to 110 °C, depending on the sulphur, chlorine and water content in the fuel, so that the waste gases in the boiler section are not cooled locally below the acid dew point and corrosion damage can thus be avoided. In system components whose surface temperatures are below the acid dew point temperatures of the flue gases (e.g. economiser), the surfaces exposed to the flue gases must be made of corrosion-resistant material (stainless steel). The cooled surfaces of the separator electrodes (plates or inner tubes) of electro-particle separators are also susceptible to corrosion during low-load operation of the biomass boiler.

Heat generation and boiler systems are subject to general health and safety principles, codes of practice and design, installation and operation standards and require official permits, corresponding type approvals, certifications and acceptance test certificates and must be equipped with the corresponding safety devices (e.g. safety temperature limiter, safety pressure limiter, thermal discharge safety device, safety valve, devices for operation without constant supervision, emergency power supply, etc.). It must be ensured that an impermissible rise in temperature or pressure in the boiler or in the hydraulic system of the heat generation is prevented in any operating state and also in the event of a blackout. For this, explicit reference is made to the applicable national legal regulations (see also chapter 19).

For the installation of the boiler, it must be ensured that operating devices are accessible and that the space required for operation and especially for maintenance (cleaning) is available.

5.5 Automatic boiler tube cleaning

During operation, fouling occurs on the boiler tubes that come into contact with hot flue gases. As the fouling soiling of the heat exchanger increases, the heat transfer decreases and the flue gas temperature increases, which has a negative effect on the efficiency of the system. This is prevented with regular boiler tube cleaning. Automatic cleaning systems remove deposits, for example, by means of pneumatic compressed air pulses or mechanical processes or blast cleaning with pressure waves. However, blast cleaning is only used for plant-specific requirements in the large output range.

In smaller firing systems, the flue tubes can be cleaned manually with brushes via open turning chamber doors if the design is suitable. Another possibility for removing deposits from the inner walls of the boiler tubes is to move the steel spirals (turbulators) up and down in the boiler tubes (manually or electrically).

For firing systems > 200 kW with a high number of full load operating hours, a pneumatic pressure surge cleaning system is used (see Figure 5.11). At regular intervals, deposits on the heat exchanger are removed with pulses of compressed air. This can increase the annual efficiency of the firing system by 3 to 4 % and facilitates cleaning. Manual cleaning is required again only after > 2,500 full load operating hours (service interval).

Figure 5.11 Automatic boiler tube cleaning (source: Schmid energy solutions).

5.6 Emissions

In order to ensure combustion with the lowest possible emissions, the design and control of the firing system is of decisive importance. The aim is to achieve the most **complete combustion** of the fuel used. In the process, the carbon contained in the fuel is oxidised with the oxygen from the supplied air. The main products of this reaction are carbon dioxide (CO_2) and water vapour (H_2O) (Table 5.2).

A by-product of complete combustion is nitrogen oxides (NO_x, in technical combustion processes mainly NO and NO_2). These have an irritating effect on the respiratory tract. They also promote the acidification of the ecosystem and the formation of ground-level ozone and secondary particulate matter. Basically, a distinction can be made between three formation pathways of NO_x. Thermal NO_x is formed at temperatures > 1,300 °C through the reaction of atmospheric oxygen with atmospheric nitrogen. Prompt NOx is formed in comparatively small quantities primarily during the combustion of fossil fuels due to the presence of hydrocarbon radicals. The formation increases with temperature. The usual temperature range for the combustion of biomass is between 800 °C and 1,200 °C. Due to these low temperatures, NO_x is formed during wood combustion practically exclusively from the nitrogen compounds contained in the fuel. NO_x formation can be significantly reduced by optimising the combustion chamber geometry and control (fuel staging or air staging; see chapter 5.3).

Table 5.2 Products from biomass combustion.

Formation mechanism / source	Product
complete combustion	CO_2, H_2O
incomplete burning	CO, soot, unburnt C_xH_y
By-products of complete combustion	NO_x
Fuel impurities	SO_2, SO_3, H_2S, NO_x, ash and trace elements

In the case of **incomplete combustion**, emissions of carbon monoxide (CO), unburned hydrocarbons (C_xH_y), polycyclic aromatic hydrocarbons (PAH), tar, soot, ammonia (NH_3) and nitrous oxide (N_2O) occur. Dust emissions are divided into two fractions based on different particle sizes: Coarse fly ash (> 1.0 µm) refers to particles that are entrained from the fuel bed. Fine particles (0.01 to 1.0 µm) are mainly produced by inorganic components in the fuel that evaporate during combustion. When the flue gas cools down, they condense again and form salts. This produces particles in the size range of 0.1 µm. In the case of untreated wood with a low bark content, mainly potassium compounds (e.g. potassium sulphate K_2SO_4) are formed. If inorganic fuel components enter the flue gas stream directly as solid components, they act as crystallisation nuclei during cooling and can grow. Particles in the size range around 1 µm are formed in the process. These are also salts, but mainly calcium compounds (e.g. calcium oxide CaO). This formation path is particularly important for fuels with a high bark content (higher Ca content). The formation of dust emissions from carbon particles is usually of secondary importance if the combustion temperature exceeds 600 °C and complete combustion is achieved.

Other relevant emissions concern sulphur compounds (sulphur dioxide SO_2, sulphur trioxide SO_3, hydrogen sulphide H_2S), hydrochloric acid (HCl) and dioxins and furans (PCDD/F). Due to the low sulphur and chlorine content of untreated wood and the relatively high incorporation rate of chlorine and sulphur in the ash, SO_2 and HCl emissions are usually low. Dioxins and furans are formed in a temperature range of 200 °C to 500 °C on the surface of unburned fly ash particles (de novo synthesis). PCDD/F emissions are normally not a problem when natural wood is burned in state-of-the-art plants. They can be significantly reduced by complete combustion, reduction of the swirling up of particles from the ember bed and efficient dust separation. A long residence time in the temperature range of the de novo synthesis should nevertheless be avoided.

During combustion, inorganic components and thus also trace elements (e.g. heavy metals) are released from the fuel matrix. Both during combustion and on the way to the chimney, the elements behave differently, the individual trace elements show different volatility. Their individual evaporation temperatures cause them to evaporate and condense again at different points in the process. Elements with a high boiling point (Al, Cr, Fe, Mn, Si) are less volatile and therefore remain for the most part in the bottom ash. If the boiling point is somewhat lower (As, Pb, Cd, Zn), the elements evaporate in the course of combustion and condense, absorb or adsorb on coarse or fine fly ash when the flue gases cool down and are thus separated from the flue gas. Elements that react with oxygen or have a very low boiling point pass first into the exhaust gas (N, S, Hg). They are treated separately in the flue gas cleaning system (targeted denitrification, desulphurisation) (Figure 5.12).

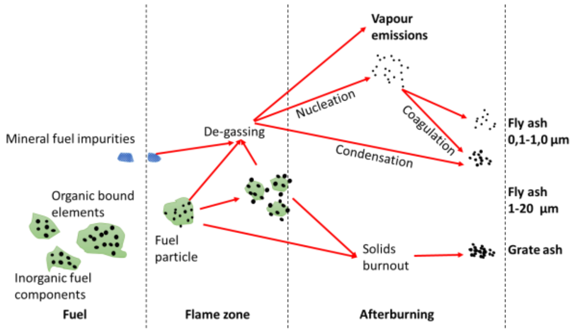


Figure 5.12 Behaviour of trace elements in the fuel during and after combustion.

5.7 Primary measures for emission reduction

Primary measures to reduce emissions from furnaces involve both design measures and suitable control of the operating parameters. By optimising the stages of the combustion process listed above, emissions from incomplete combustion can be reduced. Decisive in this context is a stable, high fuel bed in which fuel and air is well mixed with combustion gases in high temperature ranges (> 850 °C). In this context, the ratio of supplied air to required air (excess air number λ) plays an essential role. Theoretically, an excess air number λ = 1 would be optimal to achieve (stoichiometrically) complete combustion. In practice, a total excess air number of 1.3 to 1.8 is used for large systems and 1.5 to 2.0 for small and medium-sized systems, as this enables optimal mixing of fuel, flue gas and supplied air. An excess air number λ < 1 leads to incomplete combustion, and only part of the energy stored in the fuel is released as thermal energy. If too much air is supplied to the combustion process (λ >> 1), cooling occurs, which leads to incomplete combustion. The optimisation of the excess air number can be realised by geometrically separating the combustion into a primary and a secondary combustion zone. In the primary combustion zone, drying and pyrolysis/degassing of the fuel takes place at sub-stoichiometric conditions (λ < 1) as well as oxidation of the charcoal. In the secondary combustion zone, the complete oxidation of the combustible gases takes place by supplying secondary air (λ > 1) [54]. In modern furnaces with well designed control systems, the concentration of unburnt flue gas components can efficiently be reduced. Primary and secondary flue gas recirculation (see chapter 5.3.2) are also used to optimise combustion conditions and as primary measures to reduce emissions.

A suitable air supply to the installation is also of great importance for reducing dust emissions from fixed-bed furnaces. The fuel bed should be as quiet and stable as possible, with primary air flowing through it uniformly so that no particles are stirred up and entrained. However, this leads to a low mixing of combustible gases and air in the primary combustion zone. Therefore, the focus in the secondary combustion zone is on optimal mixing in order to keep the necessary total excess air low and to increase the plant efficiency. This can be achieved by narrow duct cross-sections in which the combustible gas reaches a high velocity. The secondary air is also introduced at high velocity via staggered nozzles. Other possibilities include a vortex or cyclone-like secondary combustion chamber. Overall, total excess air should be minimised, but sufficiently high to enable complete burnout.

As primary measures for nitrogen oxide reduction, the processes of air staging and fuel staging are available ([55], [56], [57], [58]) (Figure 5.13). In both processes, a reduction zone is created in which the nitrogen compounds formed during fuel decomposition react with each other under oxygen deficiency to form stable, harmless molecular nitrogen, as in the following reaction:

$$NH_2 + NO \rightarrow N_2 + H_2O.$$

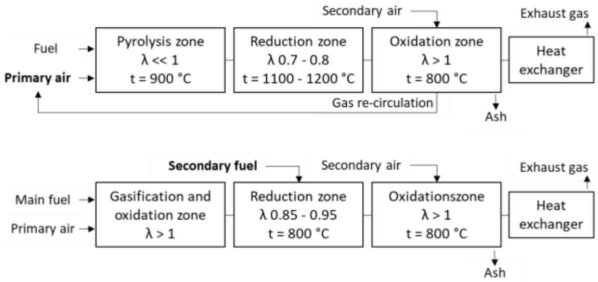


Figure 5.13 Principle of air staging (top) and fuel staging (bottom) for NO_x reduction.

Neither method can be retrofitted. Air staging is used for new plants > 200 kW, and fuel staging is used from about 5000 kW. The processes have a NO_x reduction potential of around 30 to 50 % for fuels with a low nitrogen content and 50 to 70 % for fuels with a higher nitrogen content ([55], [56]). The reduction potential of fuel staging is somewhat higher with a somewhat wider operating range of firing power [57].

Effective reduction of nitrogen compounds to N_2 by air staging occurs when combustion gases are long enough in the reduction zone (min. 0.3 s, λ = 0.7 - 0.8) at high temperatures (1,100 °C to 1,200 °C) ([55], [57]). To achieve this, the plant technology must be designed for staged combustion, and all operating parameters must be precisely controlled. To prevent back-mixing of the secondary air into the primary combustion zone, a constructive separation of the primary and secondary combustion zones is required. The use of fuels that are rich in ash or form slag is critical due to the high temperatures. In comparison, fuel staging requires somewhat less precise adherence to reaction conditions. Here, a secondary fuel is added in a second combustion chamber, which mixes quickly and well with the hot combustion gases (around 800 °C). Wood dust, for example, is suitable. Starting from a low deficiency of primary air (λ = 0.85 to 0.95), the additional fuel provides reducing conditions. In both cases, complete combustion takes place in a downstream oxidation zone with excess air.

5.8 Secondary measures for emission reduction

5.8.1 Dedusting

Cyclones are used for the separation of coarse dust. A **multicyclone** is used for large volume flows. A multicyclone is a parallel connection of several individual cyclones that are combined in one housing. A cyclone is a centrifugal separator. The particle-laden gas flows either tangentially (Figure 5.14 or axially Figure 5.15) into the cylindrical cyclone chamber where it is set into a rotating flow. In the process, ash particles are thrown out of the flow onto the wall of the cyclone shell and from there separated downwards in the direction of the dust discharge. The cleaned gas leaves the cyclone via an immersion pipe.

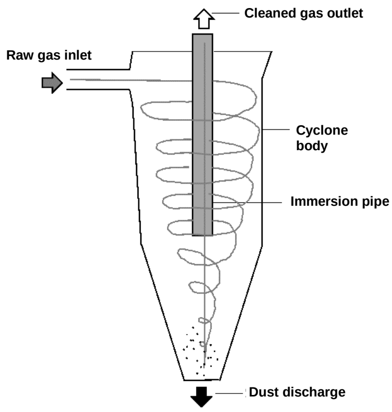


Figure 5.14 Section through a single cyclone (tangential separator).

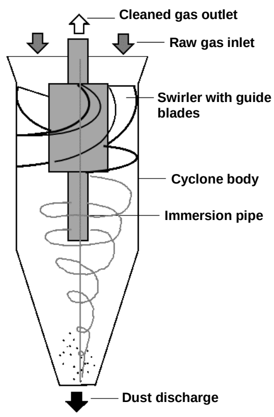


Figure 5.15 Section through a single cyclone (axial separator).

The separation effect of cyclones in wood combustion plants is limited to coarse ash particles > 10 µm. As a rule, clean gas values of 120 - 200 mg/m³ (at 11 vol.% O_2) are achieved [59]. The separation efficiency depends on the circumferential speed of the rotary flow and on the geometric design of the cyclone. The higher the circumferential speed, the smaller the particles that can be separated. With increasing speed, however, the pressure loss also increases. At reduced firing rates, on the other hand, the separation efficiency decreases due to the reduced flue gas velocity. In addition, particles > 10 µm cannot always be separated reliably if they have a very low density and the centrifugal force is therefore too low.

Due to its comparatively small space requirement and low investment and operating costs, the cyclone is the most frequently used dust collection method in wood heating systems. However, its use alone is usually not sufficient to comply with the dust limit value. Therefore, cyclones are used for coarse dust pre-separation for downstream dust separation processes. This reduces the dust load in downstream filter units, which can thus work more efficiently. In wet separation processes, the expenses for sludge management and disposal costs can be reduced.

In a **fabric filter,** the dust-laden raw gas is sucked from the outside through a filter medium, which is usually applied to a cylindrical support fabric. A filter cake forms on the filter medium, which is periodically cleaned by short blasts of compressed air in counterflow to the exhaust gas flow (Figure 5.16, Figure 5.17).

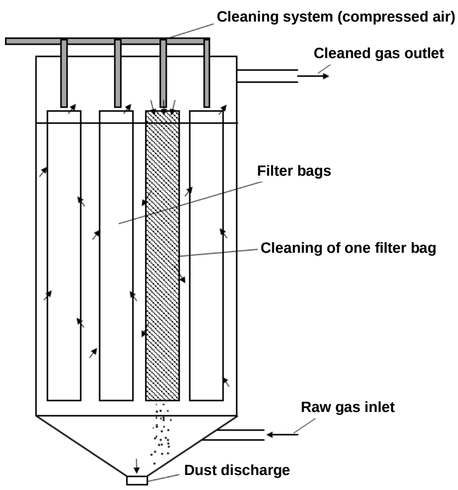


Figure 5.16 Schematic of a fabric filter: Parallel arrangement of the filter bag elements. Three elements are in working position, the fourth element is cleaned in counterflow principle (cleaning with compressed air).

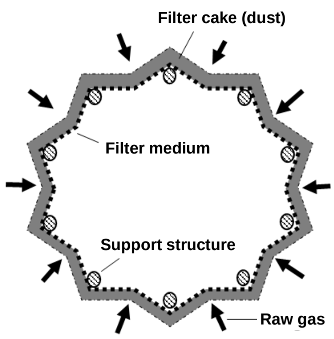


Figure 5.17 Section through a filter bag.

Common filter media are needle felts that are surface-treated depending on the chemical composition and temperature of the exhaust gas (e.g. Teflon, PTFE laminate).

An important factor in operation is the exhaust gas temperature, as exhaust gas condensation can lead to clogging of the filter and premature replacement of the filter media. The operating range is 180 to 220 °C (maximum flue gas temperature of 250 °C, minimum flue gas temperature with dry fuel of > 140 °C). A high water vapour content in the flue gas is critical (e.g. with moist fuel or in partial/low load operation). In addition, spark and ember particle separation is necessary. Fabric filters with medium investment but relatively high operating costs are used in the > 100 kW power range. Compact filter units have a low space requirement. Fabric filters have a high separation efficiency. Clean gas values of 1 to 5 mg/m³ (at 11 vol.% O_2) can be achieved [59]. Leaks such as hairline cracks or holes in the fabric drastically reduce the separation efficiency. By adding absorbents (additives), there is the possibility of additional separation of HCl, SOx and dioxins (PCDD/F).

In an **electrostatic precipitator,** particle separation takes place using an electric field. The term “electrostatic precipitator” is also used colloquially, but since the separation does not take place by filtration, the term electrostatic precipitator is used in the following (Figure 5.18). An electrostatic precipitator consists of a spray electrode connected to a voltage source and a grounded collecting electrode. Gas molecules are ionised by an electron current and adhere to the particles in the raw gas. The particles charged in this way attach themselves to the collecting electrode and are deposited there (Figure 5.19). Electrostatic precipitators can also be used at low capacities. Separation efficiency is high, with clean gas contents of 5 to 50 mg/m³ (at 11 vol.% O_2), however, with high space requirements and high investment costs as well as medium operating costs.

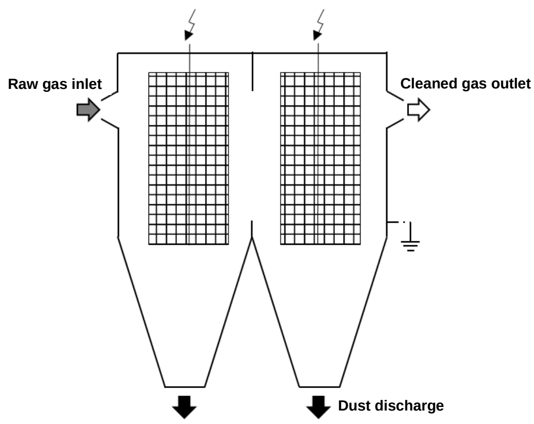


Figure 5.18 Schematic of an electrostatic precipitator.

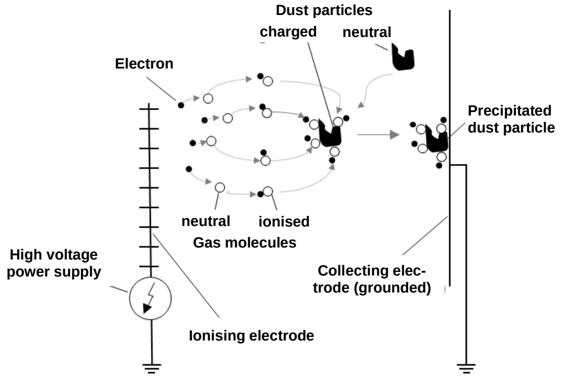


Figure 5.19 Physical principle of operation of an electrostatic precipitator.

Dry electrostatic precipitators are most commonly used. The design is usually a plate or tube-type electrostatic precipitator. Plate-type electrostatic precipitators, which are periodically cleaned with rapping devices, are available today as established technology for > 200 kW. The space requirement is high, the height corresponds approximately to the upstream boiler. Temperature drops below the dew point in the exhaust gases must be prevented as long as the high voltage is switched on. To reduce the risk of short circuits, the insulators are additionally set back from the gas flow and are often additionally heated. Despite these measures, the high voltage may only be switched on when the flue gas temperature has reached 80 °C for natural wood, for example, and 130 °C for waste wood. Below this limit value specified by the manufacturer, the electric separator is ineffective. Therefore, during start-up and minimum load operation, steady-state operation must be ensured as quickly as possible. For this purpose, a boiler bypass on the exhaust side can be used to quickly raise the flue gas temperature in the electric separator. In series units, the electric separator can be integrated directly into the boiler. Tubular electrostatic precipitators are offered for wood heating systems up to 5,000 kW. Several filter tubes with internal spray electrodes are arranged in them. The cleaning of the inner tube walls (= precipitation electrode) is done by mechanical cleaning with brushes. Compared to the plate-type electrostatic precipitator, the space requirement is reduced, but the same requirements apply with regard to falling below the dew point.

There are also **wet electrostatic precipitators** that are used in combination with flue gas condensation (see chapter 13.7.2.3). In order for the water vapour in the flue gas to condense, a maximum return temperature < 45 °C is required (even lower with dry fuel). During the condensation of the water vapour, the charged dust particles are used as condensation nuclei and, incorporated into the water droplets, are separated as condensate sludge. The degree of separation is increased by the condensation water content and the external water requirement is kept to a minimum. Sludge treatment and water treatment must still be taken into account.

Within the framework of QM for Biomass DH Plants, a **minimum annual availability** of the dust collector should be defined and checked in the course of operational optimisation (Milestone 5), since an electrostatic precipitator should be active in all phases with relevant dust emissions (Figure 5.20).

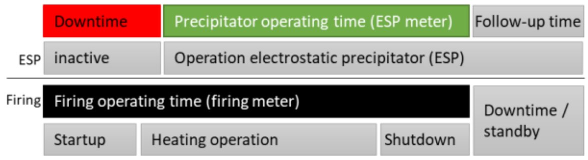


Figure 5.20 Typical operating cycle of a furnace and an electrostatic precipitator (see FAQ 38).

Start-up, heating operation and shut-down are combined as one operating phase; they correspond to the firing operating time. The separator operating time may only be counted if the electric separator is in operation at the same time as the firing (green). If the electric separator has a switch-on delay or malfunction, a downtime occurs (red). If the electric separator is operated longer than the firing system, this is a run-on time that must not be counted as operating time. During the shutdown/standby of the firing system, the dust emissions are significantly lower than during the operation of the firing system. With the follow-up time of the electrostatic precipitator, dust emissions can nevertheless be further reduced. The availability of an electrostatic precipitator is usually determined over one year and is defined as the ratio of the accumulated precipitator operating time (green) to the accumulated furnace operating time (black).

$$\text{Availibility } [\%] = \frac{100 * \text{Precipitator operating time}}{\text{Furnace operating time}}$$

For both electrostatic precipitators and fabric filters, the minimum temperature specified by the manufacturer, which depends on the fuel, must be reached as quickly as possible during start-up and a temperature drop must be avoided during minimum load operation. The maximum permissible temperature at the inlet to the separator/filter must also be observed. The configuration and mode of operation of the system has a major influence on this. While, for example, wood-processing plants and waste wood incineration plants often operate in band-load mode, mono or bivalent biomass DH plants with an increasing proportion of low-load operation are found in the area of heat supply for residential buildings.

Notes on integration and operational optimisation (see also chapter 16)

- In systems with two biomass boilers, the solution with only one particle separator and one chimney is not recommended. Equipping each boiler with its own particle separator and chimney is more expensive, but results in advantages due to clear boiler lines (no cross-influence on the flue gas side, optimum chimney cross-section, fewer problems in part-load operation, etc.).
- At flue gas temperatures > 120 °C, it must be checked whether the flue gas heat exchanger (economiser) should be installed before or after the electrostatic precipitator or fabric filter. At lower flue gas temperatures, the heat exchanger should always be installed after the electrostatic precipitator in order to

avoid condensation of flue gas components in the electrostatic precipitator.

- It is important that the heat exchange surfaces in a condensing exhaust gas heat exchanger are always wet on the exhaust gas side. This is the only way to prevent undesirable deposits that can build up in zones that alternate between wet and dry.
- In the operational optimisation concept, it must always be unambiguously specified that "particle separator in operation" (i.e. high voltage switched on or bypass closed or injection of wash water switched on) is recorded during automatic data recording and not merely a release signal.

5.8.2 Denitrification

For nitrogen-rich fuels such as waste wood, chipboard residues, untreated hardwood or softwood with a high bark content, secondary measures must be used to reduce NO_x in order to comply with defined emission limits. The scope of application is explained in more detail in chapter 13.9.2. Denitrification measures are difficult or even impossible to retrofit. Their use must therefore be considered and, if necessary, planned for from the outset when determining the firing technology and fuel range.

In the **SNCR (selective non-catalytic reduction) process**, a reducing agent is injected into a reduction zone directly in the combustion chamber. The reducing agent used is an ammonia (NH_3) or urea solution (NH_2CONH_2), which is non-corrosive and therefore easier to handle. At high temperatures, NH_2 radicals are formed which reduce with NO to elemental nitrogen (N_2). Optimal mixing is required in the reaction zone. A residence time of around 0.5 seconds in a temperature range of 850 to 950 °C is to be aimed for. NOx measurement in the exhaust gas is required for dosing the reducing agent (molar ratio n = NH_3/NOx [mol/mol] = approx. 2). The average degree of denitrification in the SNCR process is 50 to 75 %; under optimal reaction conditions, up to 95 % is possible [57]. The process is usually used in new plants, but can also be retrofitted depending on the individual space availability. There is also the option of building new plants "SNCR-ready". In this case, the furnace is already equipped with the components required for the SNCR process (reduction zone, openings for injection, space reserves for reducing agent tank, etc.). If it becomes apparent after commissioning that denitrification is necessary, retrofitting can be carried out quickly.

The SNCR process requires precise control of the reaction conditions. It is well suited for belt-load operation and in combination with a wet scrubber. Injection of the reducing agent outside the above-mentioned temperature window favours the formation of nitrogenous by-products such as ammonia, climate-relevant nitrous oxide (N_2O), hydrogen cyanide (HCN) and isocyanic acid (HNCO).

If the reducing agent is used in conjunction with a **catalytic** converter, this is called **SCR (selective catalytic reduction).** SCR enables a degree of denitrification of over 95 % with low ammonia slip. An integrated oxidation catalyst is recommended to reduce possible dioxins. NOx measurement and precise control of the mole ratio (n = NH_3/NOx [mol/mol] = approx. 1) is required. For the operating mode, a distinction is made between high-dust with downstream dust separation and low-dust with upstream dust separation (Figure 5.21). The temperature range for the low-dust process is between 200 and 250 °C, for the high-dust process between 250 and 450 °C. Here, a downstream economiser is recommended to reduce the exhaust gas temperature. With the high-dust process, clogging of the catalytic converter by dust deposits is possible, and it is only sometimes suitable for residual and waste wood. In addition, in both cases there is the possibility that catalyst poisons such as arsenic, phosphorus or alkali metals deactivate the catalytic material [51]. If catalyst poisons are separated, for example with dust, before the exhaust gases enter the catalytic converter, the tendency of poisoning is reduced and thus the service life of the catalytic converter elements. The high-dust process is therefore not recommended by QM for Biomass DH Plants because of the problems regarding poisoning and clogging.

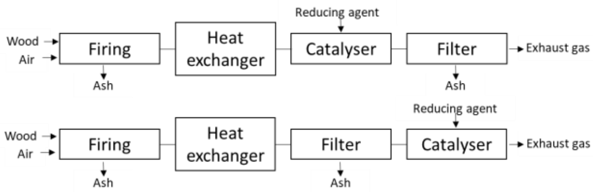


Figure 5.21 Selective Catalytic Reduction (SCR) high-dust process (top) and low-dust process (bottom).

5.9 Heat recovery with economiser and flue gas condensation

The efficiency of heat generation can be increased considerably if the flue gases are cooled further in additional heat exchangers after leaving the boiler (chapter 13.7.2).

An **economiser** is an additional heat exchanger for preheating the system return. There, the flue gases are cooled down to about 75 to 80 °C (to just above the dew point). When the heating system starts up or when the temperature in the flue falls below the setpoint temperature, part of the hot flue gas flow is fed directly into the flue via a damper until the setpoint temperature is reached again. Due to the great potential for increasing efficiency, the use of economisers should always be considered when planning a wood-fired heating plant. For example, with an excess air number $\lambda = 2$, additional cooling of the flue gases by 10 K results in an increase in the combustion efficiency by about 1 % [60]. Depending on the excess air number and water content, an increase in efficiency of 5 to 7 % can be achieved. In order to keep the necessary excess air low ($\lambda < 1.8$), good combustion control is necessary.

A **flue gas condensation system** usually consists of three stages. The flue gases leaving the boiler first pass through an economiser, then a condenser (with upstream quench) and in case needed a downstream air preheater (Figure 5.22). The application range is usually for plants > 1 MW. In the case of high fuel costs and long plant operating times (band-load operation), smaller plants starting at about 500 kW are also possible. The average return temperature from the consumers should be low and at least 10 °C below the dew point of the flue gases. A separate low-temperature return for the condenser should be considered.

In the condenser, the exhaust gases are cooled down further to below the dew point. This causes part of the water vapour contained in the exhaust gas to condense. In the process, large amounts of energy are released in the form of sensible, but mainly latent heat. The water content of the fuel plays an important role; the more water that enters the process with the fuel, the more steam can condense again. The lower the temperature to which the flue gas can be cooled, the more effectively the flue gas condensation system works. With a low total excess air number in the combustion, high water content in the fuel and low return temperature of the heating circuit (< 40 °C), the efficiency of the firing system can be increased by up to 20 %. In the inlet area of the condenser, there may be spots on the flue gas side that are alternately wet or dry, depending on the operating condition. Such areas are at risk of deposits and corrosion. To avoid such problems, a quench is often installed upstream, which moistens the exhaust gas and cools it down to the dew point. When the humidified exhaust gas reaches the condenser, further cooling takes place and the temperature falls below the dew point (condensate precipitates). This prevents dry spots in the condenser.

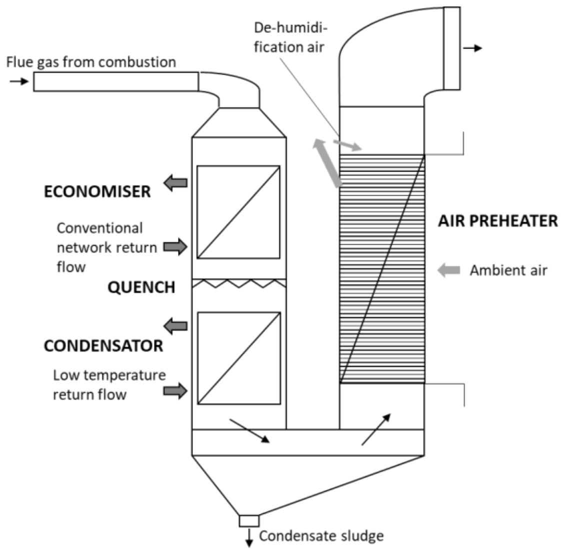


Figure 5.22 Schematic of a flue gas condensation system.

The condensate sludge produced must be separated from the liquid phase, the condensate, due to the heavy metals it contains, for example in a sedimentation tank, and then landfilled or industrially processed. This separation should take place at a pH > 7.5 to prevent elution of heavy metals into the liquid phase. If the combustion quality is high (CO < 250 mg/m³ at 11 vol.% O_2) and after the use of a neutralisation stage (pH control), the excess condensate can be discharged into the sewage system after sludge separation, in compliance with local regulations.

As a rule, systems have at least one **air preheater** in which the flue gas transfers further heat to the supply air. A part of this preheated air is used as combustion air; the other is mixed with the cooled flue gas to prevent further condensation in the downstream pipelines and in the chimney, as well as to reduce the formation of water vapour plumes on the chimney. Complete de-vaporisation is not absolutely necessary as this has no further technical benefit, but only a visual effect. This can particularly be important for biomass DH plants in tourist areas and areas close to settlements.

When integrating flue gas heat exchangers, care must be taken to ensure the correct arrangement with the flue gas cleaning components. A flue gas condensation system in combination with a wet electrostatic precipitator achieves a dust collection efficiency including fine particles of around 95 %. If a dry electrostatic precipitator or a fabric filter is installed upstream of the economiser or the waste gas condensation system, the contamination of these components can be considerably reduced and the costly disposal of the condensate sludge can be avoided.

5.10 Process control technology

5.10.1 Basics

The term process control technology is used in different areas of application. Essentially, process control technology comprises the entire measurement and control technology (I&C technology) and the associated data streams of a plant (for further definitions of terms, see [61]). I&C serves to automate plant operation and includes all the necessary control, regulation and monitoring tasks. The integration of suitable I&C systems and control concepts are the prerequisite for efficient, low-emission and safe plant operation and are therefore important components of the planning and execution of biomass DH plants. Accordingly, the importance within the framework of QM for Biomass DH Plants is high. This topic is dealt with in detail in the standard hydraulic schemes ([62]). The basics of measurement and control technology are not dealt with here (see for example [63]), except for some specific topics relevant to the planning, construction and operation of biomass DH plants.

Process control technology has developed significantly since the first biomass DH plants were built. Comprehensive I&C equipment that enables fully automatic plant operation is state of the art. Nowadays, even small boilers from series production are equipped with a fully automatic control system and a digital user interface.

Terms

Control is a process in which a variable to be set (controlled variable) is continuously measured and compared with a reference variable (setpoint). The result of the comparison influences the controlled variable in such a way that the controlled variable is brought into line with the reference variable. The resulting sequence of effects takes place in a closed control loop. In contrast, **regulation** represents an open chain of action (control chain) in which the variable to be set is influenced (controlled) depending on the most important influencing variable (disturbance variable) without measuring the variable to be set. The actual value of the variable to be set is therefore not checked and has no influence on the control chain (see [63]).

The essential task of **measurement technology** is to quantitatively record technical processes with appropriate measuring devices (sensors) and to provide the basis for controlling and regulating processes with the measured variables (for further literature see [64]).

According to EN 61131 - Part 1 [65] a **programmable logic controller (PLC)** is a digitally operating electronic system for use in industrial environments with a programmable memory for internal storage of user-oriented control instructions for implementing specific functions, such as logic control, sequence control, timing, counting and arithmetic functions, to control various types of machines and processes through digital or analogue input and output signals.

The process control technology of a biomass heating plant must fulfil the following basic tasks:

- Fully automatic control and regulation of the entire system without the need for regular manual intervention and, if possible, without the constant presence of operating personnel
- Ensuring safe plant operation in every operating state (personal and plant protection)
- Guaranteeing a heat supply for customers
- Enabling optimal system operation in any operating condition.
- Operation and monitoring of the system (system visualisation/display of the current operating status, setting of setpoints and control parameters, switching on/off of system components, etc.).
- Remote access and fault messages
- Acquisition, processing and permanent storage of all relevant operating data (measurement data), preparation and visualisation of (historical) measurement data trends.
- Recording and permanent storage of all billing-relevant data (customer consumption!)
- Enabling manual operation and emergency operation of the system if required.

Plant operation during start-up and shutdown processes, as well as special or unforeseen operating conditions (maintenance, cleaning and minor repairs during operation, failure of individual components, test runs, emergency operation, extreme load conditions) is usually carried out manually by the operating personnel (manual operation) or in semi-automatic operation.

For heat generation systems with moderate pressure and temperatures (e.g. warm water systems < 110°C), a permanent presence of operating personnel is usually not required. For hot water and steam systems, a permanent presence may be required, or additional safety-related equipment for operation without human intervention ([66]) or for operation without permanent supervision ("Betrieb ohne ständige Beaufsichtigung" BOSB) is required. For operation without permanent supervision, the respective national regulations and directives must be checked and complied with in any case (see chapter 19).

The process control system consists of several levels that fulfil different tasks (Figure 5.23).

Functional subdivision and technical design

The process control system can be divided into a **user level**, a **subordinate I&C system** (e.g. for the control of individual components) and a **master I&C system** (tasks related to the entire plant) according to the tasks to be fulfilled. This function-related subdivision helps in defining the control concept and individual control tasks as well as in developing a functional description.

However, these three levels do not automatically represent the physical limits of the individual technical components (control units) or delivery limits. The **technical design of the process control system** depends on various factors and does not have to be structured analogously to the three functional levels. For example, the operating level as well as the subordinate and master I&C system can be realised with a single PLC on a case-by-case basis, or can also consist of three separate units from different manufacturers (which are connected to each other via interfaces).

The function-related designation as master and subordinate I&C system is not always common among I&C technicians, which is more oriented towards physical components or delivery limits, so possibly other designations are used (e.g. master system).

The **user level** is realised via a master computer (heating plant computer) or a control panel (display) on the control cabinet. The operating level has interfaces to the master and lower-level I&C systems and enables complete operation of the system. Here, the current operation of the system and the current operating data can be monitored and setpoints, time programmes and the like can be adjusted, mostly with the help of a system visualisation. With higher authorisation levels (e.g. service technicians, manufacturers), detailed control settings can also be made. The selection of the system operation (e.g. automatic, semi-automatic operation, manual operation, etc.) is made via the master computer or directly at the control cabinet. All essential system components can also be controlled manually via the operating level. Manual emergency operation of the system can also be carried out independently of the master computer via operating elements on the control cabinet.

The **master I&C system** is responsible for all higher-level control and regulation functions, such as the coordination and load management of the individual heat generators (power signal for boilers) and storage management, and often also for the control of the heating house hydraulics (pumps, fittings in the heating house) and the network pumps of the heating network (see also chapter 8). The master I&C system has interfaces to the subordinate I&C systems of the individual system components and links them with each other. Often, data recording is also realised via the master I&C system (see chapter 5.10.2).

Subordinate I&C systems are used for the specific control and regulation of individual functional groups of the plant. A functional group is, for example, a biomass boiler with all associated drives, aggregates, fittings or, analogously, the functional group oil/gas boiler, particle separator, flue gas condensation systems, water treatment and others. These subordinate I&C systems are usually supplied by the manufacturers of the respective components and, depending on the component, vary from simple autonomous controllers (e.g. for a water treatment plant) up to a complex PLC for a biomass boiler. These I&C systems take over the secure operation and the detailed control and regulation tasks of the individual components. For the biomass boiler, these are, for example, the fuel supply to the furnace and the fuel bed height at the grate, the grate speeds, the speeds of the combustion air and flue gas fans (negative pressure control), the flue gas recirculation and the combustion chamber temperature, the control of the ash removal, the furnace output, the boiler flow temperature, safety-relevant control and regulation tasks and much more. The I&C systems of the main components must have an interface and communication option with the master I&C system and the operating level (master computer) in order to be able to process, for example, higher-level output and other setpoint specifications and to ensure seamless system visualisation and data recording. It is recommended that, if possible, all auxiliary systems are also integrated into the master I&C system with at least an operating and fault signal and, if applicable, the most important operating parameters. The controllers of the individual house transfer stations of a heating network are also to be considered as subordinate C&I systems that basically function autonomously, but also have a state of the art connection to a central master C&I system, a remote access option and central data recording (see chapter 8.5).

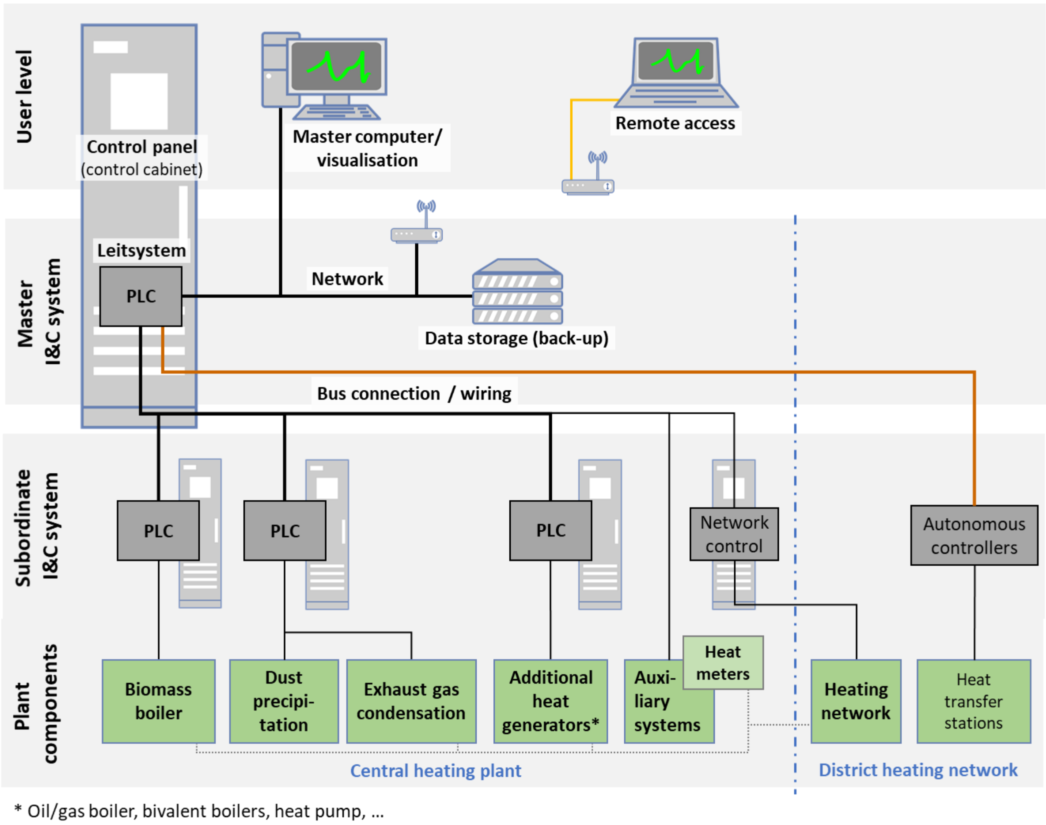


Figure 5.23 Function-related subdivision of a process control system into operating level, master C&I system and subordinate C&I systems (example for a wood-fired heating plant with heating network).

Technical execution

The process control system and the aforementioned levels can be implemented in various ways (see also Table 6 in QM Holzheizwerke Standard hydraulic schemes - part 1 [62]). In small systems, all three levels can often be taken over by the C&I system of the biomass boiler, as there are usually no further subordinate C&I systems. Modern biomass boilers, even as standard equipment, already have the option of controlling heating circuits, storage charging circuits or, for example, a solar thermal system. In this case, operation takes place directly via the control panel of the biomass boiler and without a master computer. Additional equipment is may be required for data recording.

In larger properties with a building management system, biomass boilers are integrated as subordinate I&C systems into the building management system (master I&C system) and the operating level integrated there, which is also responsible for data acquisition. In larger biomass DH plants, depending on the design, either the PLC of the biomass boiler(s) can take over the task of the master control system (e.g. with extended programming and integration of other plant components), or there is a separate PLC-based master control system. Alternatively, higher-level control tasks can be divided between different controllers or manufacturers (e.g. storage tank control and heating house hydraulics by the PLC of the biomass boiler and network control with its own unit from the manufacturer of the heat transfer station).

The structure of the process control system and, if necessary, the distribution of the control functions to different controllers/PLCs must be defined in detail in the course of the planning and taken into account accordingly in the subsequent tendering and construction of the plant.

The structure of the I&C system and the control concept are important integral components of QM for Biomass DH Plants and are explained in detail in the standard hydraulic schemes of QM Holzheizwerke [62] and in chapter 7 “Heat generation hydraulics”.

5.10.2 Requirements for measurement equipment and data acquisition

Comprehensive measurement equipment of the heating plant and the heating network and suitable control technology for the transmission, storage and visualisation of the measured operating data are state of the art in modern biomass DH plants. This is an important basis for conscientious operational management and for carrying out comprehensive operational optimisation (see chapter 16). Comprehensive and long-term data collection represents an important asset, which, in addition to ongoing operational management and optimisation, is also of great value for the planning of future plant expansions as well as the modernisation and refurbishment of plants (see chapter 18). To assist in the planning and execution of data collection, QM for Biomass DH Plants provides a comprehensive list of measuring points in combination with the standard hydraulic schemes (see [62]) as well as recommendations for the presentation and assessment of operating data (see FAQ 8).

The data acquisition system and the visualisation (on the PC in the control room - see Figure 5.24) must meet the following minimum requirements, among others:

- Automatic recording and storage of all measured values in high temporal resolution (recommendation QM for Biomass DH Plants [62]: measuring interval of 10 s and a recording interval of 5 minute mean values recommended)
- Visualisation of the system with graphical system diagrams containing the most important operating parameters and operating states of the individual components (instantaneous values)
- Graphical representation of the temporal progressions (trends) in the form of configurable diagrams and parameters
- User-friendly export option for all measured, calculated and saved operating data in a generally readable data format (e.g. text-based files in .csv format)
- Regular back-up of all operating data on an independent system

By means of data communication in the district heating network, the operating data of the district heat transfer stations should be integrated into the control technology and data recording (see chapter 8.5). With regard to the remote reading of customer data, the applicable data protection guidelines must be observed. It is recommended to include the topic of remote access and remote data reading in the heat supply contract or to make a subsequent agreement with existing customers.

To facilitate operational management and system monitoring, modern biomass DH plants also have a remote access option to the visualisation and control system for the operating personnel. This possibility should be provided for planners and selected manufacturers in order to enable quick access to current plant data if required. If several people/companies have corresponding remote access, the responsibilities and competences must be precisely defined (if necessary with limited authorisations) and every change (e.g. adjustment of setpoints or control parameters) must be documented and communicated.

5.10.3 Planning and execution

The planning of the I&C system must be taken into account in the general planning process. In particular, the main planner must define the structure of the I&C system (see chapter 5.10.1) and the responsibilities derived from it at an early stage and subsequently take them into account in the specifications for tenders and contracts.

In the course of planning, a comprehensive functional description must be created. This is, among other things, the basis for detailed planning and execution (especially hydraulic wiring and control), but also a fundamentally necessary prerequisite for successful operational optimisation.

Figure 5.24 Control room of a biomass CHP plant (source: AEE INTEC).

The functional descriptions define the basic principles of the respective control concept with a focus on the master control (load management, storage management, hydraulic heating system, heating network). The detailed programming and implementation of the control concept is the task of the C&I technicians of the manufacturers or suppliers. For example, the design of the subordinate C&I system for the biomass boilers is usually included in the scope of delivery for the boiler. The main planner is responsible for checking compliance with the basic requirements for the I&C systems and data acquisition according to the functional description and specifications.

The functional description includes the following essential components:

- Detailed description of the functionality of the system for all relevant operating states (incl. control description).
- Overview of the most important control parameters that can be adjusted during operation
- Complete list of measuring points in accordance with the hydraulic diagram. The measuring position, measuring range, temporal resolution and measuring accuracy must be specified for each measuring point (see chapter 16).
- Description of the automatic data recording (basic principle and data or file structure, location and duration of data storage, etc.).

When designing the control technology, particular attention must be paid to the following points (see also “Muster-Ausschreibung Holzkessel” - sample tender for biomass boilers from QM Holzheizwerke):

- Dust-protected installation site and ensuring that the maximum operating temperature of the electronic components is not exceeded. In case of high internal heat loads (e.g. due to frequency converters), ventilation/air conditioning must be provided.
- Providing a space reserve of around 20 % in the control cabinets or for additional control cabinets (system expansion).
- Best possible standardisation of the components used (e.g. standard control cabinets, uniform sensors, etc.).
- Ensuring compatibility of the components and systems used and communication between all levels and system parts.
- Ensuring long-term availability of spare parts.
- Definition of responsibilities and unambiguous delivery boundaries and interfaces.
- Compliance with all relevant regulations, standards and guidelines.
- Comprehensive technical documentation including circuit diagrams, data sheets and data point lists (integrate into tender specifications).
- Clear and professional labelling of field devices and wiring.
- Forwarding all fault messages of the individual components to the master PLC via potential-free contacts.
- Manual switching level labelled with plain text for manual control of the most important (safety-relevant) system components. The manual switching level must be provided with an interlock.
- Remote access option and forwarding of fault messages.
- Possibility of assigning specific access and user permissions.
- User-friendly instructions and descriptions for the operating personnel.

6 Plant components of fuel storage, fuel conveying and ash removal

6.1 Preliminary remark

This chapter describes the components of the fuel storage, conveyance and ash removal. The appropriate selection and dimensioning of these components are described in chapter 14

Chapter 19 lists the country-specific requirements for the safety equipment of the corresponding components with regard to fire and accident prevention, explosion prevention (ATEX, BGI Informationen 739-2) (light barriers, switch-off lock, access protection, railings, guardrails, fermentation gas extraction, etc.).

6.2 Fuel storage

Fuel silos with fuel discharge system
Fuel silos are suitable for dry to very moist wood chips and briquettes with limited admixture of chips and dust. They are easy to fill by tipping the fuel from the truck. As they are usually designed as underfloor silos (Figure 6.1), the storage volume is expensive (earthworks and reinforced concrete). The fuel silos have an automatic discharge system (see chapter 14.3), which conveys the stored fuel out of the silo.

Figure 6.1 Underfloor silo (source: Andres Jenni).

Mobile container system with discharge
The mobile container system (Figure 6.2) is filled with wood chips in the forest or by the fuel supplier on premises.

The filled container (filling volume around 30 m³) is delivered by truck. The discharge system installed in the container is coupled with the stationary charging device of the furnace. The firing system controls the fuel discharge of the container. A second full container stands ready as a reserve so that it can be switched over immediately if necessary and the continuous fuel supply is not interrupted. Depending on the nominal output of the heating plant, several containers are necessary. Continuous wood chips delivery in containers is a requirement. The containers can also be rented.

Mobile wood chips containers with discharge are suitable for wood chips, shredded bark and sawdust. The discharge technology is generally unaffected by oversized fuel particles and stones. It can serve as a replacement or alternative for stationary (immobile) fuel silos.

Advantages are that there are no investment costs for a stationary silo and that the unloading times for wood chips delivery are short.

The disadvantage is the dependence on the fuel supplier. In addition, storage space is needed outside the heating system. Especially in winter, a simple visual protection of the containers proves to be advantageous (windbreak). Due to the rental costs for the containers, the operating costs are relatively high. In winter, there is sometimes a risk of freezing.

Figure 6.2 Mobile wood chips containers with discharge as a substitute for silos (source: Holzenergie Schweiz).

Above ground round silos
Above-ground round silos (Figure 6.3) are suitable for fuels with a lumpiness of up to P63, a maximum particle length of 200 mm and a water content of dry to > 55%. The area of application is large biomass DH plants with short turnover times of the fuel in the silo. This prevents bridging.

Filling is usually done via scraper chain conveyors and a distribution system above the round silo.

Discharge takes place by means of a milling screw (see chapter 6.4.1).

Figure 6.3 Round silo (source: Gottwald GmbH).

Chips silos

Chips silos (Figure 6.4) are suitable for wood chips, sawdust and sanding dust from wood processing plants but also for dry wood chips and briquettes. Filling is usually pneumatic. The requirements for safety equipment regarding explosion prevention (ATEX) must be particularly observed (see chapter 19, Regulations for chips silos).

Figure 6.4 Chips silo (Source: Wooden Energy Switzerland).

Pellets storage
Wood pellets are stored in closed and dry storage rooms or containers. Steel, plastic or fabric tanks are available for installation. Filling is usually done pneumatically, in the case of larger underfloor silos sometimes also by tipping. Discharge from small storage tanks takes place by means of screw conveyors or pneumatically; in the case of larger storage tanks, an articulated-arm discharge system is often installed. In order to minimise the amount of fines, the pellets must be fed into the storage area and discharged gently and by the shortest possible route. Additional feeding devices used in wood chips storage (e.g. silo distributors) should not be provided. The penetration of water into the storage room (e.g. through walls or filling devices) and the formation of condensation in the store (e.g. on cold water pipes, on cold, non-heat-insulated storage room walls/ceilings or by damp transport air into the cold pellet storage) must be avoided at all costs. Further information can be found in the **storage room brochure *Lagerung von Holzpellets*** from the German association *Deutscher Energieholz- und Pellet-Verband (DEPV)* [67] (see also chapter 14.2.9).

Warehouse
For larger biomass DH plants with a biomass boiler capacity of more than 1 MW, storage warehouses (Figure 6.5) with a day silo should be considered instead of expensive underfloor silos. Storage warehouses are suitable for all fuels. Filling is costly, as the fuels usually have to be brought from a dumping trough to below ridge height with a conveyor system and then distributed in the storage warehouse or managed with a wheel loader. The storage warehouse itself, on the other hand, is inexpensive. Storage warehouses are also used as interim storage facilities.

Figure 6.5 Warehouse (source: Franz Promitzer).

External warehouse
Wood chips or bark can be temporarily stored outdoors on stockpiles (Figure 6.6) or log piles (Figure 6.7). The outdoor storage can be located directly at the heating plant, at a central location that is accessible for trucks all year round, or in the forest.

Figure 6.6 Interim outdoor storage of wood chips (Source: AEE INTEC).

Figure 6.7 Log pile at heating plant (source: AEE INTEC).

6.3 Filling silos and warehouses

6.3.1 Filling wood chips silos

Filling of underfloor silos is mostly done by tipping the fuel from the truck through a filling opening. A high degree of filling is achieved by optimally arranging the filling openings or by using silo distributors.

Silo lid

The construction of the silo lid is very important for silos at ground level that are filled directly with trucks. If the silo lid is not designed to be driven over, it should be placed on a concrete border at least 20 cm high (Figure 6.8 and Figure 6.10). This prevents rainwater from entering the silo. If a cover that can be driven over (Figure 6.9) is required, care must be taken to ensure that it can be closed after filling without cleaning the wastewater channel and the hinge area. Due to the high costs and possible penetration of water drive-on silo lids should be avoided.

Silo lids can also be manufactured in a split design. This improves the strength and reduces weight of the individual lid parts making it easier to use. In addition, with this arrangement, fewer wood chips fall next to the filling opening, and there is no danger of the silo lid being damaged if a compacted block of wood chips slips out of the truck.

The filling opening must be covered with a protective grid or grate in accordance with local accident prevention regulations (see also chapter 19). As wood chips tend to bridge, they can get stuck on the protective grate during filling, which slows down the material flow and increases the offloading time.

For problem-free offloading, it must be possible to open the silo lid by more than 90°, i.e. beyond the dead centre. This provides sufficient space for the tipping vehicle and at the same time prevents the silo lid from falling shut.

Figure 6.8 Silo lid not accessible when open (source: Schmid energy solutions).

Figure 6.9 Silo lid not accessible in the background and accessible in the foreground. Both in closed condition. (Source: Schmid energy solutions).

Figure 6.10 Non accessible folding lid (left closed, centre open, right filling. Source: Patrik Küttel).

Filling screws

In the case of silos in the basements of buildings, filling screws (Figure 6.11) carry out the fuel transport from the filling shaft (discharge trough) into the silo and additionally increase its filling level. The horizontal filling screws transport the fuel below the silo ceiling over the entire length of the silo to the baffle. Due to the high conveying capacity of the filling screws (> 200 LCM/h), unloading times of < 10 minutes are possible even during the last offloading process. Filling screws are suitable for all types of wood chips, shredded bark and sawdust. They are also unaffected by oversized fuel particles and stones.

Advantages:

- High fill level of silos, the majority of which are located under a building.
- Better use of space for the heating system.

Disadvantages:

- Additional investment costs
- Slightly longer offloading times for the fuel supplier

Figure 6.11 Filling screws (source: Holzenergie Schweiz).

Silo distributor

The silo distributor (Figure 6.12) conveys the wood chips horizontally so that the silo is filled evenly regardless of its shape. The silo distributor functions like a filling screw, but works in two opposite directions from the filling opening. The horizontally arranged screw conveyors transport the fuel below the silo ceiling over the entire length of the silo. Due to the high conveying capacity of the filling screws (> 250 LCM/h), unloading times of < 10 minutes are possible even for the last offloading operation. If the structural conditions allow, the installation of three silo lids instead of one silo lid with silo distributor is preferable. Silo distributors are suitable for all types of wood chips, shredded bark and sawdust. They are also unaffected by oversized fuel parts and stones.

The advantages of silo distributors are:

- Low energy consumption
- Independent of fuel form and water content
- Unaffected by larger impurities
- Long silos possible
- Additional silo lids unnecessary

The main disadvantages are:

- Additional investment costs

Figure 6.12 Silo distributor (source: Schmid energy solutions).

Vertical screw conveyor system for above-ground silos and warehouses

In the case of above-ground silos and storage warehouses, the vertical screw conveyor system (Figure 6.13) carries out the fuel transport from the discharge trough into the silo or into the warehouse. A horizontally arranged transport screw conveys the fuel from the discharge trough to the vertical screw conveyor system. This conveys it vertically upwards (maximum conveying height around 18 m) and then transfers it to the horizontally arranged distribution screws. The conveying capacity reaches about 60 LCM/h, respectively 120 LCM/h with a double screw system, provided that the volume of the discharge chute is larger than the transport volume of the delivery vehicle. The vertical screw conveyor system is suitable for all types of wood chips, for bark and for sawdust. The maximum lump size is P100.

The advantages of the system are:

- High fill level
- Low construction costs for silo

The main disadvantages include:

- Additional investment costs
- Up to one hour between individual deliveries

Figure 6.13 Vertical screw conveyor system (source: Schmid energy solutions).

Figure 6.14 Pump container (source: Amstutz Holzenergie AG).

Pump container/pump truck

A pump container/pump truck (Figure 6.14) enables silos to be filled when direct access with delivery vehicles for tipping is not possible. The wood chips are pumped directly from the container/delivery truck (filling volume around 30 m³) with the internal discharge system via flexible pipes into the underground or above-ground silo. For complete emptying, the container is tipped. Pump containers/pump trucks are mobile and versatile and are particularly suitable for dry quality wood chips from forest and industrial waste wood with a low proportion of fines. The system is sensitive to oversized fuel particles and stones.

Its main advantages are:

- No soiling of the offloading location by falling wood chips
- Lower investment costs for usual feeding and distribution systems
- Highest silo filling level (up to 90 %)

Disadvantages are:

- Dependence on fuel supplier
- Longer offloading times (approx. 30 min. compared to tipping vehicles with approx. 5 min.)
- Dust formation with dry wood chips, unsuitable for sanding dust and wood shavings
- Higher delivery costs
- Noise due to pumping system

6.3.2 Filling and management of warehouses

Fully automatic crane system

The fully automatic crane system is used for loading and unloading storage warehouses (Figure 6.15). An automatic or manually controlled grab crane picks up the fuel from a stockpile or unloading bunker, distributes it in the storage warehouse and feeds a day silo or the push floor zone. If required, different fuel qualities can be mixed. The system is independent of height and area within the crane runways. If the offloading volume is larger than the transport volume of the delivery vehicle, capacities of up to 150 m³/h can be achieved. The fully automatic crane system is suitable for all wood fuels except wood shavings and dust and is unaffected by oversized fuel particles and stones.

The main advantages are:

- Adaptable to fuel type
- Automatic management possible
- Mixing of different fuel qualities possible
- Optimal use of storage space

The disadvantages include:

- Limited to larger warehouses
- Costly operation (wear and tear of steel ropes and hoist, statutory maintenance necessary). Crane system requires industrial construction standard.

Figure 6.15 Fully automatic crane system with unloading trough and day silo (source: Schmid energy solutions).

Loading and unloading system with horizontally and vertically movable scraper chain conveyor

Scraper chain conveyors with transverse carriers are mounted in a frame that can be moved both vertically and horizontally (Figure 6.16). This way, the loading and unloading system automatically adapts to the respective filling level of the warehouse. When loading, the system acts as a distributor; when unloading, it conveys the wood chips to the fuel conveyor system of the furnace. The insert length is up to 28 m. With the exception of dust, the system is suitable for all wood fuels, and it is unaffected by oversized fuel particles and stones.

The main advantages are:

- Optimal use of warehouse volume
- Adaptable to fuel type
- Storage of different fuel assortments in different lanes in a controlled manner
- Targeted unloading

The main disadvantages are:

- Limited to large warehouses
- Elaborate construction

Figure 6.16 Loading and unloading system with horizontally and vertically movable scraper chain conveyor [68].

Wheel loader

The wheel loader (or telescopic loader) transports the delivered fuel or the freshly chopped wood on site into the storage warehouse or offloads it onto the stockpile (Figure 6.17). From there, a pre-silo is filled if required. The system is labour-intensive and time-consuming. The wheel loader cannot be automated, but it is very flexible and can be used for a wide variety of tasks. It is suitable for all fuel assortments except for wood shavings and dust.

The main advantages of the wheel loader are:

- Location flexibility, multiple use possible
- Optimal adaptation to fuel
- Separation of different fuel types possible

Disadvantages are:

- Personnel intensive
- High energy consumption
- Noise

Figure 6.17 Wheel loader (Source: AEE INTEC).

Top loader

A top loader (Figure 6.18) is a loading and unloading system that does not require a drop tray. It stores the fuel offloaded by the delivery vehicle in the storage room. If required, the top loader conveys fuel from the stacked storage into the channel of the cross discharge, which is located behind the rear wall of the storage warehouse. The system is suitable for all fuels except wood shavings and dust and is uneffected by oversized fuel particles and stones.

The top loader has several advantages:

- Multiple use of the storage room possible
- Easy offloading at ground level
- Low construction costs for storage space from floor slab, low static requirements
- Maintenance-friendly due to easy access
- Low power consumption
- Automatic management including level measurement

The disadvantages include:

- No intermediate storage of the fuel, the fuel stored last is removed first (last in, first out)
- Relatively large space requirement (parking area for top loader)

Figure 6.18 Top loader (source: Vecoplan AG).

6.3.3 Filling shavings silos

Dust, shavings and dry wood chips with a water content < 20 % are stored in shavings silos (Figure 6.19) The filling of a shavings silo is always combined with the shavings extraction system used in the plant. A chipper can also be connected to the extraction system. The shavings silo is filled with the dry and fine fuel by means of an air flow generated by a pressure fan. Due to the increased cross-sectional area in the silo, the flow rate decreases and the fuel falls into the silo. An automatically cleaning filter system separates the fine particles from the exhaust air. In central extraction systems, a cyclone filter separates the transport air from the fuel. Depending on the fine fraction, an additional filter system is required for the exhaust air. In individual extraction systems, the transport air is recirculated and reused.

The filling system of shavings silos is not affected by height difference and silo size. It has to be designed exactly for the respective wood assortment and is sensitive to oversize stones and fuel parts. Depending on the sound insulation and lumpiness of the fuel, it can be noisy.

The advantages of this system are:

- Optimal use of building structure
- Dust-free
- Large horizontal and vertical distances overcome without problems

The disadvantages are:

- Limited to dry fuel with small lumpiness
- Noisy
- Additional silo facilities required
- Explosion hazard due to dust content
- High power consumption

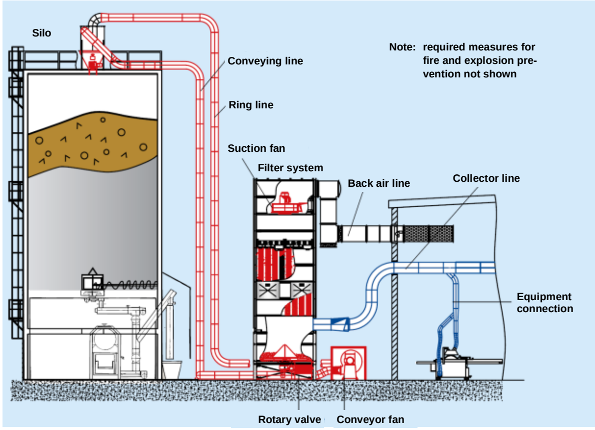


Figure 6.19 Silo filling with in-house shavings extraction system (source: BGI 739-2) [68].

6.3.4 Filling pellet storages

Wood pellets are usually delivered to the customer by pellet tanker. The pellet storage is then filled through a hose pipe that the driver couples to a filling nozzle through which the pellets are blown from the vehicle into the storage room. When the pellets are blown in, the pressure must be equalised. For this purpose, airtight rooms have a second connection to which a suction blower with a dust bag is connected during filling (Figure 6.20). Only in the case of a fabric silo can such a suction connection be dispensed with, since in this system the air blown in with the pellets can escape from the room through the silo fabric. Compressed air is used to build up the pressure for filling the room.

Figure 6.20 Pellets delivery with suction blower and dust bag (source: Holzenergie Schweiz)

If the pellet storage is an underfloor silo, filling can also be done by tipping. Large quantities of pellets can also be delivered by a vehicle equipped with a push floor that pushes the pellets into the storage area. Tipping or pushing can be gentler on pellets than blowing, but it has some disadvantages. For example, an additional underground construction, which may be accessible by vehicles, must be provided as a silo outside the building, and the filling opening is associated with the risk of moisture entering the storage area.

6.4 Discharge systems

6.4.1 Discharge systems for all fuels

Push floor
The push floor (Figure 6.21) enables continuous discharge of the fuel in large-area silos. One or more push rods are moved horizontally back and forth by hydraulic cylinders. The fuel is pushed into the discharge channel by the wedge-shaped drivers. In modern systems, the forward movement of the individual push rods takes place together, the backward movement individually. This allows the thrust forces of the individual push rods to be reduced. The forces of the hydraulic cylinders must be absorbed by the building. The weight above the push system determines the required push forces, and the whole set-up has to be adapted to the silo. The push floor is suitable for all fuels. When using bark and coarsely chopped landscape wood, the installation of an additional metering roller is recommended. The push floor is unaffected by oversized fuel parts and stones. It is suitable for underfloor silos, storage sheds, chips silos, pellet storage rooms and mobile wood chips containers.

The main advantages of the push floor are:

- Reliable operation and independent of the water content of the fuel
- No drive system parts in the silo
- Any fuel shape and size possible

Disadvantages of the push floor are:

- High shear forces on buildings
- Wear of the floor covering with high annual fuel turnover
- Limited conveying length and quantity
- Only linear use possible
- Noise emissions possible

Figure 6.21 Silo discharge by push floor (source: Schmid energy solutions).

Scraper floor conveyor
The scraper floor conveyor is used for small-area silos (pre-silo, day silo) (Figure 6.22). It functions similarly to a conveyor belt. Cross profiles attached to transport chains convey the fuel. The equipment is adapted to the respective silo situation. The silo width and height determine the number of transport chains. The scraper floor conveyor is placed on top of the fuel and thus achieves a high conveying capacity. The system is suitable for all fuels except dust and is not affected by oversized fuel parts and stones.

The main advantages of the scraper floor conveyor are:

- Adaptable to fuel and silo situation

Disadvantages are:

- Drive system parts in the silo room
- High investment costs
- High expenditure for maintenance and repair
- Complex construction

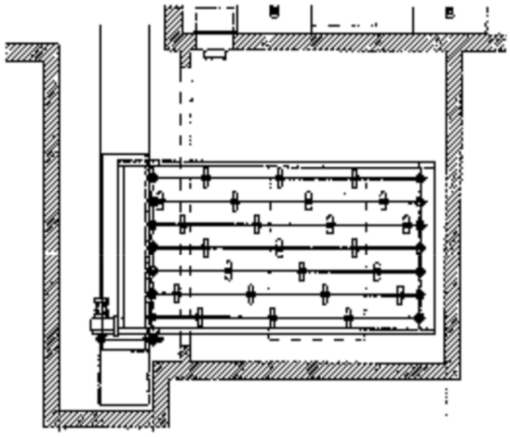


Figure 6.22 Silo discharge by scraper floor [69].

Centre screw
The centre screw can be used to discharge square and round silos. The centre screw rotates in a circle around the centre at the bottom of the silo and conveys the fuel horizontally into the centre of the silo. The effective diameter is > 4 m. The system is suitable for dry wood chips as well as for wood shavings, dust and pellets. It is sensitive to oversized fuel particles and stones.

The advantages of the centre screw are:

- Simple construction
- Low tendency to bridge
- Large silo heights possible (suitable maintenance openings for prodding necessary)

Disadvantages are:

- Sensitive to oversized fuel particles and stones (sorting required)
- Drive system parts in the silo room

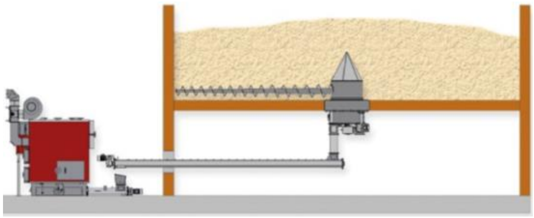


Figure 6.23 Discharge system with centre screw (source: Binder Energietechnik GmbH).

Conical screw

The conical screw (Figure 6.24) is used for continuous discharging of high silos with a circular, octagonal or round base. The conical screw conveys the fuel to the discharge device in the centre of the silo. Its design is similar to that of the centre screw but it is inclined rather than horizontal. Its effective diameter is between 1.5 m and 5.0 m. The conical screw is suitable for high silos and for dry fuels, wood chips and dust.

The main advantages of the conical screw are:

- Simple construction
- Low tendency to bridge
- Large silo height possible (suitable maintenance openings for prodding necessary)

The disadvantages include:

- Full utilisation of the storage volume not possible, a residual volume remains in the silo
- Limited accessible area
- Drive system parts in the silo room

Figure 6.24 Discharge system with conical screw (source: Schmid AG energy solutions).

Pendulum screw
The pendulum screw (Figure 6.25) can be used to continuously discharge the fuel from square and rectangular silos. The pendulum screw is attached to the silo rim. It oscillates horizontally back and forth in a semicircle within a limited sector at the bottom of the silo and conveys the fuel to the discharge device. The pendulum screw is suitable for all fuels except unshredded bark and coarsely shredded landscape maintenance wood, but is sensitive to oversized fuel particles and stones.

The advantages of the pendulum screw are:

- Simple construction
- Low tendency to bridge
- Large silo height possible (suitable maintenance openings for prodding necessary)
- No drive system parts in the silo room

Disadvantages are:

- Full utilisation of the base area not possible, a residual volume remains in the silo
- Sensitive to oversized fuel particles and stones (sorting required)

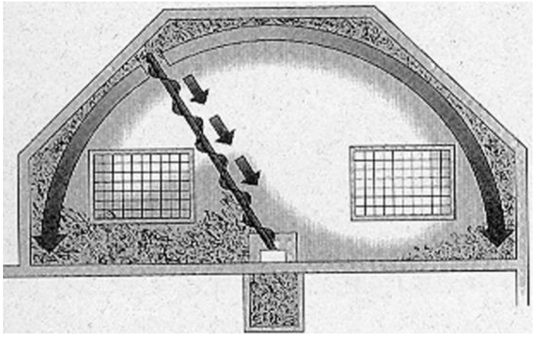


Figure 6.25 Discharge system with pendulum screw [69].

Milling screw
The milling screw (Figure 6.26) is mainly used to discharge round and high above-ground silos. The milling screw describes a circle around the centre at the bottom of the silo and conveys the fuel with an effective diameter of 2 m to 20 m into the centre of the silo. It is suitable for all wood fuels with a maximum lumpiness of 200 mm.

The advantages of the milling screw are:

- Simple, robust construction
- Large silo heights possible

The disadvantages of the milling screw are:

- Bridging possible depending on the flowability of the fuel
- Drive system parts in the silo room
- Sensitive to oversized fuel particles and stones (sorting required)

Figure 6.26 Milling screw (source: JPA Fördertechnik).

6.4.2 Special discharge systems

The following special discharge systems can be used for quality wood chips and pellets.

Articulated arm discharge
With the articulated arm discharge (Figure 6.27), square and round silos for quality wood chips and for pellets can be emptied continuously. Two articulated arms circle around the centre at the bottom of the silo and convey the fuel horizontally into the centre of the room. The radius increases in the course of the discharge so that even peripherally located fuel can still be collected and

discharged. The articulated arm discharge has a diameter of around 6 m, can handle a tipping height of 6 m and can be designed horizontally or at an angle. It is suitable for the discharge of quality wood chips and pellets.

The advantages of the articulated arm discharge are:

- Simple construction
- Large storage height possible

The disadvantages of buckling arm discharge are:

- Limited accessible area
- Drive system parts in the storage room

Figure 6.27 Discharge system with articulated arm for quality wood chips and pellets (source: Holz-energie Schweiz).

Spring core discharge

The spring core discharge (leaf spring agitator discharge, Figure 6.28) is used for continuous discharge of quality wood chips and pellets from square and round silos. Two or three leaf spring arms with drivers convey the fuel to the open channel of the discharge screw with the help of the rotary movement of the agitator. The radius described by the leaf spring arms increases in the course of the discharge, so that even peripherally located fuel can still be collected and discharged. The fuel is discharged horizontally or diagonally upwards. The maximum effective diameter is 6 m, the maximum dumping height is 4 m (pellets) or 6 m (quality wood chips).

The advantages of the spring core discharge are:

- Simple construction
- Low bridging

Disadvantages are:

- Limited accessible area
- Drive system parts in the storage room

Figure 6.28 Spring core discharge (source: Herz).

Centre screw with sloping floor

The centre screw with sloping floor (Figure 6.29) is used for continuous discharge of pellets from rectangular storage rooms. The pellets are discharged by a screw which is laid in the centre of the floor of the storage room in a trough and whose length extends over the entire storage room. An inclined floor with a smooth surface ensures that all the pellets are fed to the screw. The sloping floor prevents pellets from being left behind and stops abrasion and fragments from concentrating in the storage room. In order to keep the loss of storage space due to the inclined floor minimal, this discharge system is only used in narrow, high pellet storage rooms. The sloping floor must have an inclination of > 40 ° and be very stable. To prevent the pellets from being damaged too much during transport, the transport distance from the storage area to the boiler should be as short as possible and without deflections. Changes in direction can cause disruptions.

The advantages of this system are:

- No drive system parts in the storage room
- Low auxiliary energy consumption
- Cost-effective

The disadvantages are:

- No full utilisation of the storage room volume (usable volume ≈ 2/3 of the room volume)
- The storage volume is limited by the maximum length of the screw and by the maximum permissible tipping height.
- Elaborate construction of the sloping floor
- Only straight conveying possible, no curves
- Limited conveying inclination angle

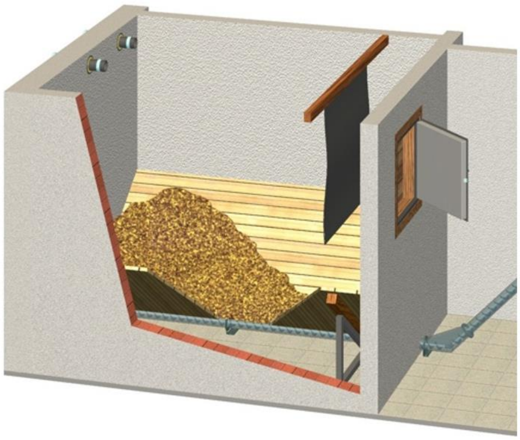


Figure 6.29 Pellet discharge system with sloping floor [69].

Suction systems for pellet storages

Pellet suction systems with suction probes arranged evenly on the pellet storage floor and the “mole” extraction system (Figure 6.30) convey the pellets pneumatically from the pellet storage room to the boiler. Suction systems for pellets are used in pellet boiler systems with a nominal output of up to 300 kW. However, these have the disadvantage of increased energy consumption for fuel delivery, which is why they must be taken into account in a full cost calculation over the service life for a nominal output of more than 50 kW. Furthermore, the wear and tear on the suction conveying equipment must also be taken into account. In return, these systems are more flexible and versatile with regard to the planning of the pellet storage and the location of the boiler system.

Figure 6.30 Pellet mole (source: Schellinger KG).

6.5 Conveyor systems

Screw conveyor

With the screw conveyor (Figure 6.31), the fuel can be conveyed horizontally to vertically. A screw spiral in single or twin design transports the fuel in an open or closed screw trough. Outside the storage room, only closed conveyor systems are to be used for reasons of occupational safety and health protection. It is driven by an electric motor that can be regulated. The screw conveyor is designed as a solid blade or wire screw (not as a shaftless blade screw).

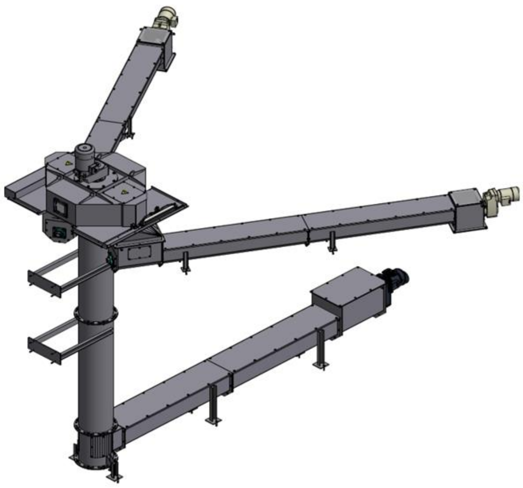


Figure 6.31 Screw conveyor conveying horizontally to vertically (source: Schmid energy solutions).

The size of the core diameter and the nominal width of the screw trough are co-determinants for the conveyable lumpiness of the fuel. The system functions independently of the water content of the fuel and, due to its simple design, enables uncomplicated handling. It is suitable for all types of fuel, including pellets, with the exception of un-shredded bark and coarsely shredded landscape wood, and it is unaffected by oversized fuel particles and stones.

The advantages of the screw conveyor are:

- High efficiency
- Small building mass
- Cost-effective and simple construction
- Easy to use
- Low electrical energy consumption

The disadvantages include:

- Limited lumpiness of the fuel
- Only linear conveying possible, no curves

Thrust system

With the thrust system (Figure 6.32), fuel can be conveyed horizontally. One or more hydraulic cylinders move one or more push rods with crossbars back and forth. Due to the wedge-shaped drivers, the fuel is pushed in the desired direction. The drivers can be adapted to the local situation. The fuel weight above the thrust system determines the thrust forces that have to be absorbed by the building. The thrust system is suitable for all fuels except wood shavings and dust and is unaffected by oversized fuel parts and stones.

Its advantages are:

- Safe operation
- Fuel can be of any shape, size and water content
- No drive system parts in the silo

Its disadvantages are:

- High shear forces on buildings
- Limited delivery length and flow rate
- Only linear use possible
- Maintenance and upkeep required

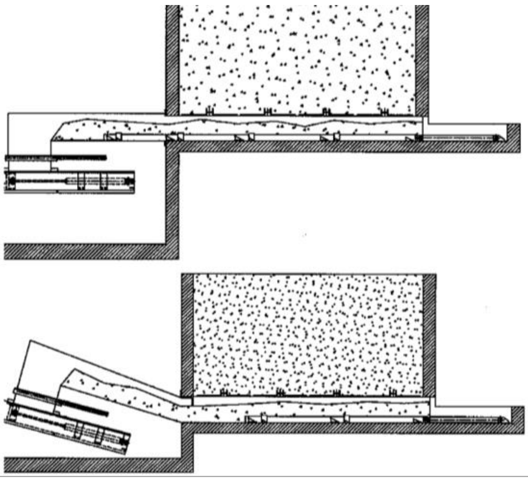


Figure 6.32 Thrust system horizontal conveying (top) and rising conveying (bottom) [69].

Scraper chain conveyor

The scraper chain conveyor (Figure 6.33) can be used to convey a wide range of energy wood horizontally or vertically. The scraper chain conveyor works similarly to a conveyor belt. Two chains run parallel in a closed box construction. Between them, carriers are mounted that push the energy wood to its destination. With appropriate modifications (different discharge openings), large silos and warehouses can also be filled. The scraper chain conveyor is insensitive to oversized fuel parts and stones and is suitable for all fuels except chips, dust and pellets.

Its advantages are:

- High delivery rate
- Wide range of applications

Its disadvantages are:

- Elaborate construction
- High investment costs
- Maintenance and repair required
- Noise

Figure 6.33 Scraper chain conveyor [69].

Pneumatic conveying

With pneumatic conveying (Figure 6.34), the fuel is blown into the silo by means of an air stream. In the process, an automatically cleaning filter system separates the fine particles from the exhaust air. In central extraction systems, a cyclone filter separates the transport air from the fuel and some of it is recycled and reused.

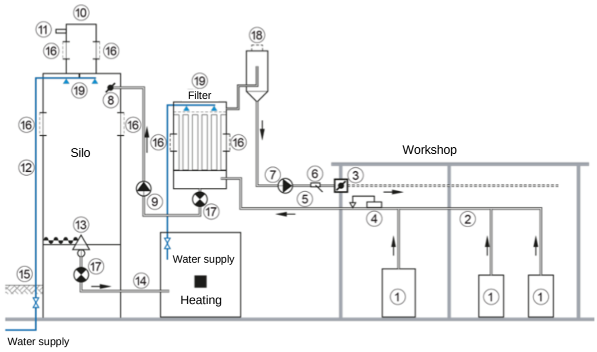
Pneumatic conveying can also be used to overcome large horizontal and vertical distances. However, it requires an exact design in function of the specific fuel assortment. The system is suitable for dry wood chips, shavings, dust and pellets and is sensitive to oversized fuel particles and stones.

The advantages of pneumatic conveying are:

- Easily adapted to the building
- Dust-free surroundings
- Large horizontal and vertical distances can be covered

The main disadvantages are:

- Limited to dry, fine fuel
- Noisy
- Additional silo facilities required
- Explosion hazard due to dust content
- High power consumption



Legend:
1 Wood processing machines
2 Suction line
3 Fire damper
4 Spark detection with extinguishing system if necessary
5 Exhaust air to the outside (summer operation)
6 Switching flap (return air-exhaust air)
7 Ventilator
8 Check valve
9 Conveyor fan
10 Filter final precipitation
11 Cleaned air to the outside (exhaust air)
12 Extinguishing line
13 Shavings discharge
14 Conveying system to furnace
15 Connection to water supply
16 Pressure relief
17 Rotary valve
18 Explosive vent with bursting disc
19 Extinguishing device

Figure 6.34 Pneumatic conveying (source: VKF 104-15 Spänefeuerungen [70]).

6.6 Furnace feed

The fuel is fed into the furnace via the feed devices. In multi-boiler systems, each system has its own feeder. As a rule, the fuel is fed by screw conveyors or hydraulic feeders.

Screw conveyor

Screw conveyors or stoker screws (Figure 6.35) enable continuous feeding without compression of the fuel. This results in a uniform loading of the furnace grate, but limited to one side. By using twin screw conveyors, the uniform grate loading can be extended to the entire width of the grate.

Figure 6.35 Feeding with screw conveyor (source: Schmid energy solutions).

Hydraulic pusher

Hydraulic pushers (Figure 6.36) discontinuously feed the furnace with fuel. Therefore, it is slightly compressed. A predetermined amount of fuel is brought through a sluice in front of the pusher and then slowly and continuously pushed into the furnace according to the required firing rate. In the case of fuels with a high proportion of foreign matter (waste wood), increased wear can occur on the push ram and the insertion duct.

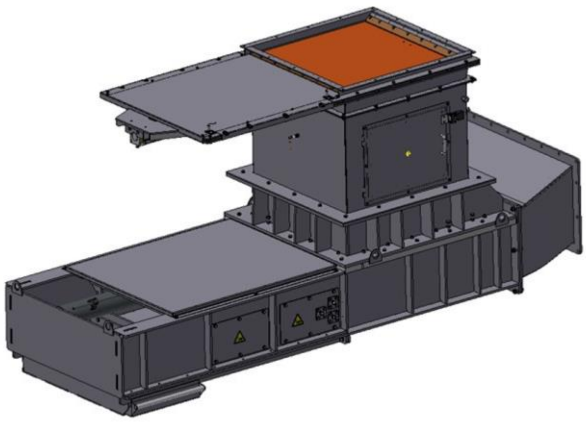


Figure 6.36 Feeding with hydraulic pusher (source: Schmid energy solutions)

Direct insertion (push transmitter systems)

In the case of direct feeders (pusher systems, Figure 6.37), a strong compression of the fuel takes place. To ensure that the compacted fuel can burn optimally on a moving grate, it must be loosened up again beforehand involving additional measures. Compression can also be reduced by arranging a relief zone in the insertion duct. In order to avoid power fluctuations, the fuel is continuously fed into the furnace according to the required firing rate.

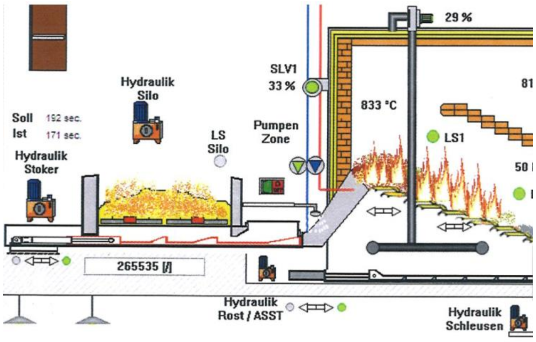


Figure 6.37 Feeding with direct feeder (source: Agro Forst & Energietechnik GmbH).

6.7 Backfire protection in the fuel conveyor system

To prevent a backfire from the combustion chamber into the fuel supply and into the fuel storage area, automatically fed wood firing systems must be equipped with backfire protection devices. The corresponding regulations are country-specific.

CH and AT: At least two independent devices are required: an extinguishing device in the fuel supply with thermal, current-independent triggering and at least one further water-independent device such as a drop step, slide valve, backfire flap, rotary valve or similar (Figure 6.38).

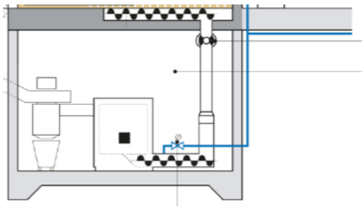


Figure 6.38 Backfire protection, drop shaft, rotary feeder (source: VKF 104-15 Spänefeuerungen [70]).

DE: In the case of mechanically fed biomass combustion systems, a safety device must be provided to prevent backfiring and flying sparks into the conveying or metering equipment and into the boiler room (see chapter 19).

Extinguishing device
With the extinguishing device, tap water is injected into the fuel channel by a thermal, current-independent trigger to prevent a backfire in the event of a release. The extinguishing water valve and temperature trigger are included in the scope of delivery of the biomass boiler. The planner is responsible for connecting the pipework and the installation of a dirt filter should be observed.

Drop step
A drop step (drop shaft) in the fuel feed creates a local interruption in the conveying system and thus prevents a backfire.

Slides and backfiring flaps
Slide valves and backfire dampers are installed in the drop shaft of the fuel supply. If an adjustable temperature limit is exceeded, a thermostat triggers the closing process and shuts off the fuel supply.

Rotary valve
The rotary valve consists of a multi-bladed sluice wheel installed in a metal housing and is placed in the drop shaft. It is driven by means of an electric motor coupled to the conveyor motors. When at a standstill, the wheel blades block the passage of fuel and thus prevent a backfire.

In the pressurised chips silo, the rotary valve separates the silo from the unpressurised transport system.

6.8 Ash removal

Mechanical ash removal conveyors include screw conveyors, push rod conveyors, scraper chain conveyors, trough chain conveyors, bucket conveyors and wet ash removal with scraper chain conveyors (Figure 6.39 to Figure 6.41). These convey ash from the combustion chamber into the ash bins or ash hoppers and, apart from screw conveyors, are also capable of covering greater distances.

Advantages are:

- Low susceptibility to interference
- Unaffected by foreign parts, slag parts and ember particles
- Low auxiliary energy requirement
- Low noise emissions.

The main disadvantages are:

- High space requirement (unsuitable for confined spaces)
- High wear with ash rich in slag or other foreign content

Figure 6.39 Fire ash screw (source: Schmid AG energy solutions).

Figure 6.40 Bottom ash removal, discharge by moving floor. (Source: Schmid AG energy solutions).

Figure 6.41 Mechanical ash removal conveyor: with scraper chain conveyor (source: AEE INTEC).

7 Heat generation hydraulics

7.1 Hydraulic basics

This chapter deals with the requirements for the heat generation related hydraulics. The hydraulics for heat distribution are not dealt with further in this QM for Biomass DH Plants Planning Handbook, please refer to the Handbook on Planning of District Heating Networks [19].

The detailed requirements for the design of the hydraulic and control solutions with regard to heat generation are listed in Volume 2 and Volume 5 of the QM Holzheizwerke publication series (Standard hydraulic schemes Part I [62] and Part II [71]).

In the Standard hydraulic schemes Part I and Part II, the hydraulic and control engineering solution is described in detail for each of the eight basic variants of a biomass heating system as a separate overall document with the following sections:

- Brief description and responsibilities
- Principle scheme and design
- Functional description
- Data recording for operational optimisation
- Annex to the approval protocol

It is recommended to choose one of the **proven standard hydraulic schemes** whenever possible in order to meet the basic quality requirements for hydraulics and control.

With regard to the hydraulics of heat generation, this means that principles such as the expandability of heat generation by a further biomass boiler, the strict decoupling of hydraulic circuits with low pressure difference (bypass/hydraulic separator) and compliance with minimum valve authorities are observed.

Simplified calculation of flow rate (volume flow), pressure difference (head) and pump capacity
In the hydraulics of heat generation, the following three questions often arise for the design of the boiler circuits:

- How large must the flow be?
- What is the pressure difference across the control valve at this flow rate?
- What is the power requirement of the pump to manage this flow?

The following three simplified formulas usually answer these questions with sufficient accuracy.

Flow:

$$\dot{V}\left[\frac{m^3}{h}\right] = 0.86\,\frac{\dot{Q}\,[kW]}{\Delta T\,[K]}$$

Pressure difference:

$$\Delta p\,[kPa] = 100\left(\frac{\dot{V}\left[\frac{m^3}{h}\right]}{k_V\left[\frac{m^3}{h}\right]}\right)^2$$

Pump capacity:

$$P_{Pump}\,[kW] = 0.86\,\frac{\Delta p\,[kPa]\;\dot{V}\left[\frac{m^3}{h}\right]}{3600\;\eta_{Pump}\,[-]}$$

$\dot{V}$	Flow rate in m³/h
$\dot{Q}$	Heat output in kW
ΔT	Temperature difference in K
Δp	Pressure difference in kPa
k_V	Flow factor in m³/h
P_{Pump}	Power consumption pump in kW
η_{Pump}	Pump efficiency

Important note:
These formulae apply approximately to water from 5...95 °C. They are numerical value equations in which the quantities must be used in the prescribed units. The factor 0.86 corresponds to the product of density [kg/m³] and heat capacity [kWh/(kg*K)].

7.2 Boiler circuit control

In order to keep boiler corrosion on the walls of the flue gas pipes low, boiler manufacturers prescribe a minimum inlet temperature of the water into the boiler (see chapter 5.4). This minimum boiler inlet temperature is ensured by appropriate admixing of the flow to the return via a hydraulic admixing circuit in the boiler circuit via a three-way valve. To ensure a constant boiler outlet temperature, this is additionally controlled indirectly via the three-way valve by raising or lowering the boiler inlet temperature. The basic principles for designing the control valve in the mixing circuit are shown below.

7.2.1 Control valve boiler circuit

Three-way valves with two inputs and one output, so-called mixing valves, are usually used in the boiler circuit (see Figure 7.1).

The hydraulic behaviour of the control valves is described by the so-called basic characteristic curve. This represents the stroke as a function of the flow rate. Three-way valves are usually offered with two different basic characteristic curves:

- **Linear characteristic curve:** equal changes in stroke result in equal changes in flow rate (application: control loop without heat exchanger).
- **Equal percentage characteristic curve:** equal stroke changes result in an equal percentage change in the current flow rate (application: control loop with heat exchanger).

Further information on control valves can be found in the Handbook on Planning of District Heating Networks ([19], chapter 8.4.4).

The manufacturers specify a flow factor (**k_{VS} value**) for each control valve. This allows the pressure drop across the fully open control valve at 100 % flow to be calculated using the following pressure difference formula:

$$\Delta p_{V,100}\,[\text{kPa}] = 100 \left(\frac{\dot{V}_{100} \left[\frac{m^3}{h}\right]}{k_{VS} \left[\frac{m^3}{h}\right]} \right)^2$$

$\Delta p_{V,100}$	Pressure drop across the valve at 100 % flow rate
$\Delta p_{V,0}$	Pressure drop across the valve at 0% flow when it is just starting to open
$\Delta p_{var,100}$	Pressure drop over the green marked section with variable flow (Figure 7.1)

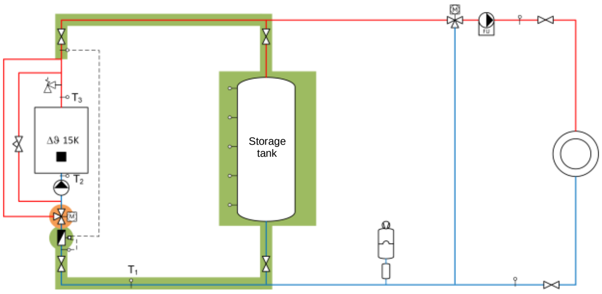


Figure 7.1 Boiler circuit with constant flow and the section with variable flow in green.

The variable flow section is decisive for the design of the control valve of the boiler return temperature protection (see green marked section in Figure 7.1). The pressure difference of the section with variable flow should be as small as possible. The pump in the boiler circuit is operated with a constant flow, which makes temperature control possible. This means that the boiler inlet temperature is regulated with the control valve so that a constant boiler outlet temperature can be run at constant flow in the boiler. The following formulae can be used to determine the valve and pump flow and the valve authority (VA) in the boiler circuit.

Valve flow:

$$\dot{V}_V \left[\frac{m^3}{h}\right] = 0.86 \, \frac{\dot{Q}\,[kW]}{T_3 - T_1\,[K]}$$

Pump flow:

$$\dot{V}_P \left[\frac{m^3}{h}\right] = 0.86 \, \frac{\dot{Q}\,[kW]}{T_3 - T_2\,[K]}$$

Valve authority:

$$VA = \frac{\Delta p_{V,100}}{\Delta p_{V,100} + \Delta p_{var,100}}$$

$\dot{V}_P$	Flow rate in m³/h
$\dot{V}_V$	Flow rate in m³/h
VA	Valve authority
$\dot{Q}$	Heat output in kW
$T_{1..3}$	Temperature at measuring point 1 to 3 in °C according to Figure 7.1
$\Delta p_{V,100}$	Pressure drop across the valve at 100 % flow rate
$\Delta p_{var,100}$	Pressure drop over the section marked in bold with variable flow (Figure 7.1)

Important note:
These formulae apply approximately to water from 5...95 °C. They are numerical value equations in which the quantities must be used in the prescribed units. The factor 0.86 corresponds to the product of density [kg/m³] and heat capacity [kWh/(kg*K)].

Valve authority

When a valve is installed in a hydraulic circuit, it no longer behaves according to the basic characteristic curve because the pressure difference across the valve becomes a variable part of the total pressure drop of the system. As a result, the basic characteristic curve is more or less deformed. With increasing deformation, the accuracy and speed of the control is increasingly impaired, and in extreme cases the control loop becomes unstable and begins to oscillate.

The valve authority is used as a measure for the deformation of the basic characteristic curve.

The formula for calculating the valve authority (VA) is given above. The pressure drop across that part of the hydraulic circuit whose variable flow is affected by the valve plays an important role (see Figure 7.1, green marked section).

In hydraulic circuits with three-way valves, no stability problems occur as long as the following rule is observed:

$$VA = \frac{\Delta p_{V,100}}{\Delta p_{V,100} + \Delta p_{var,100}} \geq 0.5$$

(target value, limit value in exceptional cases VA ≥ 0.3)

This results in: $\Delta p_{V,100} \geq \Delta p_{var,100}$

At 100 % flow, the pressure drop across the open three-way valve ($\Delta p_{V,100}$) must be equal to or greater than the pressure drop across the variable flow section ($\Delta p_{var,100}$).

Several boiler circuits are often connected in an **admixing circuit** with low pressure difference (e.g. to a heat storage tank). Each boiler pump receives water via its valve and the variable flow section (see Figure 7.2). This raises another question: *"What is the maximum pressure difference allowed over the variable flow line?"* If this pressure difference becomes too great, the individual boiler circuits will influence each other. This can lead to a reduction in the flow of a boiler pump with too low delivery, and the nominal output of the associated boiler can no longer be delivered. To prevent this, the following rule must be observed in addition to the valve authority rule.

Several boiler circuits in admixing circuit

If several boiler circuits are connected with low pressure difference in a mixing circuit (e.g. at a heat storage tank), the maximum pressure difference over the section with variable flow must not be greater than 20 % of the delivery head of the smallest boiler pump at the design point (see Figure 7.2).

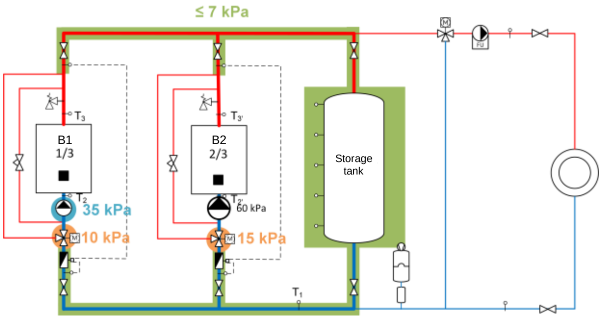


Figure 7.2 Boiler circuits with constant flow in multi-boiler systems. Boiler 1 is influenced or significantly reduced when the two boilers are operated in parallel at nominal boiler output.

7.2.2 Bypass in the boiler circuit

With a correctly designed hydraulic circuit, the control valve operates in a reasonably linear fashion.50% flow corresponds to 50% stroke, 100% flow corresponds to 100% stroke.

If the control range of the control valve without bypass in the boiler circuit is severely restricted by different temperature levels between the main return and boiler inlet temperature, this can result in inaccurate control or even oscillation of the control circuit.

With a bypass in the boiler circuit, the control range of the control valve can be significantly extended despite the different temperature levels between the main return and boiler inlet temperatures (see Figure 7.3).

Bypasses are usually useful,

- if the temperature difference between the boiler outlet temperature and the boiler inlet temperature (T_12 - T_11 in Figure 7.3) is more than 10 K smaller than the temperature difference between the boiler outlet temperature and the maximum permissible main return temperature (T_12 - T_43 in Figure 7.3). The control valve can thus be designed smaller and its control range can be fully utilised.
- if it is ensured that the main return temperature T_43 cannot rise above the design value in any operating case. Only then is it ensured that the boiler can deliver its nominal output in any case.

The bypass volume flow is designed as follows: At nominal power and maximum main return temperature, the volume flow via the bypass of the mixing valve should be approximately zero. The valve position is set to 100 % passage.

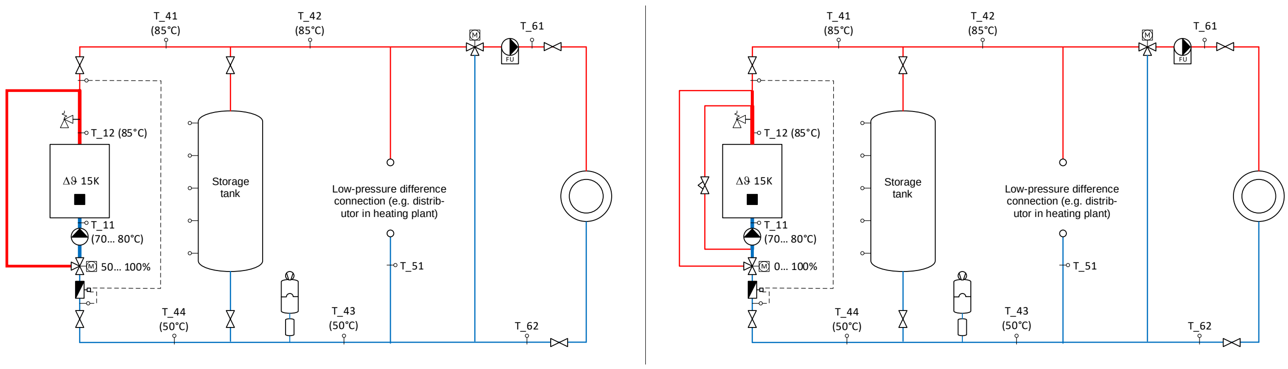


Figure 7.3 Hydraulic integration of the boiler circuit without and with bypass.

7.3 Pumps

7.3.1 Pump types

A basic distinction is made between:

- **Dry-running (glanded) pump**: The pump is connected to a standard motor via shaft and coupling.
  - With the pedestal pump, the standard motor and pump are mounted on a pedestal.
  - With the inline pump, the standard motor is mounted on a built-in pipe pump.
- **Wet-running (glandless) pump**: The casing pump and the so-called canned motor form one unit. The pumped medium lubricates the bearings and cools the motor. The pump is driven by a stepless speed-controlled DC synchronous motor with a permanent magnet rotor. The range of application is currently a maximum volume flow of 80 m³/h.

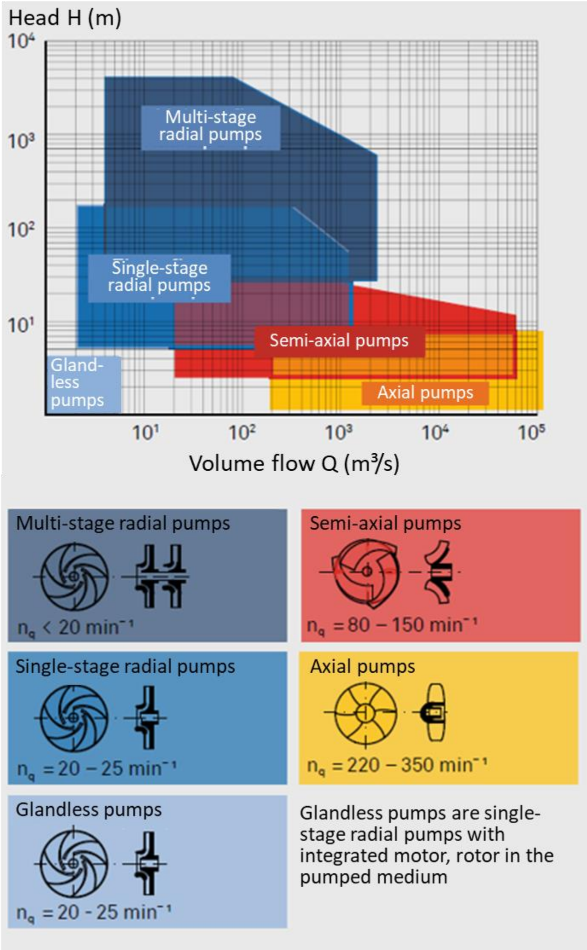


Figure 7.4 Typology of pumps by head and flow rate [72].

Stepless **speed-controlled boiler pumps** are available in the following versions:

- Glandless pump with infinitely variable speed-controlled DC synchronous motor
- Glanded pump with standard motor (inline or pedestal pump) and external frequency converter
- Glanded pump with standard motor (inline or pedestal pump) and mounted frequency converter

7.3.2 Pump design

The use of the pump sizing programmes of the pump manufacturers makes it possible to compare different pumps for the specified application range (volume flow, delivery head) with regard to energy efficiency and lifetime costs.

The product-specific data of the design programme (pump characteristic curve, overall efficiency [efficiency pump plus motor], efficiency pump) of the manufacturer enable an optimal selection.

In order to be able to check or compare the product-specific data of the design programme, the following basics of pump technology must be observed:

Pump characteristic

The pump curve shows the delivery head (pressure difference) as a function of the volume flow (flow rate). A distinction is made between flat characteristic curves of low-speed pumps and steep characteristic curves of high-speed pumps (see Figure 7.5). Boiler pumps have flat characteristic curves, capillary pumps have steep characteristic curves.

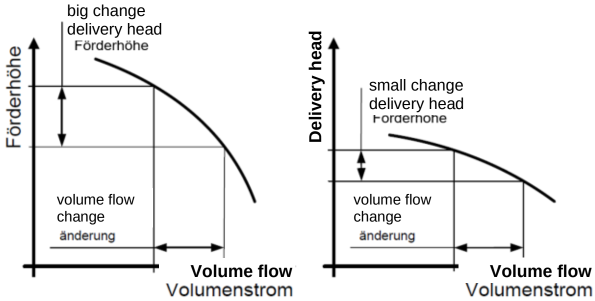


Figure 7.5 Steep (left) and flat pump curve (right).

System characteristic curve

The pressure loss of the heating network increases quadratically with the volume flow. This dependency between delivery head and volume flow is shown in the system characteristic curve. Since the pump curve also shows the same dependency between delivery head and volume flow, both curves can be entered in the same coordinate system (Figure 7.6). They have a common point of intersection. This is the operating point of the pump at which the delivery head of the pump corresponds to the pressure loss of the system.

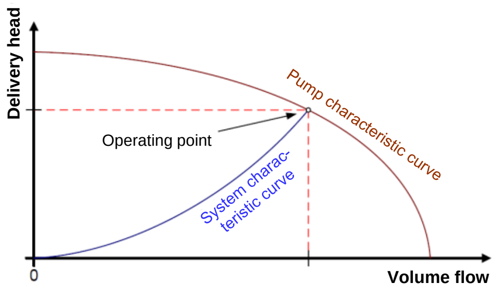


Figure 7.6 Pump and system characteristic curve [19].

Laws of proportionality

When changing the speed of a circulating pump, the delivery head, volume flow and hydraulic power behave according to the following three proportionality laws.

The flow rate is proportional to the speed of the pump:

$$\frac{\dot{V}_1}{\dot{V}_2} = \frac{n_1}{n_2}$$

The head (pressure difference) changes with the square of the speed:

$$\frac{H_1}{H_2} = \frac{\Delta p_1}{\Delta p_2} = \left(\frac{n_1}{n_2}\right)^2$$

The hydraulic pump capacity changes by the power of three of the speed:

$$\frac{P_{hydr1}}{P_{hydr2}} = \left(\frac{n_1}{n_2}\right)^3$$

So at half speed, the volume flow drops to half, the delivery head, i.e. the pressure drop, drops to a quarter and the power requirement of the pump drops to an eighth.

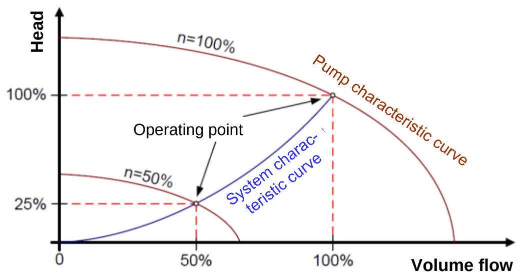


Figure 7.7 Pump and system characteristic curve for two different speeds [19].

Pump power consumption, pump efficiency, energy efficiency

The selection of a circulating pump is a question of hydraulic design. The pump power consumption must also be taken into account from the outset. For this purpose, the required energy efficiency class for the electric motor of glanded pumps and the energy efficiency index (EEI) limits for glandless pumps must be complied with (see also Handbook on Planning of District Heating Networks ([19], chapter 3.3.2).

What should be considered?

- Avoid unnecessarily high volume flows
- Network characteristic curve as flat as possible
- The position of the operating point in the pump diagram has a decisive influence on the efficiency. The optimum efficiency is usually in the middle third of the characteristic curve for the highest speed stage; however, there are exceptions.
- Only use infinitely variable speed pumps in boiler circuits with highly variable flow (see chapter 7.3.3) At the same time, make sure that the operating point is not too far away from the middle third of the characteristic curve for the maximum speed stage.
- For speed-controlled pumps, glandless pumps with DC synchronous motors with permanent magnet rotor should be used if possible.

7.3.3 Speed-controlled boiler pump

As a rule, the internal boiler circuit of biomass boilers is operated with a constant volume flow according to the specifications of the standard hydraulic schemes. This facilitates the controllability of the system, as only the three-way valve is controlled and a speed-controlled boiler pump is not necessary. A single-stage, optimally dimensioned boiler pump meets the requirements of energy-efficient pump operation. Glandless pumps with infinitely variable speed-controlled DC synchronous motor are to be operated at a fixed operating point in terms of volume flow and delivery head, i.e. constant speed.

The motivation for using a speed-controlled boiler pump is to reduce the electricity required for pump operation. A speed-controlled boiler pump is used in the following applications:

- **Control approach for indirect output setting via set boiler (outlet) temperature (boiler circuit with three-way valve for boiler return temperature protection with constant boiler inlet temperature):**
  This is an indirect output specification to the biomass boiler via the setpoint speed of the boiler pump at constant boiler inlet temperature. The setpoint value of the boiler output is specified indirectly by the controller via the boiler water temperature, by controlling to a constant boiler (outlet) temperature setpoint.

  Due to the inertia of the indirect power input, this control approach is not expedient when using a heat storage tank with direct input of the setpoint value of the firing rate by the control according to the storage tank charging state.
- **Control approach for constant temperature difference over the boiler circuit (boiler outlet temperature minus boiler inlet temperature) (boiler circuit with three-way valve for boiler return temperature protection with constant boiler inlet temperature):**
  The speed of the boiler pump is controlled according to the boiler output so that both the boiler outlet temperature and the boiler inlet temperature or their difference remain constant.

  Problematic are the operating phases of boiler start, burnout and standby, in which it is hardly possible to keep the boiler outlet temperature constant. Furthermore, the control behaviour can be negatively influenced by stratification of the boiler water at low volume flow or at partial load.

  Simplified control approach: The speed of the boiler pump is specified directly as a function of the boiler output setpoint. The required speed range must be determined or adjusted during commissioning. However, the boiler outlet temperature can show larger, undesired deviations if the boiler output no longer corresponds to the specified boiler output due to changing fuel quality.
- **Control approach for boiler circuit without boiler return temperature protection (boiler circuit without three-way valve):**
  Low-output biomass boilers can have boiler designs that do not require a minimum boiler inlet temperature and do not require a boiler return temperature protection respectively.

  The speed of the boiler pump is controlled so that the boiler outlet temperature is kept constant over the entire output range (e.g. 50...100 %) regardless of the specified boiler output. Accordingly, a variable volume flows through the boiler at a variable boiler inlet temperature.

  Here, too, the control accuracy of the boiler outlet temperature is limited by an undesirable stratification of the boiler water at low volume flow or at partial load.

As the above explanations show, the use of speed-controlled pumps in the boiler circuit of a biomass boiler is demanding. Deviations in the boiler outlet temperature disturb the temperature stratification in the heat storage and can thus lead to unfavourable control behaviour of the system. For this reason, these control approaches are not listed in the standard hydraulic schemes.

The following additional control requirements may be necessary:

- The operating phases start, burnout and standby require additional regulation or control functions, especially for biomass boilers with heavy combustion chamber linings and high inertia.
- When operating a biomass boiler with varying fuel quality, a constant boiler outlet temperature can only be achieved with additional control systems (e.g. including the instantaneous average heat output at the heat meter, taking into account the dead time of the boiler water volume).

7.3.4 Operational reliability and redundancy of the boiler pump

In warm water systems with a maximum temperature level of the heating water of < 110 °C, a replacement boiler pump connected hydraulically in parallel can be dispensed with if the boiler pump can promptly be replaced if necessary. If a replacement pump is not available at short notice, consideration should be given to keeping a replacement pump in stock. **Note**: With longer storage times, the pump may no longer be state of the art.

In hot water systems with a maximum temperature level of > 110 °C, the safety specifications (standards, legal regulations, see chapter 19) determine whether or not a replacement boiler pump connected hydraulically in parallel is required.

7.4 Heat meter

Heat meters are installed to record the amount of heat produced or drawn. Furthermore, they enable the necessary operational data recording of the current heat output for operational monitoring and operational optimisation, as required in the standard hydraulic schemes. The installation of heat meters is required for quality monitoring in accordance with QM for Biomass DH Plants.

The installation of heat meters in a heating plant must be provided at the following locations:

- In the heat generator circuit of each individual heat generator (biomass boiler, economiser, flue gas condensation, heat pump, etc.)
- At each individual group of district heating pipielines for recording the heat quantity fed into the grid and its heat distribution losses and for recording the load peaks or load reductions during the course of the day
- The installation of a heat meter is recommended in the boiler circuit of gas and oil boilers. If this is not the case, the boilers must have an operating hours meter and an oil/gas meter (in the case of a modulating burner, the oil/gas meter must continuously record the current volume flow).

The use of calibrated heat meters is necessary for the billing of fuel deliveries or the heat purchased from a customer. Heat metering requires flow measurement and temperature difference measurement between flow and return.

7.4.1 Heat meter features

The **accuracy class** of a heat meter is determined by the measuring accuracy of flow and temperature difference.

The **measuring range of the flow rate** is given by the operating range between nominal flow rate qp and minimum flow rate qi. The ratio of nominal flow to minimum flow is a measure of the bandwidth of the flow range within which a certain accuracy of the volumetric flow measurement is guaranteed. Figure 7.8 shows the error curve of an impeller meter, and Figure 7.9 shows the error curve in the oscillating jet flow measurement method.

The **pressure drop at nominal flow q_p** is often very high (20 to 25 kPa for impeller meters). Although a high pressure drop increases the working range and the measuring accuracy, it also deteriorates the valve authority of the control valve (see chapter 7.2.1), which is often located in the same flow path (variable volume flow of the boiler circuit).

The **water quality** has a great influence on the measuring accuracy in long-term use.

The following measuring methods are used for flow measurement:

- Electromagnetic flow measurement (EFM)
- Flow measurement with ultrasound
- Flow measurement according to the oscillating jet principle
- Mechanical flow measurement with impeller or turbine wheel

Table 7.1 shows an overview of the different flow measurement methods.

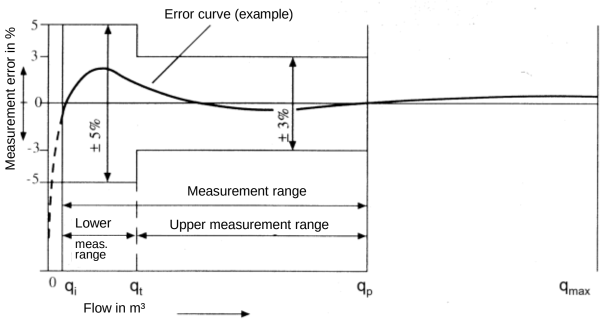


Figure 7.8 Error curve mechanical flow measurement method with impeller.

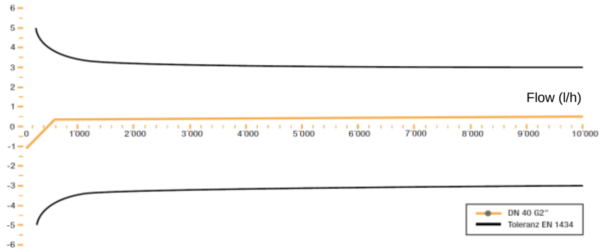


Figure 7.9 Error curve oscillating beam flow measurement method (source: NeoVac Superstatic 440).

The flow measurement methods EMF, ultrasound and oscillating jet have a higher measurement accuracy compared to mechanical flow measurement methods (impeller or turbine wheel) (see Table 7.1).

Table 7.1 Overview of the most important flow measurement methods.

Feature	EFM[1]	Ultrasound	Oscillating beam	Mechanical
Ratio q_p/q_i	100 - 150	100 - 150	25 - 100	25 - 100
Pressure drop at nominal flow q_p in kPa	7 - 15	7 - 20	9 - 25	10 - 15
Measurement accuracy	high	high	high	medium
Sensitivity of the measurement accuracy to the water quality	high	small to medium[2]	small	small
Wear and tear/service costs	low	low	low	high
Sensitivity of the measurement accuracy to electrical interference fields	high	low	low	low to moderate[3]

[1]Electromagnetic flow meter
[2]Contamination of the deflecting mirrors with small nominal diameters
[3]with inductive pulse generator

7.4.2 Requirements of the individual flow measurement methods

In principle, the installation instructions of the heat meter supplier must be observed and the required water quality must be maintained.

Electromagnetic flowmeters

- The water should not contain any magnetite, as this settles on the measuring probes and thus considerably influences the measurement (reduction of the flow measured value). Magnetite is formed during the oxidation of the oxygen bound in the water with the iron molecules of the pipe walls.
- In existing plants, the required water quality (clear water) can be achieved with a wet sludge separator in conjunction with a degassing device.
- For new systems, the water in the heating system must be sufficiently degassed from the start so that the oxygen content in the water is reduced to zero.
- If large measuring errors occur, it is recommended to clean the inner walls of the flow meters. However, this does not eliminate the cause of the problem (dirty water).
- To ensure the optimum flow rate, the heat meter must be correctly designed in the control range of minimum and maximum volume flow (partial load and full load operation).
- As a very low voltage is applied across the measuring probes (a few millivolts), the measuring method is sensitive to electrical interference fields. This is especially the case with split devices, where the sensor and the transmitter are connected by interference-sensitive lines. This can be mitigated by using compact flow transmitters.
- It is recommended to use only shielded and twisted cables and to avoid the proximity of strong magnetic fields from electric motors or frequency converters.

Ultrasonic flowmeters

- Contamination of the deflecting mirrors with small nominal diameters and gas inclusions in the water can cause measurement inaccuracies.
- Avoiding these interferences requires a high water quality as well as sufficient degassing of the water, which prevents deposits on the deflection mirrors.

Oscillating beam flowmeters

- Oscillating jet flowmeters are basically insensitive to contamination, as only a partial flow with increased flow velocity is necessary for the measurement.
- For horizontal installation, the measuring head must be mounted laterally (not at the bottom or top). For vertical installation, no special measures are needed.

Mechanical flowmeters

- The installation of a dirt filter upstream of the water inlet of the flow meter helps to avoid damage or clogging of the impeller or turbine wheel.
- Regular inspection ensures that mechanical wear and tear is excluded as a source of error.

- Careful design must ensure that the operating flow rate does not fall below the minimum flow rate qi if possible, or only in exceptional cases.

7.4.3 Installation of heat meters

To achieve the measurement accuracy required for heat billing, the following instructions must be observed:

- Compliance with the installation instructions of the heat meter supplier (inlet section, outlet section, horizontal/vertical installation arrangement, sensor installation, etc.).
- The straight inlet and outlet distances vary depending on the nominal size and technology. In AGFW worksheet FW 218 [73], an inlet section of 5 x DN and an outlet section of 3 x DN is recommended. These calming sections (inlet/outlet sections) must not contain any built-in parts such as sensors, immersion sleeves, valves, strainers, pipe bends, cross-section changes or similar (see Figure 7.10).
- The temperature sensor for the return flow must be arranged in the direction of flow after the volume measuring part.
- If possible, the volume measuring part should be placed between two shut-off devices. This facilitates maintenance work and meter replacement according to the calibration cycle.
- Design for a temperature difference > 20 K. Temperature difference in operation at least 3 K, i.e. the installation of a heat meter in the constant boiler circuit is not permitted.
- Uniform temperature distribution over the pipe cross-section in front of the temperature sensors (if necessary, additional installation of a static mixer)
- Stable control loops; oscillating controllers (small/large temperature difference or even positive/negative temperature difference) can cause considerable measurement errors.
- Prevention of faulty circulation (incl. single-pipe circulation), which can influence the heat measurement.
- If the temperature difference measurement is done on the same level as the flow measurement, disturbances due to unwanted mis-circulation can be minimised (mis-circulation is at least measured correctly).
- Heat meter operation only in the permissible flow range qp to qi
- Compact heat meters are advantageous because interference influences on the short signal transmission from the sensor to the transmitter and to the calculator are practically excluded.
- Technically correct commissioning of the heat meters and, if necessary, systematic search for sources of interference by specialists
- Extending the sensor cables is not permitted. Heat meters including the sensor are calibrated and gauged.
- The respective regulations for maintaining measurement stability (recalibration, calibration, etc.) must be observed.

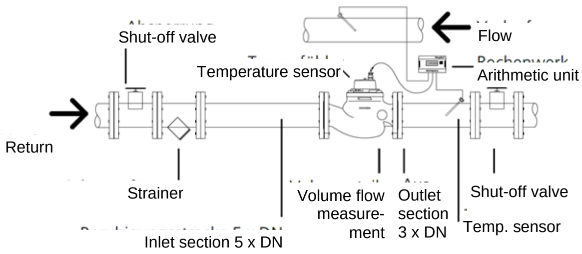


Figure 7.10 Installation heat meter (source: WDV-Molliné GmbH).

7.4.4 Influencing the valve authority

Heat meter manufacturers specify the so-called nominal flow rate for each heat meter. However, if heat meters are actually designed for this nominal flow rate, pressure drops of 20 to 25 kPa result.

These large pressure drops with the misleading designation “nominal flow rate” lead time and again to misinterpretations: The flow meter is often installed in a section with variable flow so that the corresponding temperature difference is as large as possible (best measuring accuracy). However, this has the consequence - and this is often forgotten - that the valve authority of the control valve is thereby influenced! This leads to a conflict of objectives: On the one hand, the pressure drop across the meter should be as small as possible for proper valve authority, on the other hand, a small pressure drop also means lower accuracy in the lower flow range. The following advice can be given:

- If smaller heat meters are designed so that the actual design flow corresponds to about 50 % of the nominal flow according to the manufacturer's specifications, reasonable pressure drops of around 5 kPa will result with acceptable accuracy.
- With the different types of construction offered today, suitable solutions can always be found. With magnetic-inductive flow transmitters and flow measurement by means of ultrasound (possibly flow measurement according to the oscillating jet principle), larger heat meters with low pressure drop can be realised.

7.5 Heat storage

7.5.1 Heat storage in the heating system

Wood firing systems cannot increase or decrease their boiler output at any speed; the combustion process of wood and the thermal mass of the firing systems limit this. As a rule, the output changes can take place at most in the range of 0.5 % to 1 % per minute. The task of the heat storage in the heating system is to compensate for short and rapid changes in the power demand (load peaks, load reductions) of the heat consumers, so that the biomass firing system can slowly follow the average power demand (load profile). This is the only way to ensure low emission levels, low system wear and resulting low maintenance costs as well as a long service life of the system. In order for the heat storage system to be able to fulfil this task, the following requirements must be met:

- Sufficient heat storage volume
- Temperature sensors for determining the storage tank charging status
- Optimal temperature stratification in the storage tank
- Heat storage charging management

Storage volume

For systems that are mainly used for the production of space heating, the heat storage tank should at least be able to absorb the heat released during one hour at the nominal output of the wood combustion system. The usable temperature difference between the temperature level at the top and bottom of the heat storage tank is taken into account (see Figure 7.11). The temperature level at the top corresponds to the boiler outlet temperature, the temperature level at the bottom corresponds to the maximum return temperature of the heat consumers in the design state in cold weather. In the case of two or more wood-fired boilers, at least two-thirds of the sum of the nominal outputs is selected as the reference value. However, it is also recommended that the sum of the nominal outputs be used as the reference value for multiple boiler systems. If very large and/or rapid load changes occur, for example due to process heat, domestic hot water peaks in sports facilities, use of fresh water stations, ventilation systems, greenhouses, etc., the storage volume should be significantly increased. Further information can also be found in chapter 13.5.5

If the required storage volume cannot be realised in a single storage tank due to restrictions in space and room height, it should be distributed over two or more storage tanks. As a rule, the hydraulically serial operation of the storage tanks is recommended, provided that the maximum flow velocity in the storage tanks does not exceed 6 m/h to 10 m/h. The hydraulically parallel operation of the storage tanks requires very careful piping according to the Tichelmann principle, so that all pipes to the storage tanks have exactly the same pressure drop. In practice, this is rarely implemented correctly. Figure 7.12 shows a serial arrangement of two storage tanks with the recommended positions of the temperature sensors. The Handbook on Planning of District Heating Networks [19] goes into more detail in chapter 2.10.4 Types of construction and modes of operation of heat storage tanks.

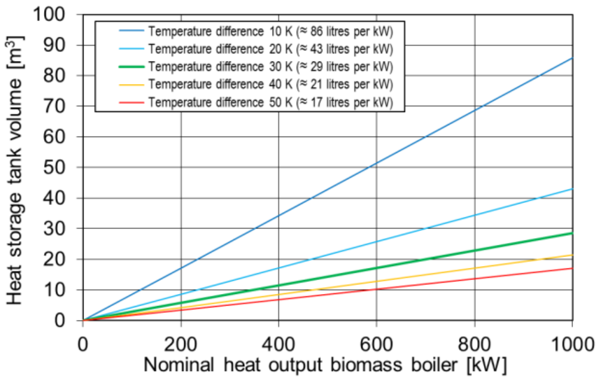


Figure 7.11 Volume of the heat storage as a function of the nominal boiler output and the temperature difference.

Temperature sensors

At least five temperature sensors should be evenly distributed over the heat storage tank. If possible, 10 temperature sensors should be used for high storage tanks. With their help, the charging state of the heat storage tank is determined. If the temperature sensors are distributed over several storage tanks, at least five temperature sensors per storage tank should be used if possible and interpreted by the control system for calculating the charging state.

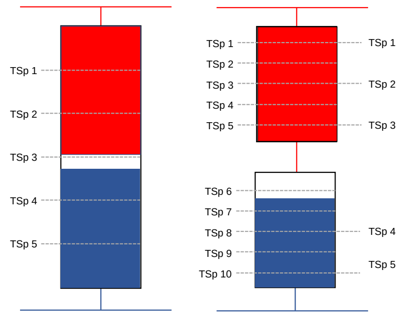


Figure 7.12 Recommended arrangement of five temperature sensors (TSp) for one storage tank (left) and ten or five temperature sensors for two storage tanks in series (right).

Temperature stratification

The heat storage tank must have a distinct temperature stratification. This requires a hydraulic balancing of the volume flows of the heat generators and the heat removal in cold weather. The flow velocities in the heat storage tank should be as low as possible. The inflow and outflow of water should not trigger any mixing processes in the heat storage tank, which can be achieved, for example, by using perforated plates in the inflow/outflow area. Figure 7.13 shows the temperature stratification in a heat storage tank during charging and discharging. A characteristic of optimal temperature stratification is that the temperature sensors do not all change at the same time, but one after the other. When discharging, the temperature of the lowest sensor drops first. When charging, the temperature of the lowest sensor is the last to rise.

Important

In order to maintain the temperature stratification in the storage tank, the boiler outlet temperature must be kept constant, regardless of the current boiler output and also when the boiler is switched off and on. This requires regulation of the boiler outlet temperature to a constant value. This is done by appropriately pre-setting the boiler inlet temperature according to the desired boiler output. By raising the boiler inlet temperature after switching off the boiler just below the boiler outlet temperature, this can be kept constant during standby operation.

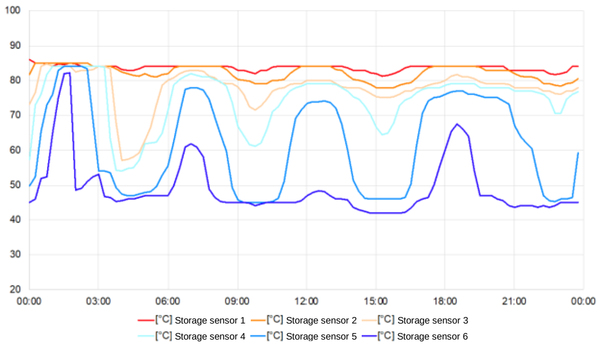


Figure 7.13 Temperatures trends in the thermal storage tank during charging and discharging.

Storage charge management

The heat storage tank is an indicator of changes in the power demand. If the power demand in the heat network increases compared to the current output of the biomass boiler, the cold layer in the storage tank slowly moves upwards, causing the charging state of the storage tank to decrease. In order for the heat storage tank to be able to compensate for the short-term increase or decrease in load demand, it must be hot in the upper half and cold in the lower half. It should therefore have a charging state of around 50 %. A PI controller compares the actual value and the setpoint value of the storage tank charging state. The charging state is controlled by slowly increasing or decreasing the output of the wood burner (see Figure 7.14). When the target state of charge is reached, the boiler output is reduced to minimum load (e.g. 30 %). If two wood burners are in operation at the same time, both boilers receive the same output specification from the storage tank charging management.

For optimum output specification to the biomass boilers by the PI controller, accurate detection of the storage tank charging state is required.

Additional information can be found in the standard hydraulic schemes Part I and Part II (storage tank charging state control variants 1 to 4).

In the course of planning, a comprehensive functional description of the system must be prepared, which in particular also contains a control strategy for storage charging management (see chapter 5.10.3). It must already be clearly defined in the tenders and contracts with planners and manufacturers who is responsible for the definition and implementation of the storage charging management.

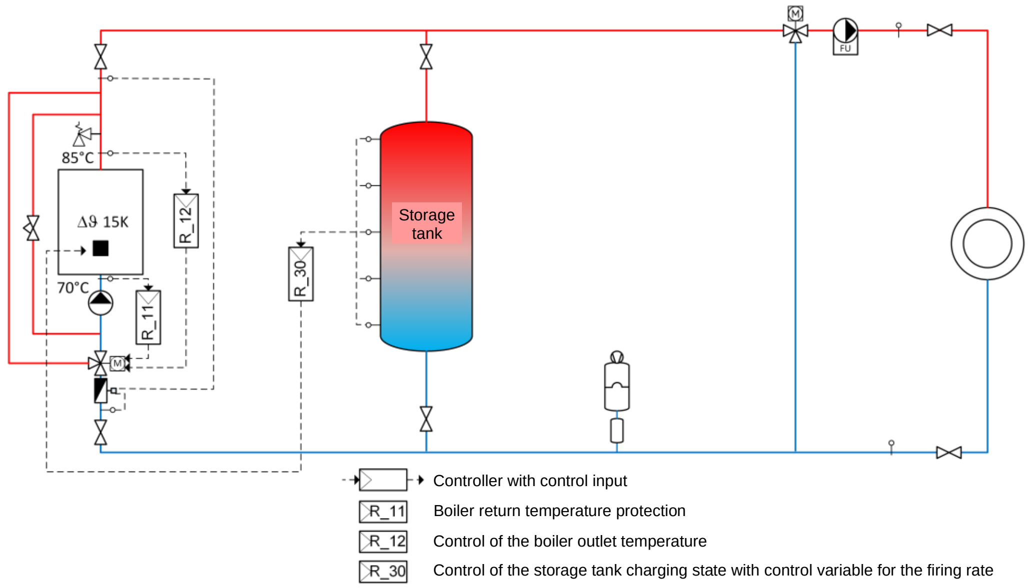


Figure 7.14 Control of the storage tank charging state with control variable for the firing rate of the biomass boiler.

7.5.2 Hydraulic integration of heat storage tank

For a problem-free hydraulic integration of heat generator, heat storage tank and low-pressure difference connections, these should be arranged close to each other in a specific order (circuit A according to Figure 7.15). Problematic **deviations** from the above basic requirement are described in circuits B - F with solution notes (see Figure 7.16 to Figure 7.20).

The basic issues that arise when a heat generator (biomass boiler, heat pump, etc.), a storage tank and a low-pressure difference connection (distributor, pre-control DH network, etc.) are connected are shown in Figure 7.15 to Figure 7.20

Circuit A

This circuit is problem-free because the pressure drop across the storage tank is low. Producer and consumer are hydraulically perfectly decoupled (Figure 7.15).

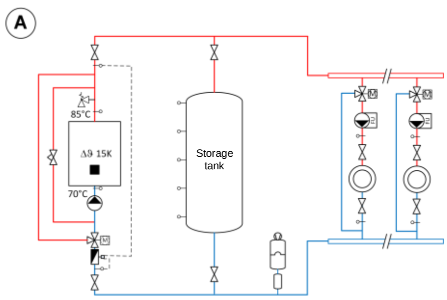


Figure 7.15 Hydraulic integration of heat storage tank - circuit A.

Circuit B

The storage tank is installed far away from the heat generator and distributor (Figure 7.16). The pressure drop Δp across the capillary and the storage tank causes an unacceptably high fluctuation of the connection pressure difference of the low-pressure difference distributor of +Δp during charging and -Δp during discharging if the storage tank connection pipe is too long. With careful design of the control valves, experience shows that a maximum pressure difference fluctuation of about 3 kPa can be tolerated.

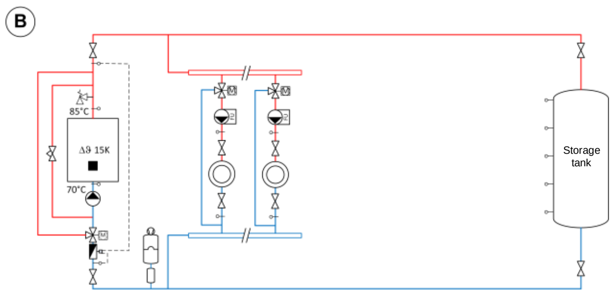


Figure 7.16 Hydraulic integration of heat storage tank - circuit B.

Circuit C

A distributor located far away presents difficulties because here the low-pressure difference distributor is pressurised according to the pressure drop across the long connecting pipes and the storage tank (Figure 7.17). At least here, in contrast to circuit B, the fluctuation of the connection pressure difference only occurs in one direction. The maximum connection pressure difference that can be tolerated can be answered as follows:

- The pressure drop across each control valve of the distributor must be greater than the connection pressure difference (valve authority ≥ 0.5); in existing distributors, experience shows that the pressure drop across the control valves is rarely greater than 3 to 5 kPa, therefore the connection pressure difference must also not be greater.
- Furthermore, the pressure drop over the long connection pipes must not be greater than 20 % of the

delivery head of the smallest group pump (prevention of interference between the groups at the distributor).

C

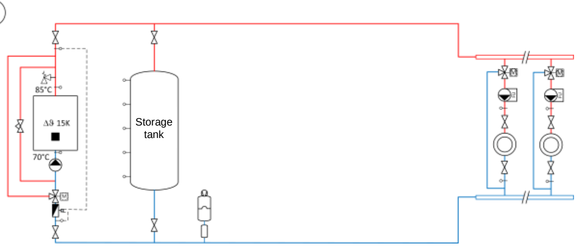


Figure 7.17 Hydraulic integration of heat storage tank - circuit C.

Circuit D

A capillary pump and a bypass in the distributor are unfortunately not a solution, because this causes an impermissible increase of the return temperature due to mixing (Figure 7.18).

D

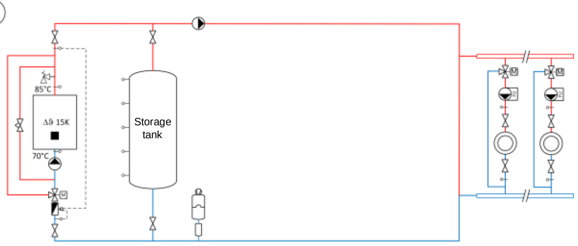


Figure 7.18 Hydraulic integration of heat storage tank - circuit D.

Circuit E

Alternatively, the storage tank can be installed as close as possible to the distributor; then the connection pressure difference of the distributor is sufficiently small (Figure 7.19). However, care must be taken that the control valve of the heat generator circuit is installed as close as possible to the heat generator (small dead time) and that the pressure drop across the control valve is at least as large as the pressure drop across the capillary and storage tank (valve authority ≥ 0.5).

E

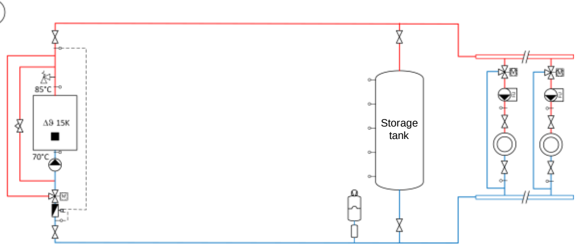


Figure 7.19 Hydraulic integration of heat storage tank - circuit E.

Circuit F

A solution that always works is an injection distributor with through valves, connected to a speed-controlled capillary pump (Figure 7.20). From a control point of view, it is most favourable if the pressure difference is measured as close as possible to the distributor, because this setpoint determines the valve authority of the control valves. It is expressly not recommended to attempt to control a low-pressure difference distributor to Δp = 0. Furthermore, a control to Δp < 10 kPa is not suitable, as a pressure difference in this range is already too high for a low-pressure difference distributor.

F

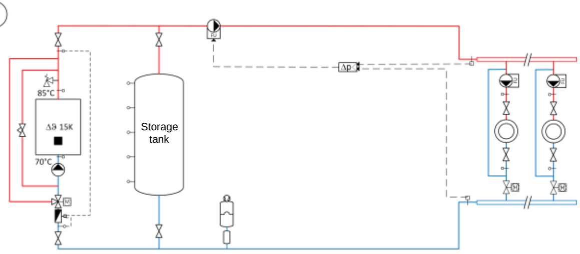


Figure 7.20 Hydraulic integration of heat storage tank - circuit F.

Additional variant hydraulic integration of storage tank with network separation heat generation/district heating network

A network separation between heat generation and heat network is necessary if high pressures in the district heating network, caused by large geodetic height differences, cannot be transferred to the hydraulic integration of the heat generation with storage (Figure 7.21). It is important to note that the gradient (temperature difference) across the heat exchanger between the primary return temperature of the heat generation and the secondary return temperature of the district heating network is a maximum of < 5 K at each operating point. The aim is to maintain a gradient < 3 K so that the storage capacity is not reduced by an increased primary-side return temperature for heat generation.

If the volume flow through the heat exchanger is too low, the gradient increases sharply due to strongly reduced heat transfer behaviour as a result of operation in the laminar flow range. The power allocation to the individual heat exchangers must therefore be carried out in such a way that a turbulent flow through the heat exchangers currently in operation is ensured at every operating point.

Furthermore, it must be ensured in terms of control technology that no short-term load peaks or load reductions occur when connecting and disconnecting heat exchangers on the primary side (heat generation). This is done, for example, by ramping up an additional heat exchanger to nominal transmission capacity, while the heat exchanger already in operation continues to be operated in parallel at nominal transmission capacity. If later the total transmission capacity is too high, the transmission capacity of both heat exchangers together is decreased. Any load peaks or load reductions that occur would also have to be compensated for by the storage tank. The heat transfer between the district heating network and heat generation must be carried out in such a way that the load curve on the primary side (heat generation) is identical to the load curve on the secondary side (heat network).

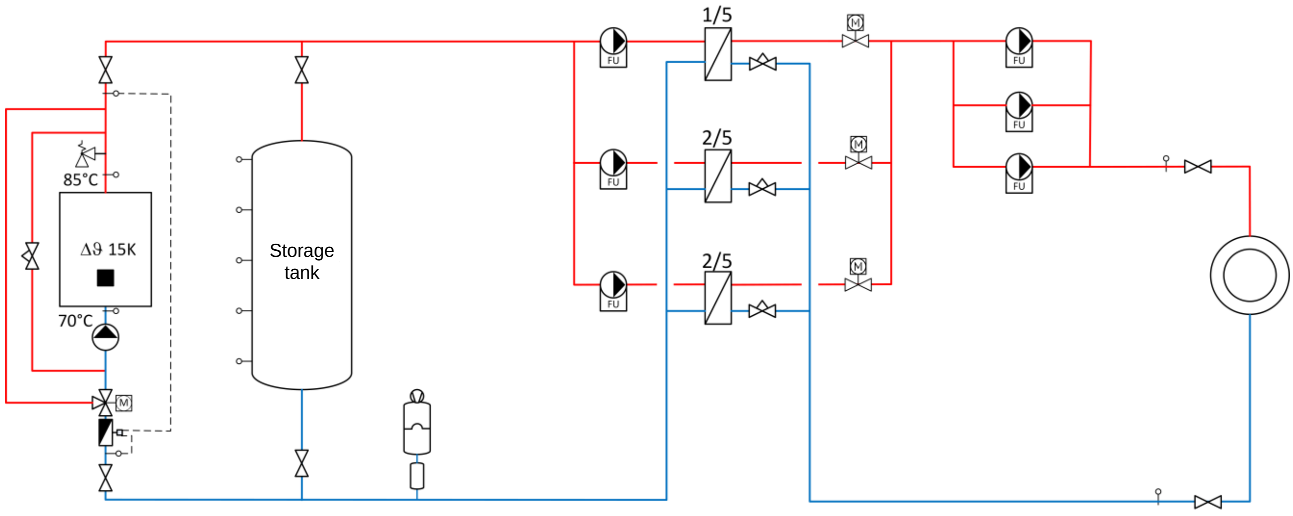


Figure 7.21 Network separation heat generation/district heating network with three heat exchangers.

7.6 Questions about heat generation hydraulics

7.6.1 Water quality

Attention must be paid to the quality of the water as a heat transfer medium in the hydraulic system of the heating system and the heating network for the following reasons:

- Prevention of corrosion: The oxygen content must not exceed the limit value specified in the directives and standards. By **systematically degassing the heating water during operation with a deaerator**, the oxygen content can usually be reduced below the limit value without chemical additives. If the oxygen content is too high, the pH value also falls below the limit value and the appearance of black magnetite particles indicates corrosion processes.
- Prevention of scale: If the total hardness or the calcium carbonate content is above the limit value, scale forms on the heat exchanger surfaces (boiler surfaces) of the heat generators. In case of heavy scale formation, this can cause localised overheating (hot spots), as scale impedes the heat transfer or the flow of heating water. This can damage the heat exchanger construction (boiler construction) when severe scale formation occurs.
- The **initial filling and replenishment of the hydraulic system of the heating plant and the heating network must be** carried out **with treated water in** accordance with the national guidelines and standards and the specifications of the boiler manufacturer.
- An **annual check of the heating water quality**, in which all limit values are checked in accordance with the directives and standards by means of water analysis, is necessary to ensure a constant high water quality.

The **requirements for** the circuit water basically differ depending on the operating temperature. A distinction is made between *warm water < 110 °C* and hot water > *110 °C.* For *hot water, a* distinction is also made between low-salt and high-salt operation. The size of the system, the water volume as well as guide values and requirements of the component manufacturers (fittings, control valves, heat exchangers, etc.) must also be taken into account.

More detailed information on water quality and requirements can be found in the Handbook on Planning of District Heating Networks (see [19] page 93ff). A comprehensive description is also provided by the AGFW regulation FW 510 [74] or the SWKI guideline BT102-01 [75]. Basically, the respective national standards and guidelines regarding water quality in heating systems and district heating networks, as well as the manufacturer's specifications, must be complied with.

7.6.2 Preventing mis-circulation

Heat generators that are switched off (biomass boilers, oil/gas boilers, etc.) are to be hydraulically separated from the overall heat generation so that faulty circulation can be avoided, which keeps the corresponding heat generator at operating temperature preventing undesired heat losses.

The following measures are to be implemented:

- Controlled closing of the three-way control valve in the heat generator circuit.
- Installation of automatic shut-off valves in the section with variable volume flow of the heat generator circuit.
- Prevention of single-pipe circulation by means of non-return dampers.

8 Plant components of heat distribution

8.1 Overview

Chapter 8 gives an insight into the basics of heat distribution and heat transfer to customers for thermal networks. The following topics are covered:

- Pipe systems
- Fittings
- Leakage monitoring
- Data transmission and communication
- Network structure
- Installation methods and situations
- Water quality
- Heat transfer

The topics listed above, however, are not dealt with in depth. For more detailed considerations, reference is made to the Handbook on Planning of District Heating Networks [19] and the Guide to Planning District Heating Transfer Stations [76]. As further literature, for example, the textbook District Heating and Cooling [77] or documents from relevant national associations (such as AGFW or VFS) can be recommended. Company and country specific requirements must also be observed.

8.2 Pipe systems

In the construction of local and district heating networks, pre-insulated pipes laid in the ground are almost exclusively used. The pre-insulated pipes consist of a carrier pipe in which the heat transfer medium is conducted, insulating material that reduces heat loss to the environment, and a jacket pipe that protects against mechanical damage. Additional elements such as data cables or leakage warning systems are usually integrated into the insulation of the pipe. The choice of the pipe system and the suitable installation technique depends on the network temperature and pressure as well as on requirements which are largely determined by site conditions. These are:

- Service lines
- Surroundings
- Buildings and/or constructions
- Roads
- Railway tracks
- Underpasses
- Groundwater
- Soil composition
- Tree population

Pre-insulated rigid steel pipes with a steel service pipe are the most commonly installed pipe system as they are standardised, robust, and inexpensive. Flexible pipe systems such as pre-insulated plastic pipes and pre-insulated flexible steel pipes are used mainly in the area of sub-distribution and house connections. Other possible pipe systems are steel jacket and fibreglass reinforced plastic (GRP) pipes (see [19] page 68 ff.).

For most of the pipe systems, **double pipe versions**, so-called duo pipes, are also available in the lower nominal diameter range. For special applications, the steel jacket pipe or the GRP pipe can also be designed in double or multiple pipe versions. Double pipe and multiple pipe systems have the following advantages over single pipe systems:

- Low laying costs (smaller trench width)
- Lower specific heat losses
- Halved number of socket joints
- Halved number of core hole drillings and wall seals for the house inlet
- Reduced number of stretching legs.

Double pipes with flexible steel or plastic pipes are particularly suitable for laying from house to house, as no branches have to be placed in the ground. When using double pipes with rigid steel pipes, exact information concerning branches must be available so that the necessary fittings can be used. Subsequent installation of a branch is of high effort. The pipe routing must be excavated precisely, as rigid steel double pipes are very stiff. Rigid steel double pipes are ideal for straight transport pipelines without branches and constant inclination of the pipeline route. In the case of subterranean pushing through (especially over long distances), a double pipe with a small diameter can be laid.

An overview of the individual pipe systems and their range of application can be found in Table 8.1.

8.3 Fittings

Fittings are installed as shut-offs. In this way, the interruption of network operation can be limited in case of later network extensions and possible repairs. In addition, valves are used for draining and venting the pipes. Valves have the following requirements:

- Low pressure loss
- Tight closure in both directions
- Tightness of the housing lead-throughs
- Low maintenance
- Low space requirement
- Low flow noise
- Interchangeability
- Insulating (thermal)
- Robust housing material
- Functionality even with infrequent use.

Individual requirements influence each other, therefore the most important criteria must be determined as required. It should be noted that shut-off valves are unsuitable for control purposes. In local and district heating networks, the four basic types of gate valves, globe valves, cocks and butterfly valves are used, depending on the nominal size, temperature and pressure conditions. The valves are installed in the pipeline either by welding or by means of flange connections.

The Handbook on Planning of District Heating Networks deals with the fittings in more detail (see [19] page 75 ff.).

Table 8.1 Overview of pipe systems [19].

Pipe system	Scope of application				Available lengths			
	Maximum permissible operating temperature	Continuous operating temperature	Nominal pressure PN	Nominal diameter DN	Bars	Rollers	Double pipe design up to DN	Special feature
	°C	°C	bar	- –	m	m	- –	- –
KMR	< 160	< 140	< 25	20 - 1,000	6/12/16*	- –	DN 150	The most frequently used pipe system due to its standardisation and robustness
MMR	< 180	< 160	< 25	20 - 150	12*	< 1,000	DN 50	Relatively expensive; use when installation conditions make it necessary
PMR	< 95	< 80	< 6	20 - 150	12*	< 780	DN 65	Relatively favourable; limited pressure and temperature resistance (in some cases massive restriction of life expectancy if maximum permissible operating temperature is exceeded). Below 70°C continuous operating temperature, however, life expectancy up to 100 years.
GRP	< 160	< 160	< 16	25 - 1,000	6*	- –	- –	Relatively expensive; only for special corrosion resistance requirements
SMR	< 400	< 400	< 64	25 - 1,200	16*	- –	**	Relatively expensive; only if pressure, temperature or installation conditions make it necessary.

KMR = Rigid steel pipe (pre-insulated with plastic casing and steel carrier pipe)
MMR = Flexible pipe with plastic casing and steel carrier pipe (corrugated or smooth)
PMR = Flexible pipe with plastic casing and plastic carrier pipe (e.g. PEX)
GRP = Rigid plastic casing pipe with a glass-fibre reinforced plastic carrier pipe
SMR = Rigid steel pipe with steel casing and steel carrier pipe
* Standard length/s, other lengths available on request.
** Special versions possible on request (e.g. multiple tube version)

8.4 Leakage monitoring

District heating networks can be designed with or without leakage monitoring equipment, depending on the installation technology and pipe system. Operational experience has shown that continuous monitoring with central leak detection increases the supply reliability of a network and can thus minimise the time and economic impact of damage. For this reason, a leakage monitoring system is generally recommended. The district heating network should be monitored continuously at designated measuring points.

Leakage monitoring is considered state of the art for plastic casing pipes with steel pipes [78]. For plastic medium pipes, leakage monitoring is usually not available as standard. For sewer installation, visual manhole inspection is considered sufficient; if necessary, automatic manhole monitoring equipment should be used. Overground pipes are usually operated without monitoring systems.

The leakage monitoring systems used today measure either the electrical resistance of the thermal insulation between two cores or between a core and the service pipe (measurement during operation should be taken at > 1 megohm). If there is moisture penetration of the thermal insulation or the indicator, the resistance decreases. By using two cores, a monitoring loop can be formed. Monitoring this loop ensures that the entire circuit is monitored. When selecting the leakage monitoring system, it is important to ensure that the measuring principle enables early detection of damage, for example moisture penetration into the insulation due to damage to the outer jacket or the carrier pipe as well as its precise location, so that maintenance work can take place immediately. The leakage measurement must be integrated into the control technology, visualisation and continuous data recording.

The Handbook on Planning of District Heating Networks deals with leakage monitoring in depth (see [19] page 73 ff.). Three different systems are presented (Nordic, Brandes and indicator system) and compared on the basis of various criteria (sensor wires, measuring method, error detection, display tolerance, monitoring possibility and length of the monitoring sections).

8.5 Data transmission and communication

When constructing district heating systems, the integration of data and leakage monitoring systems is now state of the art and should be implemented everywhere, regardless of the size of the system. These enable simple, secure and efficient billing, central fault recording and the possibility of optimising customer systems and the detection of defects (e.g. drifting of the primary return temperature).

The simplest solution for smaller systems is to control or regulate customers with individual controllers. For medium-sized and larger systems, a centralised monitoring option should also be considered (e.g. control system or remote reading). Through the constant exchange of data, the processes in the entire district heating network are made transparent and the remote adjustment of all system parameters of each individual transfer station is possible. From any location (e.g. via notebook or mobile phone), customers can be supported in adjusting the systems. By recording the individual heat meters and transferring the measured data to a central device, it is no longer necessary to read the meter on site.

8.6 Network structure

The term district heating network or heat distribution network refers to the link between heat generation and heat consumers. The choice of network structure, route, pipe system and installation method is influenced by numerous factors. Not only settlement structure but also technical, geological, economic and safety-related aspects, as well as architectural and legal issues are decisive. The catchment area and size of a heat distribution network are usually not fixed from the outset, but develop over time.

The heat distribution network is usually divided into main, branch and house connection pipes (see Figure 8.1). The main pipe corresponds to the first pipe from the central heating plant. In addition, the term branch pipe or, in the case of large heat generators that are located far away from the supply areas, the term transport pipeline is also used. Branch or distribution pipes come off the main pipelines and are used for sub-distribution to the individual supply areas. The house connection pipes are used to connect a customer to a main or branch pipe.

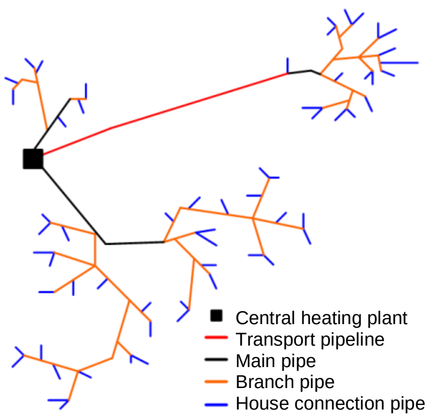


Figure 8.1 Network structure and pipe types [19].

Heat distribution networks are almost exclusively designed as closed **two-pipe systems** (one supply and one return pipe). Occasionally they are designed as **three-pipe or four-pipe systems** with several supply and return lines, which are operated at different temperature levels, for example.

In addition to the differentiation according to the number of pipes, the **structure of the heat distribution network** is influenced by the number of central heating plants as well as the number and location of the individual supply areas. Depending on the situation and development of the heat network, the heat distribution network has a tree structure, a ring connection or a mesh.

For the **sub-distribution** and the connection of the heat consumers, a basic distinction is made between standard routing, house-to-house routing and single-loop routing.

The network structure is described in detail in the Handbook on Planning of District Heating Networks (see [19] page 71 ff.).

8.7 Installation methods and situations

Pipeline laying is basically carried out according to the following **methods**:

- Above ground on pedestals or pendulum supports
- Underground in canals
- Underground in trenches
- Underground with trenchless methods
- Special cases (culverts, bridges, etc.)

The installation method depends on various factors. The most important are the pipe system used and the situation on site. Commonly encountered **installation situations** are:

- Paved (public road area, urban areas, etc.) or unpaved surfaces (rural areas, cultivated land, etc.).
- Terrain sections with existing infrastructure (railway lines, bridges, watercourses, motorways, etc.)
- Terrain with existing cables or pipes (electricity, gas or water)
- Subsequent connection to existing pipes

Depending on the situation, corresponding regulations, authorisations, concessions, etc. must be observed. The long-term operation and safety of the installed pipeline should not be underestimated and a risk analysis during planning is recommended

Civil engineering and pipeline construction are not dealt with in this Planning Handbook. Reference is made here to the Handbook on Planning of District Heating Networks, which deals with these topics in detail (see [19] page 73 ff.).

8.8 Water quality in the heating network

In order to avoid damage by corrosion, erosion or material overstressing in the systems, the circulating water in the heat distribution network must meet certain requirements.

More detailed information on water quality and requirements can be found in chapter 7.6.1and in the Handbook on Planning of District Heating Networks (see [19] page 93 ff.). A comprehensive description is also provided by [74] and [75]. Basically, the respective national standards and guidelines regarding water quality in heating systems and district heating networks and the manufacturer's specifications must be observed.

8.9 Heat transfer

8.9.1 Customer connection

The consumer's installation can be connected to the district heating network in two ways:

- Direct connection without intermediate heat exchanger
- Indirect connection with intermediate heat exchanger

In the case of **direct connection**, the heat transfer medium from the district heating network flows through the consumer's installation. When selecting the material, the chemical properties of the heat transfer medium must be taken into account. If the network pressure is higher than the permissible pressure of the consumer's installation, the direct connection must be made with pressure reduction and protection. In principle, the pressure in the return flow of the district heating network must always be lower than the permissible pressure in the consumer's installation. The maximum flow temperature in the district heating network is determined by the maximum permissible flow temperature of the consumer's installation.

With **indirect connection**, the primary heat transfer medium does not flow through the consumer's installation, but is hydraulically separated from the secondary heat transfer medium by a heat exchanger. The primary side must be designed and secured for the maximum temperatures and pressures of the district heating network, the secondary side for the in-house pressures and temperatures.

8.9.2 Requirements for heat transfer

The requirements for the execution of the heat connection are set out in the **Technical Connection Requirements (TCR)**, which are part of the heat supply contract. These serve as specifications for technical requirements in the planning, implementation and operation of the heat supply. The aim of the TCR is to achieve a minimum technical standard, to guarantee the quality of the heat supply and to prevent gross errors and defects. It also specifies whether the connection to the district heating network is made with a direct or indirect house connection.

The TCR should be short, concise and clear without specific reference to standards (which must be observed in principle). The TCR should also provide realistic specifications with regard to return temperature, temperature, pressure losses, materials, etc. and only specify products where necessary (e.g. heat meters, valves, controls, etc.). In the TCR, clear specifications should be given to the secondary side, such as impermissible hot water heating or hydraulic devices. The structure of the TCR can be as follows:

- General information
- Technical basics
- Equipment specifications
- Integration secondary side
- Operational requirements
- Supplements.

Further notes and detailed information on the contents of the TCR listed above can be found in the Guide to the Planning of District Heating Transfer Stations [76] and in the AGFW Leaflet FW 515 Technische Anschlussbedingungen - Heizwasser (technical connection conditions - heating water) [79].

As a **minimum requirement,** a district heating transfer station should be user friendly and allow easy service and maintenance and must comply with the technical connection regulations of the heat supply company as well as with the relevant standards and guidelines. In the guideline for the planning of district heating transfer stations [76] the following minimum components are defined (see Figure 8.2):

1. Shut-off valves in the supply and return lines
2. Visual display of temperature (thermometer) in the supply and return lines
3. Visual display of pressure (manometer) in the supply and return lines
4. Venting in the flow (top) and draining in the return (bottom)
5. Dirt trap in the flow before the heat exchanger (primary side) and dirt trap in the return before the heat exchanger inlet (secondary side)
6. Heat exchanger
7. Combination valve including drive

8. Heat meter (volume and temperature measurement, calculator, temperature sensor in flow and return)
9. Safety valve, spring-loaded
10. Expansion vessel (pressure maintenance)
11. Control unit for flow temperature secondary side
    - Temperature sensor in the flow on the secondary side
    - Temperature sensor in the return on the primary side
    - Temperature sensor for outside temperature (if weather-compensated)
    - Connection to the combination valve
12. Outdoor temperature sensor.

The guidelines for planning district heating transfer stations [76] provide basic recommendations for the design of the most important components, set requirements for the heat delivery system and for the hot water heating in the connection property (secondary side), and describe the procedure in the planning and operation of the system.

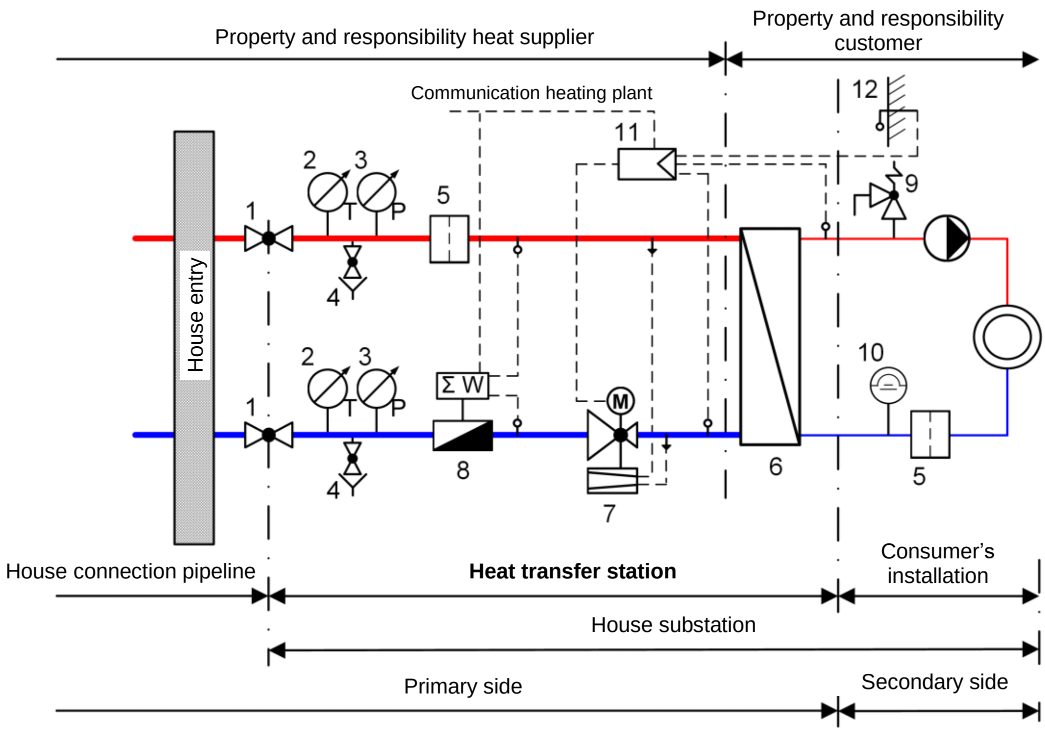


Figure 8.2 Minimum requirements for district heating transfer station [76].

9 Ash

9.1 Ash accumulation

When wood fuels are used to generate energy, wood ash is produced in various quantities and qualities. These must be disposed of or recycled in an environmentally sound manner to protect water and soil. In terms of quantity, the wood ash produced during wood combustion is in the order of 0.5 to 8 percent of the weight of the wood input. The lowest percentage of ash is found in pellets. The best pellet quality (ENplus A1) has a maximum of 0.7 percent ash by weight. When using wood fuels with a high bark and needle content and many impurities or waste wood, the ash content can be up to 8 percent by weight. As a guideline, it can be assumed that the annual ash accumulation per MW nominal boiler output is about 10 t/a to 20 t/a when using wood chips with bark, and about 8 t/a to 15 t/a when using wood chips without bark [80]. Table 9.1 shows the annual ash production from wood-fired systems in Austria, Germany and Switzerland. Due to the increased use of wood as an energy source, these quantities will increase in the future.

Table 9.1 Ash production in tonnes dry matter per year [t dry matter/a] from wood-fired systems in Austria (2017), Germany (2015) and Switzerland (2018); sources ([81], [82], [83]).

Country and origin of the ashes		Ash accumulation t TS/a
Austria total		254,000
Germany total		> 1,000,000
Switzerland total of		72,000
which:	Plants < 50 kW	18,000
	Grate ash plants > 50 kW	41,000
	Cyclone fly ash plants > 50 kW	9,000
	Filter ash plants > 50 kW	4,000

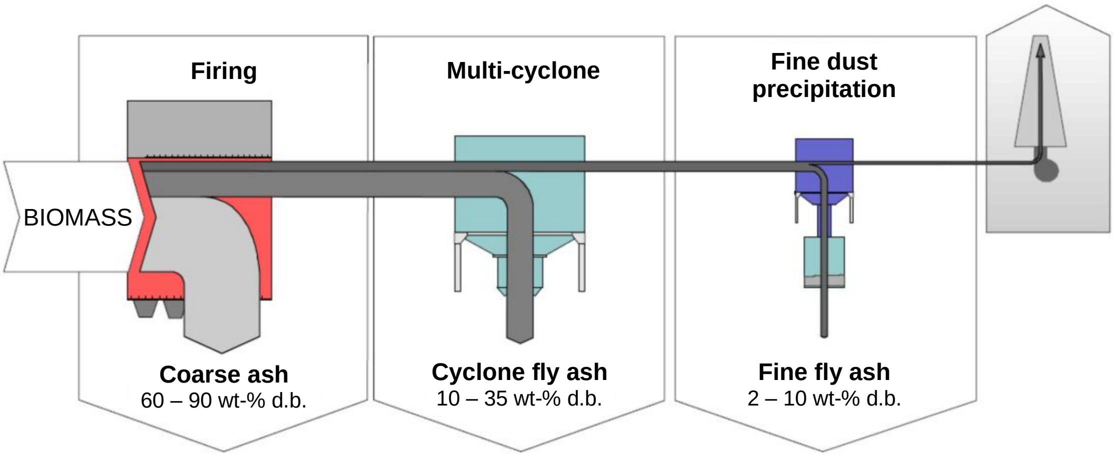


Figure 9.1 Proportions of the different ash fractions in percent by weight (dry base) [81].

9.2 Ash fractions

Location of ash accumulation

In larger automatic wood firing systems, a distinction is made between the following fractions based on the location of the ash accumulation and the particle size (see Figure 9.1):

- Coarse ash (grate ash, boiler ash, bed ash)
- Cyclone fly ash (cyclone ash, fly ash, boiler fly ash)
- Fine fly ash (filter ash).

Grate ash

The proportion of coarse ash (in the case of fluidised bed furnaces, this is referred to as bed ash) is between 60 and 90 percent of the total weight of ash produced. Coarse ash is produced in the combustion section of the furnace and is a predominantly mineral residue. Depending on the type of fuel and the degree of contamination, this ash fraction is often interspersed with foreign material such as sand, soil and stones, which increase the proportion of coarse ash. In the case of waste and residual wood, a notable coarse ash fraction is mainly due to impurities in the form of nails, hinges, cement residues, etc. These non-combustible parts are also mainly separated as bottom ash. In contrast, volatile components such as heavy metals and salts are increasingly transferred into the gas phase and therefore accumulate in increased concentrations in the cyclone and fine fly ash. The burnout quality also has a major influence on the proportion of coarse ash. One indicator of this is the TOC content ("Total Organic Carbon") of the ash. A high TOC content means a large quantity of unburnt material and makes certain recycling paths (e.g. cement industry) or landfilling impossible. For the latter, country-specific TOC limits apply. Coarse ash also includes the ash and deposits that accumulate in the combustion chamber and boiler during periodic cleaning of the combustion plant.

Impurities in the fuel (waste wood) cause a reduction in the temperature of the ash melting point. This leads to slagging and caking on the grate and walls as well as too high combustion chamber temperatures. When cooling down, the caking becomes glass-like and is difficult to remove.

Cyclone fly ash

Between 10 and 35 percent of the weight of the ash accumulates as cyclone fly ash. This consists of solid, predominantly inorganic fuel components that are carried in the flue gases and accumulate in the cyclone separators (multi-cyclone separators, centrifugal separators) downstream of the boiler. The particle size of cyclone fly ash is large enough that it can still be separated with heavy or centrifugal force (see chapter 5.8).

Fine fly ash

Fine fly ash has a content of 2 to 10 percent and has such small particle sizes that it behaves like a fluid and is carried with the exhaust gas flow. It can therefore only be separated with mechanical or electrostatic particle separators (electrostatic precipitators, fabric filters) or scrubbers, which are installed downstream of the boiler and the cyclone separator. In scrubbers (flue gas condensation), the filter ash accumulates as condensation sludge.

9.3 Ash composition

The composition of ash depends on the type of fuel used, the burnout quality and the place where it develops. Ash from untreated wood consists mainly of minerals, alkali metals and salts. Phosphorus and potassium are contained in relevant amounts as nutrients (see Table 9.2). In addition, there are numerous other relevant substances such as calcium and magnesium as well as trace elements such as manganese and sulphur.

Table 9.2 Proportions of relevant nutrients in different ash fractions from the combustion of untreated wood in percent by weight of dry matter [84].

Nutrients	Grate ash [wt-%]	Cyclone ash [wt-%]	Filter ash [wt-%]
Calcium CaO	32 - 48	25 - 46	25 - 40
Magnesium MgO	5 - 7	3 - 5	3 - 4
Potassium K2O	4 - 8	4 - 9	7 - 21
Phosphorus P2O5	2 - 5	2 - 5	2 - 4
Sodium Na2O	< 1	< 1	1 - 2

However, ash also contains relevant pollutants such as the heavy metals arsenic, lead, cadmium, chromium (as total chromium or chromium III and as chromium VI), copper, nickel, mercury and zinc (see Table 9.3). These are found in particularly high concentrations in the finest fly ash and are highest in waste wood. But also grate ash from the combustion of untreated wood contains heavy metals. These were absorbed by the tree during its life through the roots and are found in concentrated form in the ash. In the case of waste wood, the heavy metals originate from fittings, paints, coatings and foreign substances in the fuel. Ash from wet electrostatic precipitators has significantly higher heavy metal contents than that from dry electrostatic precipitators.

Chromium-VI is one of the most toxic heavy metals. This is absorbed by the tree from the soil as chromium-III and oxidised to chromium-VI in the thermal process when the wood is burnt. This oxidation occurs largely independently of the wood assortment used and is practically not influenced by combustion measures. In contrast to chromium-III, chromium-VI is highly water-soluble, highly toxic, mutagenic and carcinogenic. For this reason, care must be taken when handling wood ash to avoid dust formation and to use appropriate personal protective equipment.

Chromium-VI plays only a minor role in coarse ash from plants that have a wet ash removal system, since the chromium is predominantly present as chromium-III.

Figure 9.2 Dust-free depositing of wood ash into a landfill (source: Amstutz Holzenergie AG/Holzenergie Schweiz).

Under certain conditions, the ageing of the ash together with the addition of water turns the chromium-VI back into chromium-III. However, this process needs space and time and can be accelerated by adding reducing agents such as iron-II sulphate.

Table 9.3 Typical heavy metal contents in mg/kg dry matter of ash from the combustion of different wood fuels and different ash fractions. For fine fly ash, only ash from dry electrostatic precipitators was considered ([84], [85], [86]).

Heavy metal	Natural wood			Waste wood			Waste wood		
	Coarse ash	Cyclone fly ash	Fine fly ash	Coarse ash	Cyclone fly ash	Fine fly ash	Coarse ash	Cyclone fly ash	Fine fly ash
Antimony Sb	< 10	< 10	< 10	10 - 31	< 30	n.a.	10 - 790	n.a.	50 - 810
Arsenic As	< 1	n.a.	< 15	n.a.	n.a.	59 - 140	13 - 41	< 60	20 - 290
Lead Pb	2 - 45	10 - 70	33 - 266	6 - 350	180 – 1,182	n.a.	10 – 2,144	< 8,500	< 50,000
Cadmium Cd	1 - 6	21 - 36	3 - 81	3 - 30	16 - 30	n.a.	10 - 100	< 70	5 - 590
Chromium Cr total	12 - 325	127 - 189	101 - 332	72 - 747	78 - 212	n.a.	109 - 873	< 1,415	< 404
Chromium Cr-VI	3 - 14	n.a.	4 - 47	7 - 13	n.a.	42 - 66	3 - 66	n.a.	3 - 62
Copper Cu	100 - 996	120 - 350	84 - 630	< 372	< 288	< 820	170 – 2,800	n.a.	< 422
Nickel Ni	42 - 80	10 - 79	28 - 99	∅ 113	∅ 61	n.a.	23 - 412	∅ 167	∅ 74
Mercury Hg	< 0.05	< 0.1	< 3.5	< 0.5	< 0.7	n.a.	< 0.5	n.a.	< 1.0
Zinc Zn	22 - 738	1,271 – 2,469	22 – 25,177	∅ 503	∅ 3,656	n.a.	1,234 - 22,000	∅ 15,667	∅ 164,000

The different composition of the various ash fractions influences not only their recycling possibilities, but also the type and costs of their disposal. Different framework conditions apply in the various countries. “Today's waste is tomorrow's raw material”! With a view to future recycling, it is therefore recommended that the three ash fractions be collected separately in new, larger plants or that provisions be made for subsequent ash separation (see chapter 6.8).

However, the current and future utilisation possibilities depend strongly on the quality of the ash. This can be positively influenced during plant operation as follows [87]:

- Use of the correct fuel adapted to the firing system
- Avoiding impurities in the fuel
- Setting firing system parameters correctly (too much primary air leads to slag formation, too little primary air increases the unburnt fuel content).
- Reduction of grate temperature (water cooling, primary exhaust gas recirculation)
- Continuous operation without rapid load changes
- Correct storage at the heating plant.

9.4 Disposal and recycling

Wood ash can basically be disposed of or recycled. The following options are available for disposal ([81], [82], [88]):

- Depositing in a landfill
- Backfilling of mines (can also be seen as a form of recovery because of the stabilisation effect).

The following options are available for recycling:

- Industrial use (e.g. as aggregate or raw material) for cement and concrete
- Recycling in road construction
- Use as agricultural fertiliser
- Addition to compensatory liming in the forest
- Recovery of valuable substances

The prerequisite for **industrial use** in the cement industry is that sufficient quantities are produced in consistent, high quality. Therefore, only very large combustion plants can be considered for this purpose. It is important that the ash fractions are collected dry and separately. Foreign particles, impurities and a high proportion of unburnt material make it impossible to use them in the cement industry. Less demanding in this respect is the utilisation in the production of some concrete assortments (“lean concrete”).

In principle, wood ash can be used as a base material in **road construction**, as long as the locations are outside water protection areas and hydro-geologically sensitive zones, as well as flood plains. The ash is deposited underneath a water-impermeable surface layer of asphalt or concrete and serves as an unbound base layer (frost protection layer or gravel base layer), as a bound base layer (hydraulic or bituminous) or as a road embankment (substructure). During installation and handling, dust formation must be avoided for health and safety reasons.

Due to the fact that wood ash contains plant nutrients (see Table 9.2) and thus presents fertilising properties, it is excellently suited as an **agricultural fertiliser**. Because of its heavy metal content, only coarse ash from the combustion of untreated wood is suitable for this purpose. In combination with organic components (compost, fermentation products), organic-mineral fertilisers can be produced that can also be used in organic farming. In times of climate change, potassium (K_2O) as a “drought-resistant element” and lime (CaO) as a basic requirement for the absorption and storage of water are of particular importance. A condition for use in agriculture is strict quality assurance, such as the RAL quality label in Germany. The use as agricultural fertiliser is subject to country-specific regulations, which in some cases differ significantly from one another (see chapter 19).

In Baden-Württemberg, the use of wood ash as an **admixture to compensatory liming in the forest** has recently been established. The maximum ash content in the mixture may not exceed 30 %, 70 % is dolomitic lime. Within 15 years, a maximum of 2.5 tonnes of ash per ha may be applied. Here, too, only quality-assured bottom ash from the combustion of untreated wood is permitted.

Analogous to the slag from waste recycling plants, wood ash will also be used in the future for the **recovery of valuable substances**. Projects are underway in various countries (e.g. recovery of zinc from fine fly ash from waste wood furnaces).

The recovery and disposal paths of wood ash depend very much on national laws, directives and regulations and are sometimes complex. The situation in selected countries is discussed below. The regulations mentioned can also be found in collected form in chapter 19.

9.4.1 Situation in Switzerland

In Switzerland, the focus is currently on disposal. The corresponding Waste Ordinance [89] provides for the landfilling of wood ash according to Figure 9.2.

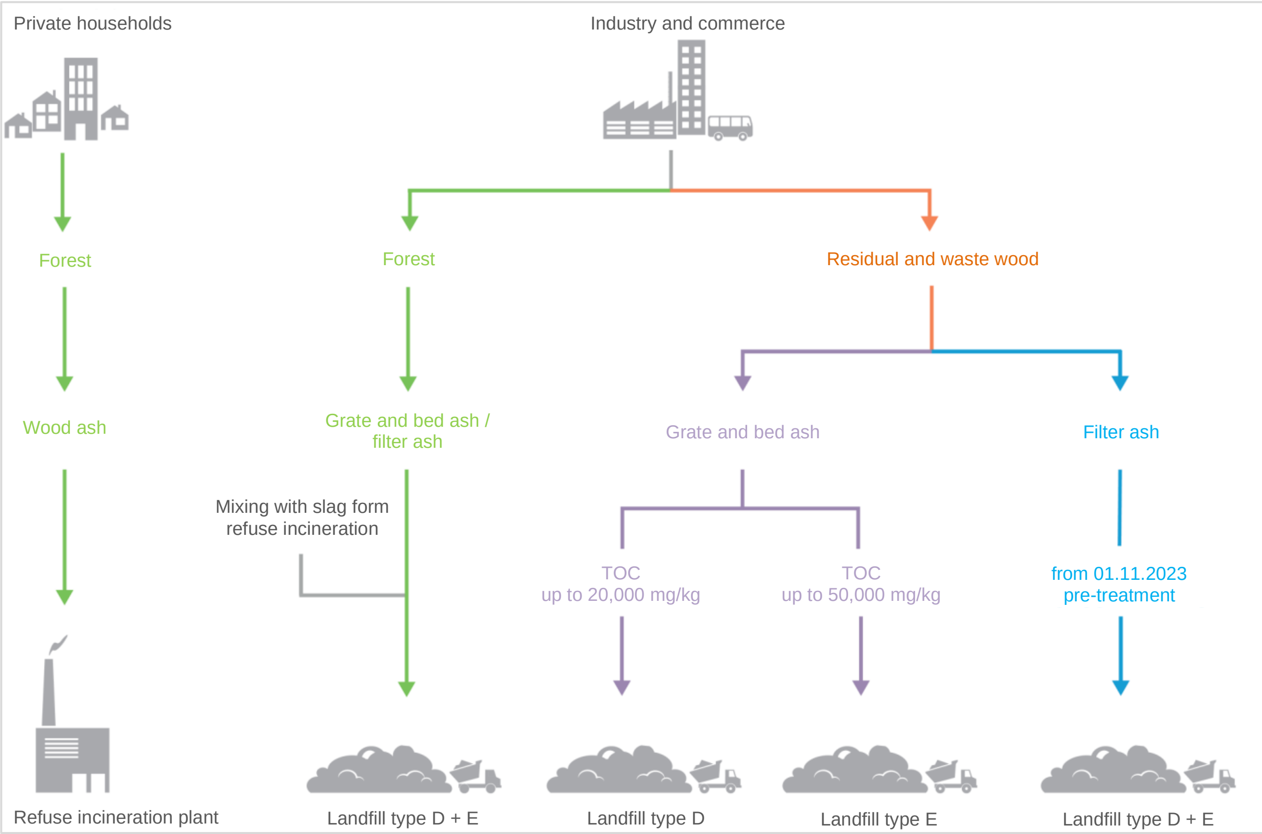


Figure 9.2 Disposal paths in Switzerland (TOC ... total organic carbon, landfill types according to Swiss Waste Ordinance) [89].

Wood ash from small plants should be disposed of in a refuse incineration plant. Grate, cyclone and filter ashes from the incineration of forest and residual wood in larger plants are to be disposed of in type D and E landfills. Rust ashes from the incineration of waste wood are also to be disposed of at landfill types D and E. As slag from waste incineration containing large amounts of free iron, is also disposed of at these two landfills, the chromium-VI is quickly reduced to chromium-III if it is well mixed. At the Type D landfill, ash must comply with a maximum TOC limit of 20,000 mg/kg; at the Type E landfill, the TOC limit is 50,000 mg/kg. According to the Waste Ordinance, filter ash from the incineration of waste wood will have to be treated as of 1 January 2026 (heavy metal recovery).

This enforcement will be regulated in detail in the future enforcement aid “Incineration residues, Part II, wood ash” of the Federal Office for the Environment (FOEN). It will also define the performance limit above which disposal in landfills is required.

Recycling as agricultural and forestry fertiliser is not possible due to current regulations. Industrial utilisation is only beginning to take place. One reason for this is the relatively small average capacity of the Swiss plant fleet. For this reason, efforts are currently being made to set up regional pooling systems.

9.4.2 Situation in Germany

In Germany, the Bundesgütegemeinschaft Holzasche e.V. (Federal Quality Association for Wood Ash) began around 2010 to set up a quality assurance system for coarse ash from untreated wood fuels (waste code number 100101 according to the Waste Catalogue Ordinance [90]). The aim is to classify wood ash according to plant nutrients such as phosphorus, potassium and magnesium as well as basic active substances and at the same time comply with pollutant limits, especially for heavy metals.

The basis of the quality assurance system is the so-called “Quality Management Manual” for wood ash as a raw material for fertiliser and as fertiliser. Qualified wood ash receives the RAL quality label “Fertiliser” (RAL-GZ 252) after a successful recognition procedure and then remains permanently in the monitoring procedure (see www.holzaschen.de).

The label is awarded by the Bundesgütegemeinschaft Holzasche e.V. as an independent institution under the Bundesgütegemeinschaft Kompost (BGK). In addition to ash from untreated wood, suitable ash fractions from other biomass fuels such as straw can also obtain the label RAL-GZ 252 (www.kompost.de).

The quality assurance of wood ash aims to implement recycling economy concepts within the framework of the relevant provisions of waste law (KrWG [91], BioAbfV [92], DepV [93]) and fertiliser law (DüMV [94], DüngG [95], DüV [96]). Quality-assured wood ash replaces mineral fertilisers in conventional and organic agriculture, maintains lime in forests and thus contributes to a sustainable and resource-conserving bioeconomy. Waste that is subject to disposal is thus transformed into a valuable product. Economic aspects play a decisive role here. The additional personnel and financial costs of quality assurance are offset by revenues for the fertilisers produced and savings in previous disposal methods, e.g. landfilling. Lime works (mineral fertiliser) and composting plants (organic-mineral fertiliser) that have a permit in accordance with the Federal Immission Control Act (BImSchG) are predestined to accept, process and refine wood ash.

Professional landfilling is still the most common disposal path in Germany for coarse ash from plants with untreated wood (AVV 100101 according to the Waste Catalogue Ordinance [90]). As a rule, these are landfills of class DK II according to DepV for contaminated but non-hazardous mineral waste, whose operators are certified specialised waste management companies. Before the ash is handed over to an authorised transport company or in the case of direct delivery to the landfill, a declaration analysis must always be submitted by the waste producer. This is prepared by a specialised laboratory on the basis of a material sample taken by professional sampling on site. The parameters to be determined, such as heavy metals, dissolved solids and glowing residue (max. 5 %), are regulated by the Landfill Ordinance.

Filter dusts from plants with untreated wood (AVV 100103 according to the List of Wastes Ordinance [90]), if they are cyclone fly ashes, can be deposited in surface landfills in individual cases, depending on the analysis of the material and the respective approval of the landfill. This does not apply to hazardous waste fractions marked with * in the AVV (e.g. AVV 100118 Waste from waste gas treatment containing hazardous substances according to the Waste Catalogue Ordinance [90]). Such fine fly ash from electrostatic precipitators or fabric filters contain significantly more pollutants and can only be deposited in underground landfills (DK IV), e.g. in mine backfill. Locations of above-ground DK III hazardous waste landfills are extremely rare in Germany. In Bavaria, there is currently only one facility in the Augsburg area. Waste producers and transporters of hazardous waste are obliged to provide verification in accordance with the Ordinance on Waste Recovery and Disposal Records (NachwV [97]).

The use of ash from biomass combustion plants in the cement and building materials industry (“wood ash concrete”) is currently being tested at the University of Stuttgart, among other places. Important questions are the durability and strength of the concrete, always in accordance with the relevant DIN standards and conformity criteria.

9.4.3 Situation in Austria

In Austria, ashes from wood (plants) are generally considered waste. The provisions of the Landfill Ordinance 2008 are decisive for landfilling. Grate ash and cyclone fly ash (after lowering the pH value) can be deposited in landfills for non-hazardous waste (residual waste or bulk waste landfill) if the heavy metal content is below the legal limits [98]. If the heavy metal limits are exceeded, landfilling is only permitted at landfills for hazardous waste (underground landfill). Currently, a large part of the wood ash produced in Austria is landfilled. Where appropriate opportunities are available, wood ash is also supplied by disposal companies to the cement industry as an aggregate, which reduces disposal costs.

The utilisation of wood ash as fertiliser on agricultural or forestry land is possible under certain conditions. However, wood ash utilisation is currently not explicitly regulated by legal provisions in Austria. Therefore, several laws and ordinances must be observed:

- Waste Management Act 2002
- List of Wastes Ordinance 2003 (identification key for record-keepers)
- Waste Balance Ordinance (record-keeping obligation)
- Contaminated Sites Remediation Act
- Compost Ordinance
- Fertiliser Act
- Forestry Act (spreading in the forest)
- Water Rights Act
- Fertiliser bans within the framework of the nature conservation laws of the federal states
- Soil protection laws of some federal states

Which of these laws and ordinances must be observed in individual cases, or whether other regulations not mentioned above may apply, must be checked in each individual case. In the following, some generally applicable information on ash utilisation is presented [80].

In principle, coarse ash and cyclone fly ash are suitable for recycling as fertiliser, provided that the corresponding limit values regarding the ash composition are complied with. Mixtures of these ash fractions are only permitted for recovery if they already occur as a mixture and the composition of the mixture complies with the limit values. Filter ashes (fine fly ash) are generally not suitable due to their high heavy metal content.

Ash sampling is mandatory at regular intervals ranging from every 10 years to three times a year, depending on the nominal boiler output and intended use (agricultural/forestry). Based on the ash analysis, wood ash is classified by quality. Depending on the quality class achieved, wood ash can be spread on agricultural and forestry land without further testing (quality class A) or only with additional soil testing. Due to the Waste Balance Ordinance, there is an obligation to record the quantity, origin and whereabouts of the ash in the form of an annual electronic report. Wood ash used as fertiliser in agriculture must be taken into account in agricultural fertiliser management. When spreading, prescribed minimum distances from bodies of water must be observed.

For further information, [80] in overview and [99] in depth (incl. flowcharts for practical implementation with regard to required applications, records, etc.) are recommended.

10 Economic efficiency

10.1 Economic efficiency issues for biomass DH plants

Various questions arise when assessing the economic efficiency of biomass DH plants. The most important are:

- How high will the heat production costs be?
- How does the economic efficiency of the wood-fired heating plant compare to other energy systems?
- What heating prices can be offered to future customers?
- Which tariff structure should be chosen (connection fee/basic price/ energy price/meter charge)?
- What are the most significant economic risks?
- How should the economic development and changing framework conditions (e.g. fuel prices, declining heat sales due to thermal refurbishment and climate change, CO_2 pricing, political and social environment) be assessed over the operating time of the plant?

The choice of the appropriate method for the economic efficiency assessment depends on the question and the project status. In the early project phases (feasibility study), an estimate of the investment and heat production costs based on experience and guidelines is sufficient (see also chapter 3.2). The investment costs for heat generation and heat distribution can be estimated within the framework of a feasibility study using the diagrams in chapter 10.8. Later, the accuracy of the cost positions is increased by concrete offers and the sensitivity and economic development of the project is considered over the project duration. The following chapters show which methods are suitable and which tools can be used to answer the above questions. First, however, it should be clarified how the responsibilities are distributed between the project participants in the performance assessment.

10.2 Responsibilities

The main responsibility for assessing the economic efficiency of a biomass heating plant lies with the building owner. As a rule, the planner provides the building owner with reliable data regarding the economic efficiency of a wood-fired heating plant:

- Power and heat demand of the intended heat customers
- Energy content of the intended fuel assortment and information on possible expected follow-up costs (particularly important for low-cost fuel assortments).
- Investment costs
- Maintenance and repair costs
- Energy costs, consisting of fuel costs and auxiliary energy costs (demand or consumption-related costs).

The planner must be able to advise the client when carrying out the economic efficiency calculation. As an additional assignment, the planner can also carry out the economic efficiency calculation instead of the client. In any case, however, the client must decide which basic assumptions are to apply to the economic efficiency calculation. These include:

- Calculation interest rate
- Service life of the plant components
- Inflation rate (rate of price increase)
- Increase in operating costs
- Energy prices: For biomass DH plants, this also includes the choice of fuel assortment and the resulting fuel price.
- Increase in energy prices
- Development of the heat demand due to the rate of modernisation or expansion and densification of the heating network.

It is advisable to agree on these basic assumptions in writing.

If various customers are to be supplied with heat in a planned heating network, the responsibilities between the client and the planner are to be divided as follows:

Building owner

- Mainly responsible for the profitability calculation. Must check and critically question basic data necessary for calculation
- Responsible for deciding which potential customers to consider
- Responsible for deciding on assumed time of connection (influences time of investment costs incurred and expected income)

Planner

- Responsible for the reliable determination of the required heat capacity demand including the load profile and the expected annual heat demand of potential customers
- Responsible for determining the investment costs for the connection of potential customers

10.3 Cost structure of biomass DH plants

According to VDI Guideline 2067 [100], the following four cost groups are taken into account when determining the costs of technical building systems:

- Capital-linked costs (including repair and refurbishment/upgrading)
- Consumption-related costs
- Operational costs
- Other costs

Table 10.1 shows the allocation of the individual cost types to these cost groups for a wood-fired heating plant.

For individual cost types, the costs are estimated in the economic efficiency calculation on the basis of guideline values, for example as a percentage of the investment sum or the quantity of heat produced. It must be clearly defined which cost types are assigned to the individual cost groups. According to VDI 2067 [100], maintenance means the implementation of measures to preserve and restore the target condition and includes the cost types “repair”, “maintenance” and “inspection”:

- **Repair**: Measures to restore the target condition.
- **Maintenance**: Measures to maintain the target condition
- **Inspection**: Measures to determine and assess the actual condition

Table 10.1 gives an overview of the cost types and shows which basic data should be used for the calculation. In part, guideline values are also given. These can be used for the economic efficiency calculation according to the annuity method as well as for a budgeted balance sheet and a budgeted income statement. The planner must not accept the given standard values without checking them. Since the specific costs (e.g. given as costs/MWh) are partly dependent on the plant size and/or the number of full load operating hours, it must be checked for each individual case whether a guideline value can be used and how high it should be set. For Austria, the ÖKL-Merkblatt 67 [101] makes individual specifications. These are essentially minimum requirements that should not be undercut.

Table 10.1 Cost groups and cost types of a wood-fired heating plant. Basic principles and guideline values for determining the annual costs. It should be noted that - in deviation from VDI 2067 [100] - the costs for maintenance are included in the personnel costs. The figures in brackets () refer to ÖKL-Merkblatt 67 [101].

Cost group	Cost type	Basis for the determination of the annual costs	Reference values
Capital-related costs	Capital costs of fixed asset components and structural assets (investments)	Investment sums of the plant components, useful life, interest rate	Useful life: see Table 10.2: as specified by the developer or the funding institutions (funding according to [101])
	Maintenance costs (repairs according to VDI 2067 [100])	Investment sums of the plant components, percentage of the investment sum	See Table 10.2
Consumption-related costs	Fuel costs	Annual consumption and calorific value or fuel consumption, fuel price	Effective prices based on offers (additionally minimum price 23 € per MWh raw energy, based on calorific value H_u, according to [101]).
	Auxiliary energy (electricity) for heat generation and heat distribution	Percentage of heat (generated or distributed) x electricity price	for heat generation: 1 - 1.5 % of the heat generated for heating network: 0.5 - 1 % of the distributed heat quantity (min. 1.5 % related to the generated heat quantity; 2% for systems with flue gas condensation or electric separator according to [101])
	Operating materials for heat generation (e.g. for SNCR plants)	Price, quantity consumed	Estimate effective costs
	Ash disposal	Fuel input, ash content, disposal method	Estimate effective costs (possibly included in fuel price)
Operating costs	Personnel costs (for operation, cleaning, maintenance, inspection, without administration)	Percentage of investment costs, heat generation	by 1.5 % of the investment costs for heat generation (at least 2.5 - 5 € per MWh of heat generated according to [101])
	Rents, leases, concession fees	depending on the individual case	Estimate effective costs
	Chimney sweep, exhaust gas inspection, emission measurement	depending on the individual case	Estimate effective costs
Other costs	Insurance, taxes, general charges, administrative costs	Percentage of the investment sum	0.5 - 1.5 % of the total investment

The assumed useful life for the profitability calculation must be determined together with the building owner and possibly with potential funding institutions (banks, funding agencies, etc.). When determining the useful life, it should be noted that it is not necessarily dependent on the technical service life. The useful life is also influenced by changes in needs and technological developments. In addition, often several building elements are replaced at the same time during renovations - regardless of whether each element has reached the technical service life.

Table 10.2 Guide values for useful life and repair costs

Trade	Duration of use	Special maintenance costs
	Years	%
Wood-specific plant components*	20	3.0
Peak load specific plant components*	20	2.0
Hydraulics	20	2.0
Electrical and building services installations	20	2.0
Structural facilities and access	50	1.0
Main network (incl. pipelines and earthworks)	40	1.0
Heat transfer station	30	2.0
Vehicles	15	3.0
Planning**	averaged	-

* incl. regulation and control

** The averaged useful life for planning must be weighted with the planning costs for the individual trades or the planning costs must be allocated to the individual trades.

VDI Guideline 2067 [100] contains more detailed and partly deviating information on Table 10.2. For calculations according to VDI, the information from VDI Guideline 2067 must be used.

10.4 Economic efficiency calculation

10.4.1 Introduction

In the economic efficiency calculation, the heat generation and distribution costs, investment costs and costs for operation and maintenance are determined. In a comparison of variants, different heating systems or design variants can be compared in terms of their costs. The economic efficiency calculation is also the basis for pricing and the pricing of heat sales.

For a comparison of variants, the heat production costs of each variant should be determined in addition to the investment costs. The comparison of the heat production costs allows a full cost comparison over the useful life of the system. The calculation of the heat production costs according to the annuity method is often used in practice and is described in chapter 10.4.2.

In order to be able to assess the economic development of a heating network, the expenses and returns should be calculated over several years. For this purpose, the net present value method (NPV method) is very suitable, with which the effective (internal) interest rate (IRR) of the investment can be calculated. The economic efficiency tool of QM for Biomass DH Plants is based on the internal rate of return method (see chapter 10.7).

For the analysis of energy systems, which usually have a long useful life and where price increases and other future changes in the input data are therefore important, the use of **dynamic calculation methods** is recommended. In these methods, the changes expected in the period under consideration are estimated or specified using statistical mean values in order to be able to forecast the annual costs for the entire useful life of the system. **Static calculation methods**, on the other hand, only consider the conditions as they exist at the time of the profitability analysis. With observation periods of usually at least 15 years, this can result in significant deviations from dynamic methods. In many cases, simplified assumptions can be made for dynamic methods, so that simple sum formulas can be used for the economic efficiency calculation and the calculation effort is thus not significantly greater than for static methods.

The most important dynamic calculation methods are

- Net present value method
- Annuity method
- Net present value method.

10.4.2 Calculation of the heat production costs with the annuity method

The annuity method is usually used to calculate the heat production costs. This is described in detail in VDI Guideline 2067 [100]. The annuity method determines the average annual costs incurred in the period under consideration. The annual costs consist of capital, operating and energy costs. In the capital costs (I * a), interest is paid on the investment over its useful life (the life of the plant) and repaid. The operating costs consist of maintenance and personnel costs. The energy costs result from the expected energy consumption including auxiliary energy per energy source. The annual operating and energy costs A are added to the capital costs, taking into account their possible development (d * a).

Since the cost items relevant for the heat production costs depend strongly on the country/region, location, general conditions, construction method, wage structures, energy prices, interfaces, etc., the indication of guideline values is deliberately omitted. A comparison of the heat production costs with other solutions in the context of a comparison of variants is often more useful.

Calculation of **annual costs K**:

$$K = I * a + A * d * a$$

- K Annual costs [EUR/a; CHF/a]
- I Investment costs (per plant component) [EUR; CHF]
- A Annual operating costs [EUR/a; CHF/a] consist of:
  - Maintenance and repair costs
  - Energy costs (fuels and auxiliary energy)
  - Other costs
- a Annuity factor [-], calculated from:

$$\text{für } i = 0 : a = \frac{1}{n} \qquad \text{für } i > 0 : a = \frac{i * (1+i)^n}{(1+i)^n - 1}$$

  - i Calculation interest rate [%]
  - n Observation period [a] (useful life)
- d Present value or discount factor [-] calculated from:

$$d = \frac{(1+e)^n}{(1+i)^n}$$

- e Annual price increase [%]

The useful life and the repair costs can be determined according to Table 12.2. However, the assumed useful life can also be specified by the building owner, a lending institution (bank) or a possible funding agency.

In many cases, the following simplifications are possible compared to the method described in detail in VDI 2067:

- The investments only occur at the beginning of the period under consideration.
- The period under consideration corresponds to the lifetime of the investments. This means that no replacements have to be made within the period under consideration and that there are no residual values at the end of the period under consideration.

If the useful life does not correspond to the period under consideration, this must be taken into account as follows:

- If the useful life is shorter than the period under consideration, the replacement investment must be taken into account accordingly (add the present value to the initial investment).
- If the end of the useful life has not yet been reached at the end of the period under consideration, investment I is reduced by the present value of the residual value.

Dividing the annual costs by the planned average useful heat generated annually yields the **heat production costs k:**

$$k = \frac{K}{Q_{use}}$$

- k Heat production costs [EUR/MWh; CHF/MWh]
- K Annual costs [EUR/a; CHF/a]
- Q_{use} Useful heat generated annually [MWh/a] (in combined heating networks, the heat production costs can also be related to the sold heat)

The calculation of the heat production costs according to the annuity method is also included, for example, in the Economic Profitability Calculation tool (see chapter 10.7) or the open-source software Sophena [102]. In addition, many planners have developed tools in spreadsheet programs for the economic efficiency calculation based on the annuity method.

In practice, the annuity method is often simplified by using the current interest rate for bank loans as the calculation interest rate and not taking price increases (inflation) into account. Thus, the annuity method becomes a static consideration that does not take future change into account. This can lead to considerable errors in systems with different cost structures. However, if the shares of the capital-linked cost types are similar and an equally high price increase can be assumed for all consumption- and operation-linked cost types over the entire utilisation period, a system comparison with the current interest rate and without price increase is enough in the context of a preliminary study.

This procedure alone is usually not sufficient for assessing whether the selected system and thus the project at hand can be operated economically. In order to assess the economic situation over the lifetime of the system, a business plan should always be prepared for a system with a heating network and the economic development over several years should be considered (see chapters 10.6 and 10.7).

10.4.3 Net present value method (NPV) and internal rate of return (IRR)

The annuity method described in chapter 10.4.2 calculates the average costs over the project duration. Since investments in biomass DH plants usually have a long useful life and only pay off over some years, it makes sense to assess the economic development over a longer period of time. For this purpose, the net present value (NPV) method is very suitable, which can also be used to calculate the effective (internal) rate of return (IRR) of the investment. The profitability tool presented in chapter 10.7uses these methods.

The internal rate of return is the average return on invested capital over the useful life. The calculation takes into account the fluctuating income (payments from customers) and expenses (energy costs, maintenance) and determines an average annual return. The interest rate sought is the one at which the net present value is zero at the time of calculation [103].

$$I_0 = \sum_{t=1}^{n} \frac{e_t - a_t}{(1+i)^t} + \frac{L_n}{(1+i)^n}$$

- t Time index, where t = 1, 2, ..., n
- n Useful life of the investment in years
- i Discount rate (calculation interest rate)
- I_0 Disbursements in connection with the procurement of the investment object, e.g. purchase price of a machine
- a_t Payments during the useful life, due at the end of the respective time period t, such as

payments for fuel, wages, maintenance and repair

e_t Payments received during the useful life, due at the end of the respective time period t, such as revenue from the sale of energy

L_n Liquidity proceeds at the end of the useful life

To determine the internal interest rate, the above equation must be solved according to i. For investment projects with more than two periods of use, this results in considerable mathematical difficulties, so that approximate solutions have to be used. The procedure is as follows [103]:

- A calculation interest rate i is determined at which the capital value calculated is as close to zero as possible, but is still positive.
- A second calculation interest rate i is determined at which the capital value calculated is also as close to zero as possible, but results in a negative value.
- With the two values determined, the interest rate at which the capital value just becomes zero is calculated by means of interpolation.

Modern spreadsheet programmes such as Excel have functions that simplify these calculations.

If the calculated internal interest rate of an investment is greater than the calculation interest rate, the investment is considered economic and vice versa.

10.4.4 Variant comparison

To determine the heat production costs of a wood-fired heating plant, the procedure described in chapter 10.4.2 can be applied. A distinction must be made as to whether the heat production costs of the first year of operation (price increase not relevant) or the average heat production costs over the period under consideration are to be calculated (nominal approach). Only the nominal approach ensures that the average heat production costs are determined as accurately as possible over the period under consideration.

When **comparing the variants of a wood-fired heating plant,** the calculation method described below can be used with the real approach. This is much easier to carry out than the nominal method.

With this consideration, the relations of the compared heat generation variants are correctly reflected. However, it should be noted that the calculated heat production costs may deviate from the actual costs due to the simplifications in the calculation.

Thus, it is assumed that the replacement of the assets at the end of their useful life will be at the same price in real terms as the original investment.

The real interest rate represents the interest rate in excess of the general inflation rate and is approximately the difference between the interest rate and the inflation rate.

Example: If the nominal interest rate is 3% with a general inflation rate of 1%, the real interest rate is 2%. In Switzerland, the long-term average real interest rate is between 1 and 3%.

If inflation is not taken into account when comparing the heat production costs of different heating systems, the real interest rate must be used as the calculation interest rate.

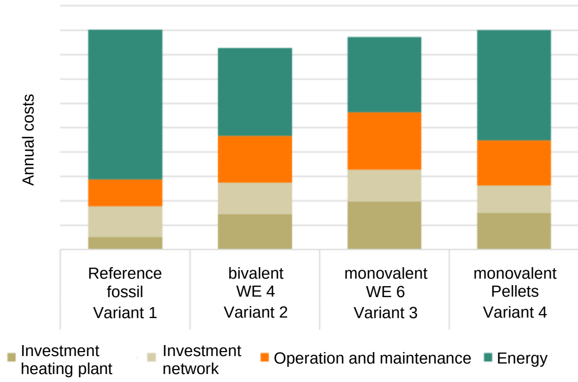


Figure 10.1 Exemplary breakdown of annual costs into capital, maintenance and energy costs.

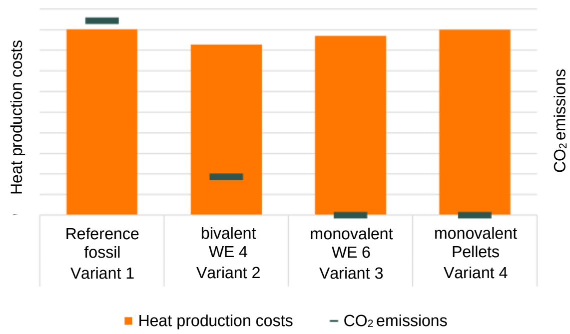


Figure 10.2 Exemplary comparison of heat production costs and CO_2 emissions.

10.4.5 Sensitivity analysis

With a sensitivity analysis, the influence of fluctuations of individual input parameters on the results of the variant comparison can be shown and the following questions can be answered:

- Which input variables have a particularly strong influence on the value of the result variable?
- Within what limits can the values of the input variables fluctuate without jeopardising the success of the company?

For example, the effects of cost overruns on investment costs, reduced heat sale or the influence of fluctuating energy prices, levies and taxes on the heat production price can be calculated.

In Figure 10.3 different factors are entered for the various energy costs. Fossil energy sources and electricity are assessed as critical and their volatility is taken into account with - 10 %/+ 20 %. The volatility of biomass, on the other hand, is assumed to be lower (- 5 %/+ 10 %). Thus, it can be seen that due to the more stable energy costs, the annual costs of renewable heat generators vary much less than those of fossil energy sources.

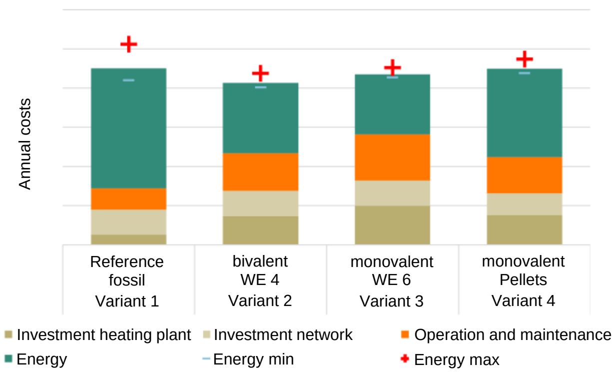


Figure 10.3 Annual costs with sensitivity comparison “energy prices”.

Figure 10.4 shows the sensitivity analysis (+ 20 %/ - 10 %) based on the investment costs. Due to the significantly higher investments of the renewable variants, the capital costs vary significantly more than in the base variant.

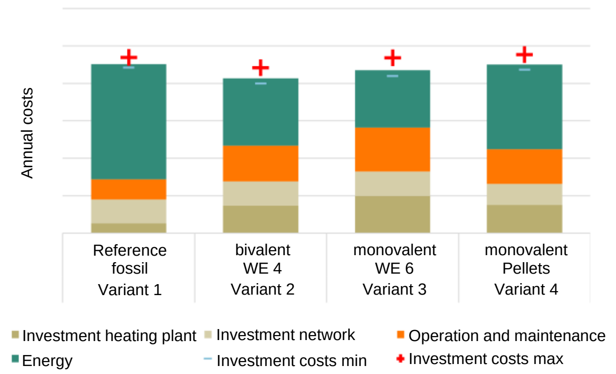


Figure 10.4 Annual costs with sensitivity comparison “investment costs”.

10.5 Tariff structure heat sales

The costs listed in chapter 10.3 must be included in the tariff structure for heat sales. It makes sense to divide the costs into consumption-dependent and consumption-independent costs. The investments as well as the costs for maintenance and servicing are largely independent of the heat sales. The expenses for the purchase of fuel and the electricity costs for auxiliary energy depend on the energy produced and are therefore consumption-related costs.

The tariff structure for district heating is often made up of three or four components:

- **One-off connection fee**: Investment cost share of the customer for the construction and the house connection. The payment is made once, usually after completion of the house connection.
- **Annual basic price** per kW of subscribed capacity: The fixed costs independent of consumption are charged with the basic price. Depending on the connection fee, part of the investment costs must also be charged as capital costs via the basic price.
- **Energy price**: Energy costs for the heat supplied, billed at the calibrated heat meter of the customer. In addition to fuel costs, costs for auxiliary energy and heat distribution losses as well as other consumption-dependent costs are also included in the energy price.
- **Meter charge**: In addition, the tariff structure may also include a meter charge, which covers the costs for the metering equipment and its maintenance/calibration. The share of the meter charge in the total amount of the tariff is small.

The recurring prices (basic price and energy price) are often indexed and adjusted periodically (e.g. annually). Depending on the country and region, a variety of price indices are available here, covering for example the price development of consumer prices, energy prices (heating oil, gas, electricity, energy or firewood prices), personnel or construction costs. For example, the labour price can be indexed with an energy or fuel price index and the basic price with a general consumer price index.

Price variation clauses should be drafted in such a way that they adequately take into account both the development of costs for the production and supply of heat by the company and the respective conditions on the heat market. They must show the relevant calculation factors completely and in a generally understandable form [104].

The tariff structure, the method of determining the individual price components and the price index adjustment must be specified in full and in detail in the heat supply contract or an applicable supplement (e.g. tariff sheet). In the case of indexed prices, in addition to the base price, the name, reference year and sources of the index(es), the threshold value at which adjustments take effect and calculation formulas must be specified. All laws, regulations and guidelines regarding the design of prices and contracts for energy supply and billing must be complied with. For a legally secure design of a heat supply contract, it is recommended to seek legal advice from law firms experienced in this field (also for small systems with only a few customers). The heat supply contract and the technical connection conditions contained therein must be designed in such a way that there are motivation and legal options for optimising the load behaviour and the flow and return temperatures. To this end, so-called "motivation tariffs" are increasingly being used. These take into account, for example, the return temperature or a specific volume flow in order to calculate a bonus or malus on the heat price depending on this. Further information on heat supply contracts can be found in the Handbook on Planning of District Heating Networks [19].

Figure 10.5 shows the distribution of costs of a heat network according to the tariff structure. The distribution is to be determined individually and by the system operator. If, for example, a one-off connection fee is waived, the entire investment costs including the risk share must be capitalised and included in the basic price.

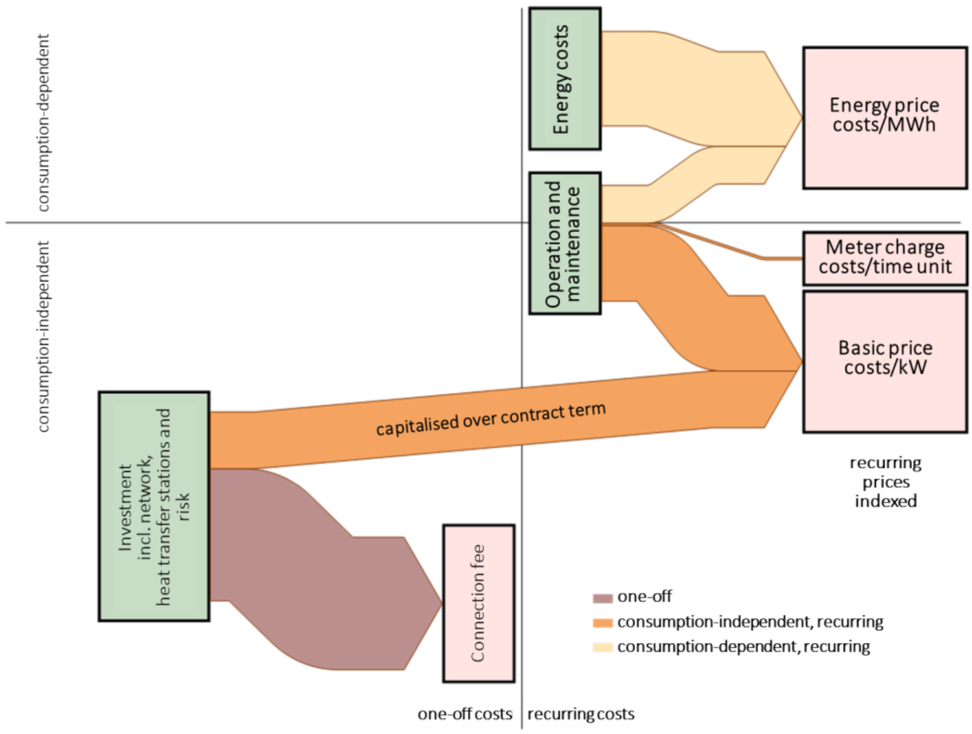


Figure 10.5 Cost distribution according to the tariff structure.

10.6 Business plan

10.6.1 Structure and content

The business plan describes a concept or plan for a business idea that shall be implemented in a company. The construction and operation of a biomass heating plant - especially a district heating network - is also a business in this sense and requires a business plan. A business plan is thus an instrument that provides information about the quality of a company. A good business plan helps with financing and the acquisition of customers. For the following explanations, the business plan comprises a document in the following two parts:

1. Text: This is the **business plan** as a written formulation of the business idea in terms of product, service, clientele and marketing. The business plan provides information about the development of the business and enables an assessment of the risks.

For a heating network, it is important to show the effects of different network expansion variants.

2. Finances: budgeted balance sheet and budgeted income statement provide information on planned income and expenditure, subsidies, financing and liquidity planning. The budgeted balance sheet and budgeted income statement usually cover a period of at least 20 years.

The business plan should cover the following elements in these two parts:

- Executive Summary (maximum two pages)
- Company: Founding team, company profile, company goals
- Product or service: advantages and benefits for customers, state of development, production
- Industry and market: industry analysis, market analysis and market segmentation, target clientele, competition, location analysis
- Marketing: market entry, marketing and sales concept, sales promotion
- Management and key positions
- Implementation planning
- Opportunities and risks
- Financial section: Planning for the next 20 to 25 years: personnel planning, investment and depreciation planning, budgeted profit and loss account, liquidity planning, showing financial requirements.
- Sensitivity analysis as a supplement to the investment calculation, in which the following questions are answered by varying the most important input variables:
    - Which input variables have a particularly strong influence on the level of the result variable?
    - Within what limits can the values of the input variables fluctuate without jeopardising the success of the company?
- Important input variables include:
    - Debt ratio and interest on debt
    - Fuel price (and secure supply)
    - Construction and plant costs
    - Electricity price
    - Personnel costs
    - Funding

The business plan should always be written by the developer. The developer is responsible for the business idea which best represents the business plan to the outside world. The task of the planner is to support the client in the preparation of the business plan.

10.6.2 Budgeted balance sheet and budgeted income statement

The assessment of the profitability of a company cannot be based solely on the calculation of the average heat production costs. Even if the heat production costs are lower than the revenues over a longer observation period, it is not possible to compensate for any losses in the first years of operation with profits in later years if the liquidity for this is not secured. Special attention must therefore be paid to the liquidity situation, which is the purpose of the budgeted balance sheet and budgeted income statement with proof of the economic situation over each year.

In chapter 10.7an Excel-based **tool** developed by QM for Biomass DH Plants is presented, which can be used to map the economic situation of a heating network over 25 years.

General conditions such as the structure and connection density of the heating network influence the economic efficiency. This data must be collected by the planner and used in the economic optimisation process.

The **audit** of the economic viability and the associated planning calculations should not only be carried out once after preparation but regularly updated and checked with the effective costs during the entire project duration and supplemented with the examination of possible cost optimisations.

Inflation should be taken into account when **calculating** the budgeted balance sheet and the budgeted income statement for the individual years. However, the simplified real approach (see chapter 10.4) is not permissible for this purpose because the difference between the real interest rate and the bank interest rate increases when the inflation rate is high. This leads to a correspondingly higher interest burden in the first years. The use of the real interest rate can therefore lead to an underestimation of the capital costs with a corresponding risk, especially in the first years.

If **inflation** is not taken into account by using the nominal interest rate without price increases, the interest burden will be somewhat higher in the planning income statement compared to the income than later in reality. If inflation is low, this deviation can be neglected compared to other uncertainties. Since inflation affects both expenditures and revenues, it is usually negligible compared to other uncertainties. The assumptions regarding interest rates and inflation should be discussed and agreed with the lending institutions.

10.7 Profitability calculation tool

QM Holzheizwerke has developed a simple tool for Switzerland (“QMH-Berechnungstool Wirtschaftlichkeit”) for the preparation of a budgeted balance sheet and budgeted income statement over a plant operating period of 25 years. The tool is based on an economic efficiency calculation programme developed and offered by the Austrian QM Heizwerke team [105]. With this tool, the cost development, economic bottlenecks and the success of the project can be presented. The following questions, among others, can be answered with the help of the tool:

- How does the project develop over the operating period?
- What are the economic risks?
- Is the debt capital secured by the residual value of the plant?
- How high are the heat production costs of the customers?

The current version of the Excel template and sample files (in German language) can be found in the download area of QM Holzheizwerke [17].

Disclaimer

The Excel tool *QMH-Wirtschaftlichkeitsrechnung (Economic Profitability Calculation)* has been prepared very carefully, nevertheless the persons and institutions involved in its preparation cannot assume any guarantee or warranty for the results determined and the conclusions derived from them. The simplifications made result in certain deviations due to the nature of the calculation, for example, it is not taken into account whether a payment is made at the beginning of the year or at the end of the year, since a year is considered as one period.

Note: Even if the tool provides warning feedback regarding various input limits, it cannot be ruled out that incorrect input values may lead to an incorrect representation of the final result. The correct assessment of the consequences of certain assumptions is the responsibility of the persons using the tool.

The Excel tool has various worksheets. The worksheets are read-only, but all formulae and calculations are visible. It should be noted that changes to them can lead to errors and thus to incorrect statements by the tool.

Instead of a manual or handbook, the tool is described in worksheet **I1_Explanations**. The input and output fields are linked to the corresponding explanations.

In the worksheet **E1_Project data**, the information concerning the entire project is entered. This includes:

- General project data, heat distribution losses and other
- Energy prices and apportionment, operating costs, inflation
- Maintenance costs
- Investment costs including useful life
- Debt financing and loans (incl. term and interest rate)
- Subsidies.

Four different tariff structures (prices and contract periods) can be defined in the worksheet **E2_Heat price**. The tariffs correspond to the tariff structure presented in chapter 10.5

Heat consumer data is recorded in worksheet **E3_Consumers**. The connection data for each customer can be entered in the table. The general data and the heat demand can be taken from the Excel tool for demand assessment and appropriate system selection or entered manually. It is important that the contractually agreed output is entered for the subscribed output, not the calculated output requirement. From the consumption data and the tariffs, the annual costs and the heat production price can be calculated from the point of view of the heat customer or the sales income from the point of view of the heat supply company.

The inputs are compiled in worksheet **B1_Calculations** and evaluated over a project duration of 25 years. During operation, the file can be used for simple control and post-calculation by using the effective values for the total expenditure and yield.

The most important results and graphs are compiled in worksheet **A1_Results** and can be printed on two A4 pages.

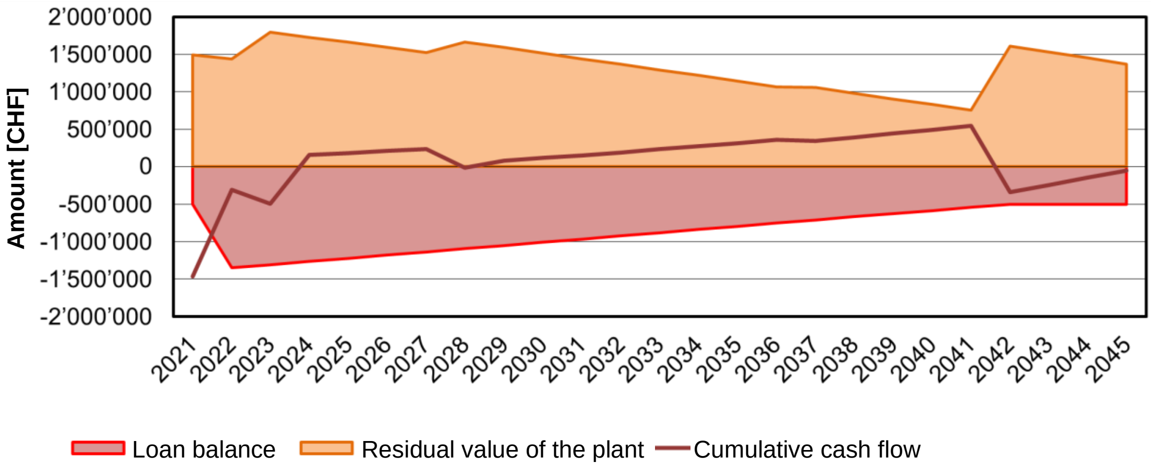


Figure 10.6 Chart on loan balance, residual value of the asset and cash flow.

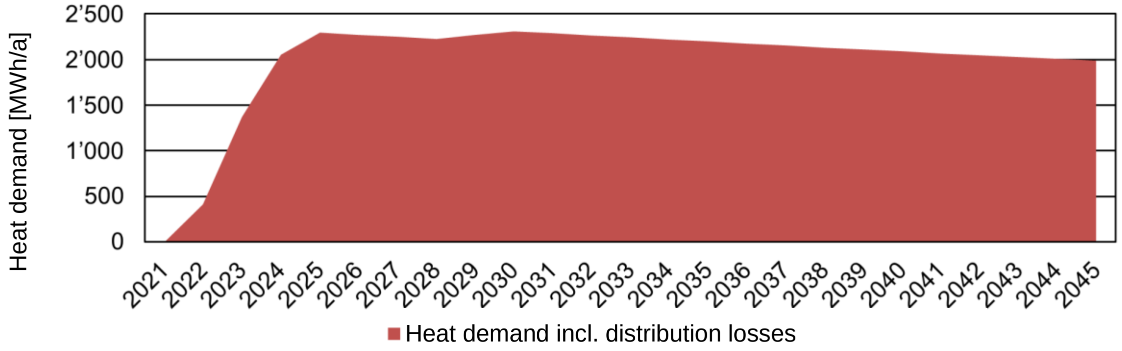


Figure 10.7 Development of heat sales. Due to renovations and efficiency measures on customer side, heat demand and sales decrease over the years if no new customers are connected.

Other recommended tools

Together with the documents developed and provided by QM for Biomass DH Plants, there are further calculation tools that can be recommended for the design and calculation of economic efficiency.

Sophena [102]
The open-source software Sophena offers the possibility to carry out the technical and economic planning of a heat supply project quickly and in a well-founded manner. At the heart of Sophena is a boiler and buffer storage simulation, from which annual duration curves and key energy figures are determined. Based on these calculations, a profitability analysis is carried out according to VDI 2067 incl. determination of the heat production costs. Further results include a greenhouse gas balance and the heat demand density of the network.

THENA [106]
THENA (Thermal Network Analysis) is an Excel-based calculation tool and is used for simple technical analysis of the network design and a supplementary rough cost estimate of the heat distribution network.

DN-Sensi [107]
With the excel-based calculation tool DN-Sensi, the optimal dimensioning as well as the sensitivity of different parameters to the costs of heat distribution for nominal diameters from DN 20 to DN 250 can be calculated and graphically displayed in a simple way.

10.8 Estimation of the investment costs

The following figures show the total investment costs of heat generation with central heating plants (see Figure 10.8) and heating network including house stations (see Figure 10.9). The curves are based on the data of realised systems from the QM monitoring in Switzerland and Austria in the period 2009 to 2018. The graphs represent the majority of the evaluated systems that comply with the most important Q-requirements. The fluctuation range is sometimes considerable and depends on various factors.

Notes
The following diagrams are only intended as a first **estimate of the investment costs** (preliminary study, feasibility study). They provide indications, but must not be used to determine the investment costs as part of the in-depth planning phase of a wood-fired heating plant. The diagrams serve as a benchmark for comparison with project-specific calculations.

The **EUR/CHF conversion** is not a pure currency conversion but also takes into account the **price differences** in Austria and Switzerland according to the evaluated plant data and is justified in the different price, construction cost and wage levels.

Further tables and graphs with guide prices for district heating pipes and house stations were determined by QM Fernwärme and published in the Handbook on Planning of District Heating Networks [19] (district heating pipes) and in the Guide to Planning District Heating Transfer Stations [76] (house stations).

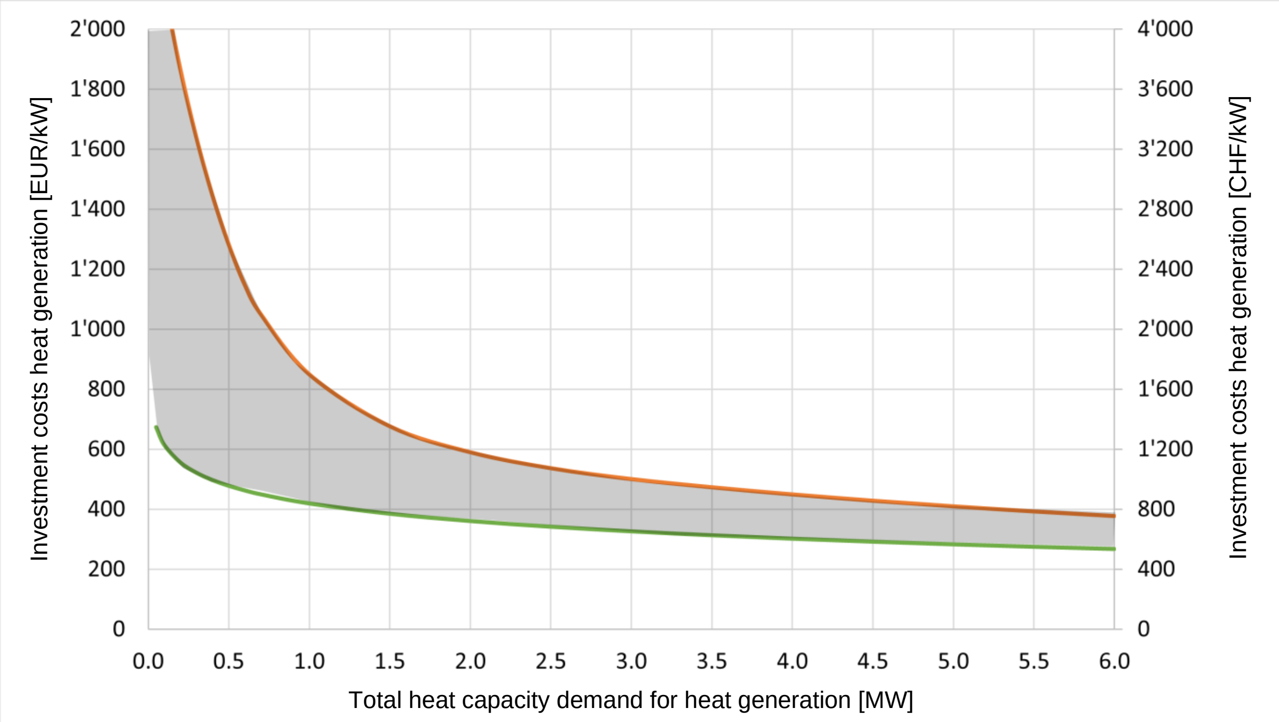


Figure 10.8 Specific investment costs for heat generation – evaluation of realised installations from AT and CH in the period 2009 - 2018.

The costs include heat generation, particle separator, economiser and/or condensation (if present), heat storage, chimney system (flue), hydraulic integration, electrical installations, control/regulation (C&I), boiler room, fuel storage including discharge system for monovalent and bivalent systems with heat storage. The design fulfils the Q-requirements “E4 heat generation”; EUR/CHF - conversion takes into account different price levels in AT and CH.

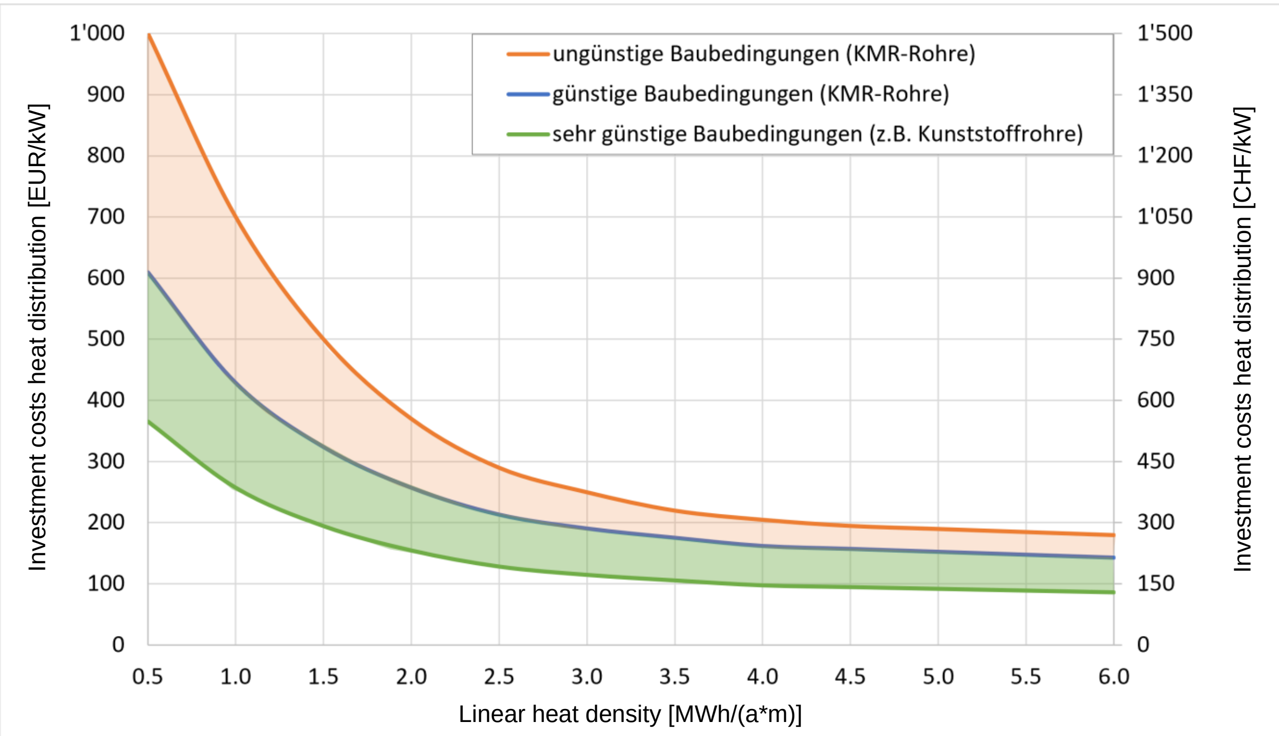


Figure 10.9 Specific investment costs for heat distribution – evaluation of realised installations from AT and CH in the period 2009 - 2018.

The costs include the district heating network related hydraulics in the heating plant, the district heating network including excavation work, and the house connections up to and including heat transfer stations (without consumer’s installation); EUR/CHF - conversion takes into account different price levels in AT and CH.

Part 3 - Planning process

11 Demand assessment

11.1 Introduction

The analysis of the current situation (demand assessment) is the basis for the system selection in order to define a suitable heat generation and heat distribution system for the building or area to be supplied.

The **demand assessment is the most important basis for all further planning steps** and plays a decisive role in the successful course of the project and the operation of the plant. Overestimating the power and heat demand and the associated over-dimensioning of plants can have massive negative technical and economic effects on a project.

Accordingly, attention should be paid to the implementation of the demand assessment already in an early planning phase. The implementation is the responsibility of experienced planners and should be checked for plausibility by an independent body (e.g. Q-manager of QM for Biomass DH Plants).

In a holistic approach, the demand assessment includes the determination of the current and future heating and cooling demand as well as the evaluation of all possible renewable and regionally available heat sources. As a result, the demand assessment provides the annual heat demand of the entire system for different supply and expansion scenarios as well as the corresponding load profile and annual duration curves for the further system selection (see chapter 13).

QM Holzheizwerke and **QM Fernwärme** offer helpful documents and tools for this purpose:

- Detailed **project procedure** according to QM for Biomass DH Plants in the Q-Guidelines [15], in Part 3 of this Planning Handbook and in the Handbook on Planning of District Heating Networks ([19], page 102 ff.).
- **Questionnaire** for a district heating connection as template document in Word [108]
- **Excel tool for demand assessment and appropriate system selection** [109] for the plausibility check for each heat consumer and for the entire system. In the Excel tool, the system selection for heat generation is directly evaluated using the target values of QM for Biomass DH Plants.

It is recommended to involve all relevant project stakeholders as early as possible. This includes the site municipality, canton or federal state, operating company (e.g. contractor), customers, fuel and energy supply companies and indirect stakeholders such as residents and homeowners, associations, regional energy agencies, business and biomass associations. The relevant project participants are described in detail in the reports “Risks in thermal grids” [20] and “Socio-economic aspects of thermal grids” [18].

Required work steps

The following **work steps must be** available or defined to varying degrees of accuracy depending on the progress of the project and the milestone according to QM for Biomass DH Plants:

- In the preliminary study or in the project development, a first rough preliminary analysis of the **supply area** is carried out. In this process, existing potentials of heat sources and heat sinks (heat demand) must be clarified. Information sources such as guidelines and recommendations for energy planning, Geographic Information Systems (GIS) tools or cadastral maps can be used for this purpose (see also chapter 12):
    - Guide to municipal heat planning by KEA [110]
    - Modules for spatial energy planning from EnergieStadt [111]
    - Tool PETA 5.1 [112]
    - Tool THERMOS [113]
    - Tool Hotmaps Toolbox [114]
    - Info map map.geo.admin.ch [115]
    - Tool webGIS for Switzerland [116].
- Coordination and clarification of potential supply areas by means of existing national, regional and municipal **energy strategies** or **energy master plans**. In the Heat Roadmap Europe programme [117], strategies for CO_2-neutral heating and cooling have been developed at European level.
- Clarification of interest among the most important **key customers**
- Analysis, evaluation and plausibility check of the data, for example with the **Excel tool for demand assessment and appropriate system selection** [109] of QM Holzheizwerke.
- Carrying out an in-depth heat demand and interest assessment through house-to-house surveys, information events and questionnaires to collect **detailed data** (chapter 11.2, Demand of individual heat consumers)
- Update of the analysis and preparation of different possible **variants** for heat supply. The selection of variants is based on the following criteria:
    - Availability of local and renewable energy sources
    - Required minimum share of renewable energy sources
    - Coverage of peak load
    - Investment and operating costs
    - Existing demand for cooling energy
- Repeat process depending on project progress and milestone and increase degree of accuracy (iterative process).

Result of the demand assessment

Annual heat demand of the entire system for different supply and expansion scenarios as well as the corresponding load profile and annual duration curves for the further system selection (see chapter 13)

11.2 Analysis of heat demand

11.2.1 New buildings

The **annual heat demand for space heating** should be calculated according to EN ISO 52016 [118]. If necessary, other equivalent national standards and guidelines should be consulted. Heat gains from solar radiation, people, electrical appliances and others are taken into account in this standard.

The calculation of the **annual heat demand for domestic hot water** is usually based on a given standard use. In addition to Table 11.2, the relevant national standards and guidelines can be consulted for this purpose (see chapter 19).

The **standard heat capacity demand for space heating** should be calculated according to EN 12831-1 [119]. Other equivalent national standards and guidelines can also be used for the calculation. Heat gains from solar radiation, people, electrical appliances and others are not considered in this standard. To compensate for the effects of intermittent heating, an additional heating capacity can be taken into account. Without additional heating capacity, a 24-hour average value is obtained without taking heat gains into account.

The average value of the heat capacity demand for **domestic hot water** is calculated by dividing the heat demand for hot water by the number of heating hours (winter operation) or 8,760 hours (year-round operation). The peak value of the heat capacity demand for hot water results from the connected load of the water heater. Since storage water heaters with a priority circuit are generally used, it is usually sufficient to divide the annual heat demand for hot water by 4,000 to 6,000 hours. If instantaneous water heaters or flow water heaters or fresh water stations are used, the number of full load operating hours may have to be reduced. This takes into account a higher peak load than the theoretical mean value, because the peak load on certain days can be higher than the mean value and depends on the day of the week and the season.

The **temperature demand** results from the design of the heat capacity and the domestic hot water preparation. The design of radiators, underfloor heating and heat exchangers is usually based on manufacturer specifications.

11.2.2 Existing buildings

The calculation of the total **annual heat demand** is usually based on the previous final energy consumption (e.g. previous heating oil consumption) and the degree of utilisation of the previous heat generator. From this, a breakdown is made into space heating, domestic hot water and processes (see Table 11.1). It is not recommended to select the capacity according to previously installed boiler systems, to take the energy and capacity demand from the energy performance certificate or to rely on a rough and unprofessional estimate.

If no reliable data on past consumption is available or no reliable division into space heating, domestic hot water and processes is possible, measurements or a professional estimate should be made.

The best method for determining the **heat capacity demand** is to determine the load characteristics with the help of measurements. This usually involves too much effort for small heat consumers, but is definitely recommended, especially for large heat consumption and for process heating systems. Early planning is important in these cases, as measurements are only possible if sufficient time is available and a functioning heat generation system is available.

Experience has shown that useful existing **heat capacity demand calculations** are hardly available or are based on outdated calculation methods. New calculations often fail due to the lack of necessary information on the detailed building structure.
The heat capacity demand is most often determined from the previous heat demand:

- Maximum heat capacity demand for **space heating**: Division of the heat capacity demand by a suitable number of full load operating hours (for explanation and limitations see box “Number of full load operating hours space heating”)
- Average heat demand for **hot water**: Division of the heat demand by the number of heating hours (winter operation) or 8,760 hours (all-year operation). In order to take into account a higher peak load than the theoretical mean value, the annual heat demand for hot water is usually divided by 4,000 to 6,000 hours.
- Required heat capacity for **process heat**: Division of the heat requirement by a suitable number of full load operating hours, which is to be determined or estimated individually, taking into account operating times, heating peaks, breaks, night setback and weekends. It should be noted that in the Excel tool for demand assessment and appropriate system selection, the process heat is considered averaged over the operating hours per year (daily average values). Thus, maximum power peaks are not taken into account. In some cases, this information alone is not sufficient for dimensioning the system.

It is possible to estimate the **temperature demand** solely on the basis of the existing heat supply systems such as underfloor heating, radiator heating or water heaters. However, it is recommended to take temperature measurements at the individual heat consumers during cold outdoor temperatures and to extrapolate the measured value pairs (flow/return temperature, outdoor temperature) to design values.

Upcoming **energy-saving measures** are to be surveyed in the course of the demand assessment and taken into account in the annual heat demand, the heat capacity demand and the temperature demand.

Related discussion on the number of full load operating hours for space heating
The number of full load operating hours for space heating [h/a] (also called “full load operating hours” or “full utilisation hours”) is the ratio of the useful energy demand for space heating in kWh/a to the maximum heat capacity demand for space heating in kW. The number of full load operating hours depends on the annual duration curve of the outdoor temperature at the system location, the heating limit and the size of the non-weather-dependent share of the heat capacity demand.

Depending on the building standard and type of use, other values result, which are sometimes difficult to estimate, especially in the case of non-residential buildings, due to the limited operation and reheating, as well as room temperatures and internal loads that differ from those of residential buildings (see the comparison between residential and non-residential buildings in Table 11.1). Accordingly, the numbers of full load operating hours given in Table 11.2 only apply to **existing residential buildings** (space heating without hot water) that were built before about 1990. These numbers of full load operating hours may not be applied to **new buildings and** very well insulated existing residential buildings with heating limits < 15°C as well as non-residential buildings; lower values result here.

The number of full load operating hours is basically intended as an aid for estimating the required heat capacity and for plausibility checks. However, depending on the situation, power demand and intended use, this method is not sufficient for an investment decision and requires a more precise clarification of the power demand on the basis of EN 12831-1 [119] or, in the case of existing buildings, with the help of measurements (see chapter 11.2.1 and 11.2.2).

11.2.3 Building area

If there is no exact building plan for building areas and thus no possibility of calculation, the **heat demand** is determined approximately on the basis of the energy reference area and the specific heating demand. The specific heating demand should be set according to the current and expected future building standard, but in no case too high. The specific heat demand for domestic hot water is used in the calculation according to a standard use.

Analogous to the existing buildings, a calculation of the **heat capacity demand** is possible from the heat demand (estimated here). The **temperature demand** is estimated on the basis of the expected heat delivery systems.

Table 11.1 Comparison of residential buildings with selected non-residential buildings.

	Housing	**Shops and restaurants**	**Hotels without spa area**	**Indoor swimming pools and spa areas in hotels**
Problems	• Heat capacity demand calculation without heat gains, but this is taken into account in the Excel tool for demand assessment and appropriate system selection • Relatively predictable, uniform domestic hot water demand • No restricted operation, or only during the night	• Often unreliable heat capacity demand calculation • Often inaccurate figures for waste heat loads • High air heater connected load • Restricted operating hours in terms of day and week • Domestic hot water consumption high in restaurants and low in shops (but varies by sector).	• Heat capacity demand calculation like residential construction, but the heat gains are unclear • Widely varying, seasonal operating times and occupancies possible • High domestic hot water peaks that do not occur in normal residential construction	• Often unreliable heat capacity demand calculation • Often inaccurate figures for waste heat loads • High connected loads of bath water heat exchangers • Restricted operating hours in terms of day, week and year • Large daily domestic hot water consumption with high peak demand
Space heating Specific heat demand	Midland / lowland Old 100 kWh/(m²*a) Existing 80 kWh/(m²*a) New 40 kWh/(m²*a) Mountain region Old 120 kWh/(m²*a) Existing 100 kWh/(m²*a) New 50 kWh/(m²*a)	Midland / lowland Existing 80 kWh/(m²*a) New 40 kWh/(m²*a) Mountain region Existing 100 kWh/(m²*a) New 50 kWh/(m²*a)	Midland / lowland Existing 80 kWh/(m²*a) New 40 kWh/(m²*a) Mountain region Existing 100 kWh/(m²*a) New 50 kWh/(m²*a) Lower values possible with interruptions in operation	Midland / lowland Existing 300 kWh/(m²*a) New 150 kWh/(m²*a) Mountain region Existing 375 kWh/(m²*a) New 190 kWh/(m²*a) (including domestic hot water and bath water heating)
Number of full load operating hours	Midland / lowland Old 2,000 h/a Existing 2,000 h/a New 1,200 h/a Mountain region:' Old 2,500 h/a Existing 2,500 h/a New 1,500 h/a	Midland / lowland: Existing 1,350 h/a New 800 h/a Mountain region Existing 1,700 h/a New 1,000 h/a	Midland / lowland Existing 2,000 h/a New 1,200 h/a Mountain region Existing 2,500 h/a New 1,500 h/a Lower values possible with interruptions in operation	Midland / lowland Existing 2,000 h/a New 1,200 h/a Mountain region Existing 2,500 h/a New 1,500 h/a (including domestic hot water and bath water heating)
Specific performance requirements	Midland / lowland Old 50 W/m² Existing 40 W/m² New 30 W/m² Mountain region Old 50 W/m² Existing 40 W/m² New 30 W/m²	Midland / lowland Existing 60 W/m² New 50 W/m² Mountain region Existing 60 W/m² New 50 W/m²	Midland / lowland Existing 40 W/m² New 30 W/m² Mountain region Existing 40 W/m² New 30 W/m² With business interruptions equal values necessary	Midland / lowland Existing 150 W/m² New 125 W/m² Mountain region Existing 150 W/m² New 125 W/m² (including domestic hot water and bath water heating)
Hot water Specific heat demand	Single-family house (EFH: 15 - 20 kWh/(m²*a) Multi-family house (MFH): 25 - 30 kWh/(m²*a)	Restaurants higher values than residential 30 - 70 kWh/(m²*a) Retail shops lower values than residential buildings: 5 - 15 kWh/(m²*a)	Significantly higher values than MFH, but possibly compensated by low occupancy 30 - 50 kWh/(m²*a)	Domestic hot water preparation and bath water heating are included in the key figures listed above. With the help of these key figures, only the approximate total demand can be estimated.
Number of full load operating hours	Not 8,760 h/a, as daily consumption varies; recommendation: 4,000 - 6,000 h/a	Lower values than residential construction (higher power peaks): 2,000 - 3,000 h/a	Lower values than residential construction (higher power peaks): 2,000 - 3,000 h/a	
Specific performance requirements	Single-family house (EFH): 5 W/m² Multi-family house (MFH): 8 W/m²	Restaurants higher values than residential: 25 W/m² Retail shops lower values than residential buildings': 5 W/m²	Specific domestic hot water demand is much higher than in the MFH: 15 - 25 W/m²	

Table 11.2 Number of full load operating hours for existing residential buildings (space heating without hot water). These numbers of full load operating hours may not be applied to new buildings and very well thermally insulated existing buildings with heating limits < 15° C and non-residential buildings (notes on application in the box).

Location	**Number of full load operating hours for residential buildings** Calculated with the help of the Excel tool for demand assessment and appropriate system selection	**Number of full load operating hours for residential buildings** Common values used in the individual countries
Zurich (CH)	2,050 h/a *	2,000 - 2100 h/a *
Davos (CH)	2,800 h/a *	2,600 - 3,000 h/a *
Locarno-Monti (CH)	1,800 h/a *	1,700 - 1,900 h/a *
Graz University (AT)	1,900 h/a **	1,800 - 1,875 h/a ***
Tamsweg (AT)	2,350 h/a **	1,766 - 1,840 h/a ***
Vienna inner city (AT)	1,700 h/a **	1,714 - 1,813h/a ***
Munich-Airport (DE)	2,050 h/a **	1,913 h/a ****
Karlsruhe (DE)	1,750 h/a **	1,611 h/a ****

* Long-term empirical values from Switzerland. The figures are partly specified in cantonal energy ordinances.

** The figures for Austria and Germany were calculated solely on the basis of the annual duration curve using the Excel tool for demand assessment and appropriate system selection based on Swiss values. These values should only be used as comparative figures in Germany and Austria.

*** Source: Handbook for Energy Consultants, JOANNEUM RESEARCH Forschungsgesellschaft mbH, October 1994 edition.

**** Source: Recknagel/Sprenger/Hönmann, Taschenbuch für Heizung und Klimatechnik 1990/1991.

11.3 Heat demand of the entire system

11.3.1 Determination of the required heat capacity

When determining the required heat capacity of the entire system from the figures of the individual heat consumers, the following problems often arise:

- The required heat capacity for the entire system results from a mixture of calculated values with more or less large **safety margins** and real measured values without safety margins.
- The standard heat capacity demand for space heating, calculated according to EN 12831-1 [119], is based on a standard outdoor temperature. In contrast, load characteristics determined based on measurements refer to **real outdoor temperatures**.
- The standard required heat capacity for space heating, calculated according to EN 12831-1 [119], does not take into account **internal and external heat gains** due to solar radiation, people or electrical appliances, etc. In contrast, load characteristics determined based on measurements correctly take heat gains into account.
- To estimate the heat capacity demand for space heating in existing buildings from the heat demand, a number of full load operating hours is required, which depends on the annual duration curve of the outdoor temperature at the location of the system, the room temperature, the heating limit and the size of the non-weather-dependent component. **Which number of full load operating hours** should be used?
- The calculation of **additional heating capacities** to compensate for the effects of intermittent heating (e.g. heating up on Monday morning in an office building after reduced weekend operation) is often not considered.
- Measured load characteristics can be created for different load cases by regressing daily average values to 1-hour average values. It must be noted that peak loads determined based on measurements do not only depend on the heat consumption, but also on the heat generator (possible over or under-dimensioning) and the location of the measuring point.
- Load curves determined by measurement often show a considerable **non-weather-dependent share of the heating power demand**. How should this non-weather-dependent share of the heat capacity demand for space heating be taken into account in new buildings?
- The average value of the **heat capacity demand for domestic hot water** (annual heat demand for hot water divided by 8,760 hours) is something completely different from the peak value of the heat capacity demand for hot water (connected load of the water heater). The hot water consumption often varies from day to day and depends on the day of the week and the season.

Questions to be answered

In order to determine the figures for the entire plant from a mixture of calculations and real measured values as realistically as possible, the following questions must be answered:

- How are heat gains taken into account in new buildings?
- What are the appropriate number of full load operating hours for determining the heat capacity demand for space heating based on the previous heat demand for existing buildings?
- How should the non-weather-dependent share of the heat capacity demand for space heating be taken into account?
- To what extent are additional heating capacities taken into account to compensate for the effects of intermittent heating in the overall system?
- To which outside temperature does the total system refer?

11.3.2 Thermal power demand shown as load characteristic

The representation of the heat capacity demand as a load characteristic with outdoor temperatures that are as real as possible requires empirical support and has emerged from practical experience with measurements in renovations and expansions of larger building services systems. The great advantage is that the combination of numerical material from calculations of previous energy consumption and from measurements can be clearly presented. This method is implemented and applied in the Excel tool for demand assessment and appropriate system selection of QM Holzheizwerke [109].

The method is based on the following fundamental considerations:

- Space heating, domestic hot water and processes must be considered separately for each heat consumer.
- For standard residential buildings, the daily average value for the required heat capacity for space heating is used in the calculation. Experience and numerous measurements show that the space heating required in residential buildings at a certain outside temperature (also daily average) can be supplied at any point within 24 hours - in “packages”, so to speak. It is sufficient if the balance is correct again after 24 hours. So-called night setbacks are therefore hardly noticeable in normal residential buildings. This is especially true for residential buildings constructed after 1985 and for older buildings that have been thermally renovated. At very low outside temperatures, night setbacks can also be switched off if necessary!
- Special cases such as systems with reduced weekend operation and possible cold air ventilation systems are designed - as moderately as possible - for peak loads.
- In the case of storage water heaters with internal or external heat exchangers, the required heat capacity for water heating is taken into account as the highest average value that occurs, and not as a peak value. The systems are mostly operated with domestic hot water priority circuits (boiler priority).
- For flow-through water heaters (fresh water stations) without stand-by storage tank, the heat capacity demand for domestic hot water preparation is taken into account as the peak value. For systems with standby storage, the heat capacity demand can also be taken into account as the highest occurring average value. The volume of the standby storage tank and the question of whether or not the systems are operated with domestic hot water priority circuits (boiler priority) must be taken into account.
- Safety factors and peak load surcharges are taken into account for the individual heat consumers and must be plausibly justified. Each building is therefore used as realistically as possible in the overall calculation, so that concurrency factors are generally not required. However, moderate concurrency factors are not “forbidden” (see chapter 12.2.5). Using assumptions made for customers as well as safety margins, there will always be a certain balance.
- The representation is done as a load characteristic of the entire system. For space heating, a distinction is made between a weather-dependent and a non-weather-dependent share. This is independent of the non-weather-dependent components for the required heat capacity for domestic hot water and process heat as well as heat distribution losses.
- The average capacity of heat distribution losses of the district heating network is calculated on the basis of the manufacturer's specifications.

A great advantage of the method via the load characteristic is that the annual duration curve of the heat capacity demand can be calculated from it with the help of the annual duration curve of the outdoor temperature.

Load characteristic
The load characteristic is the representation of the heat capacity demand as a function of the daily mean value of the outdoor temperature. For the outdoor temperature, the 24-hour average value must always be used, whereas the heat capacity demand can be a daily average value (e.g. for residential buildings) or a peak value (e.g. for bank buildings). The load characteristic of the entire system results from the stacking of several load characteristics (see Figure 11.1).

Annual duration curve of the outdoor temperature
The annual duration line of the outdoor temperature is the representation of the cumulative frequency of the outdoor temperature as the number of days per year. From Figure 11.2 for example, it can be read that the 10-year daily mean outdoor temperature in Zurich was below 4 °C on 100 days.

Annual duration curve of the heat capacity demand
The annual duration curve of the heat capacity demand results from the weighted load characteristic and the annual duration curve of the outdoor temperature. From Figure 11.3 for example, it can be seen that the heat demand exceeds 880 kW on 50 days. The heat demand for these 50 days results from the area under the curve.

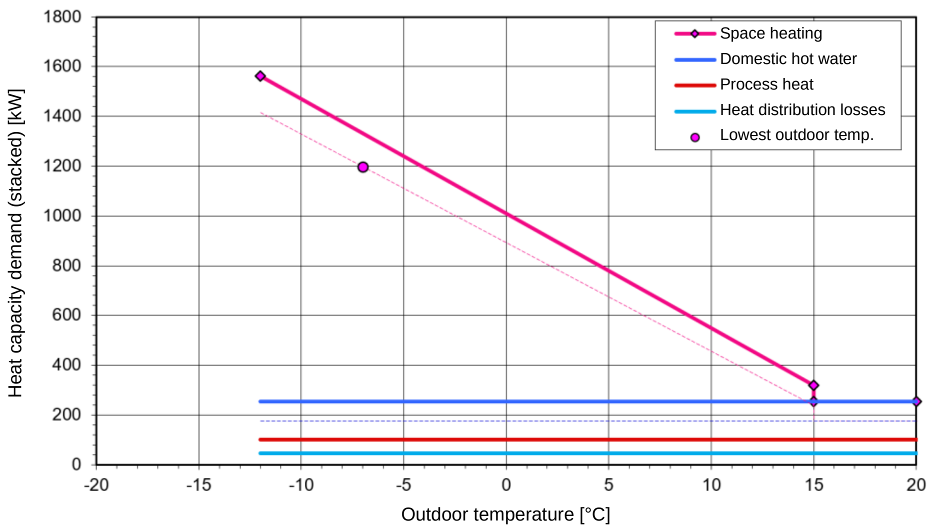


Figure 11.1 Load characteristic of the entire system (solid line) and weighted load characteristic (dotted line) for the calculation of the annual duration curve of the required heat capacity.

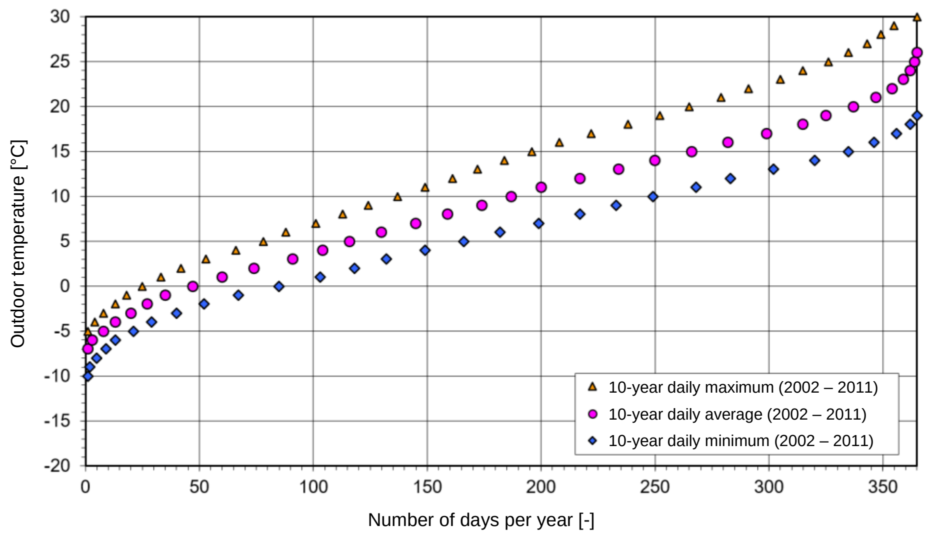


Figure 11.2 Annual duration curves of outdoor temperature for the Zurich-Fluntern site (10-year mean 2002-2011).

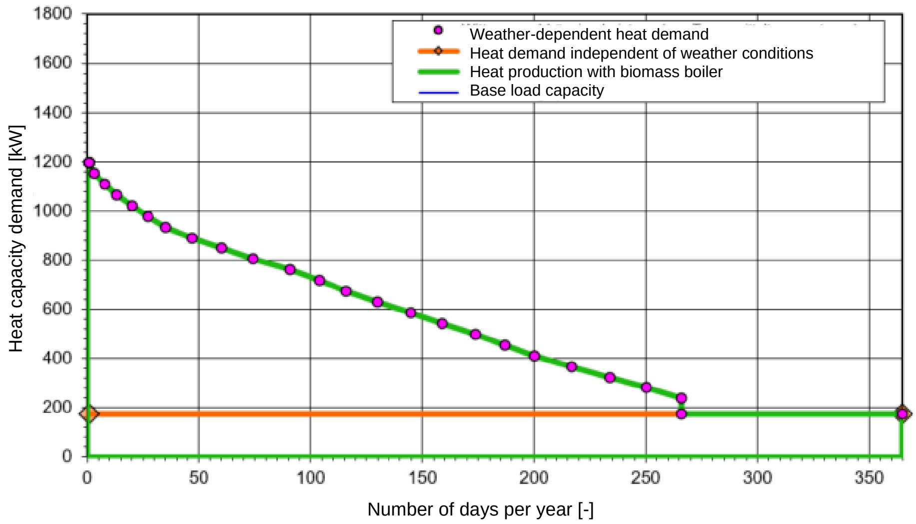


Figure 11.3 Annual duration curve of the required heat capacity, framed in green is the annual amount of energy produced with biomass.

11.4 Heat source analysis

In addition to wood, other renewable heat sources are increasingly being used to achieve a completely renewable and CO_2-neutral heat supply in the future (see chapter 1.3.2). For biomass DH plants with heat grids are an ideal starting point to make regionally available heat sources usable.

Accordingly, in addition to the analysis of the heat demand and the wood supply strategy (see chapters 11.2and 12.2.1), the situation of the (locally) available heat sources must also be analysed in an early planning phase. The focus here is on CO_2 neutrality, availability and economic efficiency when tapping the heat source.

An existing energy strategy (e.g. energy master plan), which defines which energy sources are to be used for buildings, neighbourhoods or larger supply areas, is also helpful in the analysis.

Preferably, local energy sources are used first. Only in a further step should non-local energy sources be considered. Local energy sources are characterised by the fact that they cannot be easily transported, but are usually available in abundance, such as river and lake water or industrial waste heat. Non-local energy sources, on the other hand, can be easily transported and stored, but are not available everywhere at all times (e.g. wood and solar energy).

Already during the initial analysis of available heat sources, data on situational conditions available potential in terms of capacity and energy quantity as well as respective special characteristics of heat source such as temporal availability/load profile, controllability or temperature level must be collected.

Based on this data, a prioritisation and pre-selection of energy carriers/heat sources can be made, which will be considered in the further system selection of heat generation (see chapter 13).

11.5 Integration into the QM for Biomass DH Plants project process

As described in chapter 2, quality monitoring according to QM for Biomass DH Plants requires that a plausibility check is carried out for each heat consumer and for the entire system using the **Excel tool for demand assessment and appropriate system selection** [109]. The calculation of key figures and characteristic curves is required. The Q-manager then compares these key figures and characteristic curves with information from selected literature and own empirical values.

Demand assessment, appropriate system selection and the use of the Excel tool is an iterative process. In the QM for Biomass DH Plants project process, a demand assessment and appropriate system selection is required at the latest in Milestone 2 in the design planning stage. This is updated in Milestone 3, when the tender project is ready, and repeated in Milestone 5 after the operational optimisation. In Milestone 4, if accepted, the demand assessment and appropriate system selection should be checked and the plant documentation should be updated.

With each milestone, the level of information increases, but the degrees of freedom decrease accordingly. While a change in Milestone 2 often means only a pencil stroke, in milestones 4 and 5 the plant is being built and a misjudgement is correspondingly expensive.

Table 11.3 provides an overview of the status of the demand assessment and appropriate system selection for the individual milestones and can be used as a checklist. Although the column “Heat generation” is only the subject of the subsequent system selection (see chapter 13), it is already dealt with here for the sake of clarity.

Table 11.3 Overview and checklist of the status of the demand assessment and appropriate system selection in the individual milestones.

Milestone	Heat consumers	Heating network	Heat generation in general	Heat generation with wood
2 **Design planning**	☐ A list of potential heat consumers is available, and at least 70% of potential customers should have signed a declaration of intent. ☐ For new buildings, the planning data on heat, heat capacity and temperature requirements are available (with varying degrees of accuracy depending on the progress of the project). ☐ The previous fuel consumption figures are available from the existing buildings.	☐ A site plan with the location of the central heating plant and the marked branch pipes, branch lines and house connections is available. ☐ The district heating network is designed according to size in terms of nominal diameters (no precise pipe network/pressure drop calculation yet). ☐ The heat distribution losses have been determined in terms of size on the basis of the linear heat density.	☐ The necessary heat, heat capacity and temperature demand is known (see column "Heat consumers"). ☐ The national, regional or municipal energy plans and strategies were consulted. ☐ The heat sources available for selection were analysed in terms of characteristics, availability and economic efficiency. ☐ The system selection (energy mix, type and number of heat generation systems) has been made. ☐ The capacity allocation to the heat generation systems has been made. ☐ The mode of operation in summer and winter is fixed.	☐ The necessary heat, heat capacity and temperature demand is known (see column "Heat consumers"). ☐ The fuel range and its availability have been clarified. ☐ The system selection (type of firing, monovalent/bivalent, number of boilers) has been made. ☐ The power allocation to the boilers has been made. ☐ The mode of operation in summer and winter is fixed.
3 **Tender project**	☐ The list of heat consumers for the first expansion stage and the final expansion has been determined. ☐ At the start of construction, at least 60 % of the annual heat demand[1)] must be secured by signed heat supply contracts. ☐ For new buildings, the latest planning data on heat, heat capacity and temperature requirements are available. ☐ For existing buildings, the previous fuel consumption figures have been checked and the temperature demand is reliably available (if possible based on measurements).	☐ The location of the central heating plant and the route of the main, branch and house connection pipes have been definitively determined. ☐ The final design of the district heating network in terms of nominal sizes and pressure drops is complete. ☐ The heat distribution losses have been calculated on the basis of the definitive network design.	☐ The heat source is established and a corresponding concession, fuel supply contract or equivalent document is available. ☐ The heat generation is specified or a description with principle scheme, functional description, measurement concept, etc. is available. ☐ The final principle scheme with registered outputs, temperatures and flow rates is available.	☐ The fuel range is fixed and a corresponding fuel supply contract is in place. ☐ The standard circuit is specified or an equivalent description with principle scheme, functional description, measurement concept, etc. is available. ☐ The final principle scheme with registered outputs, temperatures and flow rates is available.
4 **Acceptance**	☐ The list of heat consumers has been updated.	☐ Changes due to the implementation planning have been updated in the installation documentation.	☐ Changes due to the implementation planning have been updated in the installation documentation.	☐ Changes due to the implementation planning have been updated in the installation documentation.
5 **Operation optimisation**	☐ The operational optimisation has been completed. ☐ The list of heat consumers actually connected in the first year of operation has been compiled. ☐ The actual heat consumption, necessary peak power and temperature demand of the heat consumers according to the list are known. ☐ A comparison of the actual remaining expansion potential and possible further heat consumers (with intention to connect) has been made. ☐ If necessary, a concept for the advertising of additional heat consumers has been created.	☐ The operational optimisation is completed ☐ Changes made in the course of the operational optimisation have been updated in the system documentation. ☐ The actual heat losses of the district heating network in the first year of operation are known.	☐ The operational optimisation has been completed. ☐ Changes made in the course of the operational optimisation have been updated in the system documentation. ☐ The actual utilisation of the heat generation plants is known (number of full load operating hours).	☐ The operational optimisation has been completed. ☐ Changes made in the course of the operational optimisation have been updated in the system documentation. ☐ The actual utilisation of the boilers is known (number of full load operating hours).

1) QM for Biomass DH Plants bases the value on the annual heat sales of the first construction stage or the first five years of operation. External requirements (e.g. funding agencies) may deviate from this value and should be clarified at an early stage.

12 Heat distribution design

12.1 Introduction

Chapters 2 and 11 explained in detail the project procedure for quality monitoring with QM for Biomass DH Plants and the demand assessment and appropriate system selection in general. Chapter 12 gives an overview of general requirements for the design of heat distribution as well as the most important key figures and terms. For more details please refer to the Handbook on Planning of District Heating Networks [19].

As shown in Figure 8.1 a heating network consists of one or more central heating plants, one or more main pipes, one or more branch pipes and the house connection pipes. Since a heating network is a costly infrastructure project with a long service life, subsequent changes are difficult to implement and associated with high costs - the same applies to remedying defects, such as leaks or burst pipe. Due to the long service life, a careful balance must be made between a foresighted expansion reserve with increased investment costs and heat losses and a tight line dimensioning. This difficult task must be approached situationally and with strategic foresight. In the case of capacity bottlenecks, there are optimisation options such as load management, decentralised heat storage, lowering the return temperature, integrating decentralised heat generators or ring connection. In the case of an oversized heating network, on the other hand, there are hardly any optimisation options other than selling more heat.

Heat distribution or heat network design is an iterative and cross-sectoral process and must be considered holistically as a system with demand assessment, system selection and network expansion in stages.

The following explanations and key figures consider the third generation of heat distribution with warm water temperatures < 110 °C, buried and permanently connected pre-insulated plastic jacket pipes and compact indirect transfer stations (see [19], page 65 ff.). The final chapter 12.5 deals with the further development of district heating network technology, which is characterised by lower temperature levels and increases in complexity due to the integration of diverse systems.

12.2 Key figures and terms

12.2.1 Potential supply area

The tools and methods described below for identifying potential supply areas serve as an aid for the initial evaluation and rough assessment in a feasibility study (see also chapter 11). Detailed planning is mandatory for an investment decision.

In addition to the conventional estimation of potential supply areas, digital information sources such as GIS tools, cadastral maps or similar are increasingly available, which offer data on heating and cooling demand as well as other useful information. These include, for example, the following free web-based software (see also Figure 12.1):

- THERMOS [113] is used to plan and optimise district heating networks according to user and project-specific requirements such as budget, climate and energy targets. With THERMOS, instant mapping and integrated energy demand estimations are possible.
- Hotmaps-Toolbox [114] and PETA 5.1 [112] support authorities, energy service companies and planners in strategic heating and cooling planning at local, regional and national level. The two tools contain data for estimating heating and cooling demand in European regions (hotmaps incl. Switzerland and Norway).
- From map.geo.admin.ch [115] there is a similar software to the Hotmaps-Toolbox for Switzerland. It contains data for estimating heating and cooling demand. In addition, over 1,000 existing thermal networks are mapped.

For an estimation of heat demand density in a heat supply area, the annual heat demand for space heating, domestic hot water and process heat of individual buildings can also be roughly estimated. The following methods are used for this purpose, which are described in more detail in chapter 6.4.2 of the Handbook on Planning of District Heating Networks [19]:

- Estimation of annual heat demand via energy reference area and building quality.
- Estimation of annual heat demand via building volume and building quality.

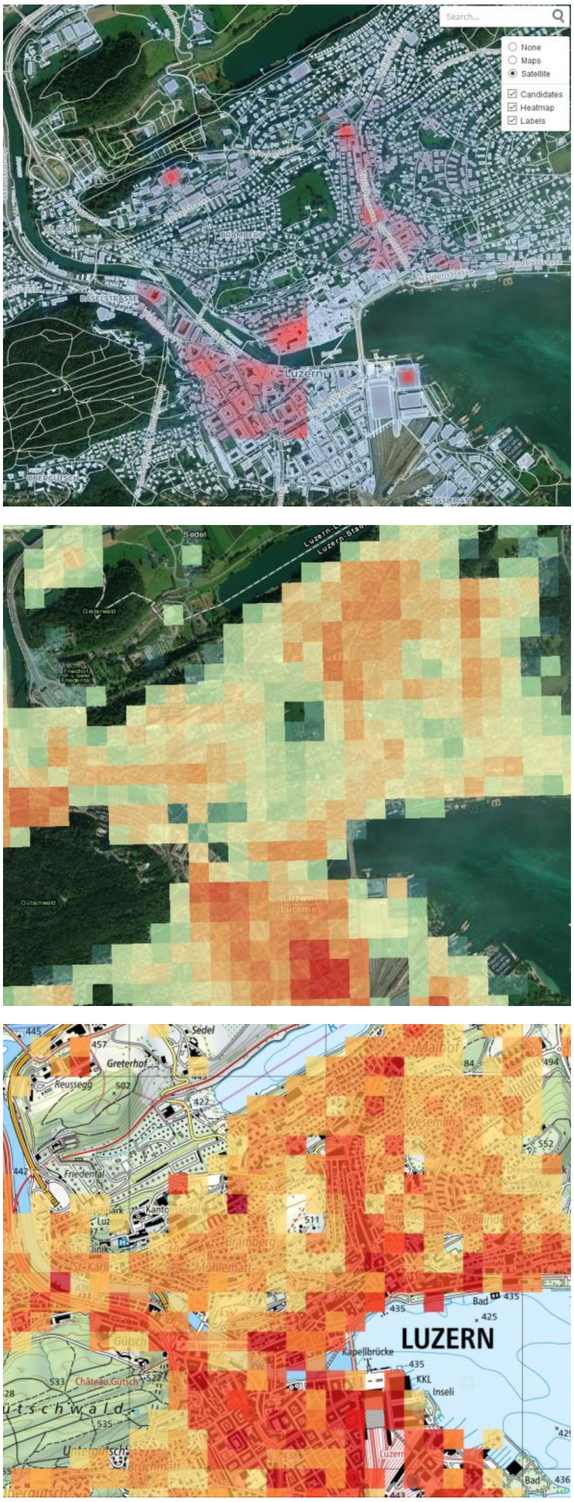


Figure 12.1 Map section from THERMOS (top), Hotmaps toolbox (middle) and map.geo.admin.ch (bottom) for the city of Lucerne (CH). The coloured fields represent different heating and cooling demand values.

12.2.2 Heat demand density

The heat demand density is a suitability criterion of a supply area for connection to a district heating network. It relates the annual heat consumption of all buildings in an area to the total area of the territory. It is recommended to use Table 12.1 for the assessment of heat demand densities.

Table 12.1 Recommended heat demand density of a zone as a suitability criterion.

Suitability for heat network	Heat demand density kWh/(m²*a)
Not suitable	< 50
Conditionally suitable	50 - 70
Suitable	> 70

Statements of the heat demand density

- Single-family house neighbourhoods are generally not of interest (heat demand density 15 - 30 kWh/(m²*a)).
- Areas with dense construction, such as multi-family house neighbourhoods, village or town centres, of interest.
- The heat procurement density and the economic efficiency of a heating network can be improved if the large consumers located in the area (key customers) are integrated as a priority.
- A heating network for a single large consumer is usually only of interest if the surrounding areas also have a high heat procurement density.
- A heat network can also be set up for only a few large consumers, provided that a suitable heat procurement density results from the corresponding local proximity.
- With low investment and fuel costs or low heat losses (high insulation standard, low supply temperatures), areas with a lower heat demand density than 70 kWh/(m²*a) can be economically connected to district heating.

12.2.3 Key customers

In addition to the heat procurement density as a measure of the suitability of an area, properties with large heat consumption, also referred to as key customers, are essential for the economic operation of a district heating network.

An early survey of key customers should clarify the interest in connection and provide planning data. Often, suitable data is not available for existing buildings or special structures, especially for industries with process heat, or it is costly to collect it. To keep costs low, in the preliminary study, verbal enquiries and qualified estimates should be used.

12.2.4 Degree of development

In a potential supply area, it is rare that all buildings are connected. Particularly in the case of new developments of larger supply areas, for example in a feasibility or preliminary study, the annual heat demand in an area must be taken into account with the so-called degree of development or connection. The degree of connection should be considered according to the situation and can be between 50 % and 80 %.

12.2.5 Concurrency factor

For dimensioning the heat distribution network, a concurrency factor must also be taken into account. In a network with many heat consumers, this factor describes the effect that at no time all heat consumers draw the maximum power simultaneously, and is calculated from the maximum simultaneously occurring heat capacity demand in relation to the total subscribed heat capacity demand.

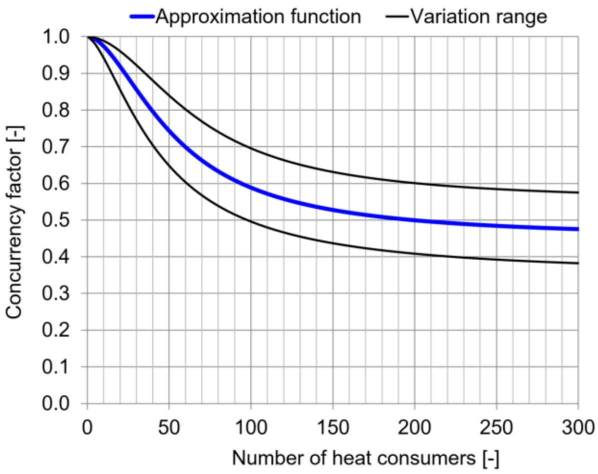


Figure 12.2 Proximity function and scatter range for concurrency factor approximation based on the number of connected customers (see [19]).

Figure 12.2 shows the concurrency factor as an **approximation function** depending on the number of customers. Accordingly, with 10 to 20 customers, a simultaneity of about 95 % in the range of 85 % to 100 % can be expected. For connections with more than 100 heat consumers, a simultaneity of about 60 % can be assumed.

The decisive factor for determining the simultaneity is the **customer structure**. Permanent process heat consumers lead to a higher simultaneity than, for example, a neighbourhood of single-family houses. A temporary or seasonal heat demand reduces the simultaneity, whereas seasonal peak loads lead to increased concurrency factors, for example during the holiday season in winter sports resorts with maximum occupancy of hotels and holiday flats. The estimation of simultaneity is based on a profound knowledge of the consumer structure and experience.

When using the **Excel tool for demand assessment and appropriate system selection** of QM for Biomass DH Plants, it should be noted that no concurrency factor is used, as the design of the heat generator is based on a daily average power demand, which means that the described effect is already taken into account, similar to the concurrency factor.

12.2.6 Connection density

District heating networks are assumed to be economically viable if the revenue from the sale of heat exceeds the heat production costs from capital and operating costs. An important indicator for estimating economic efficiency is the connection density (also called linear heat density). The connection density is the ratio between the annual quantity of heat sold in MWh/a and the total trench length of main, branch and house connection pipelines in metres. Similar to the heat demand density, the linear heat density can also be calculated for individual sub-networks or branches and used for assessment.

For a rough assessment without more detailed knowledge of the boundary conditions, supply areas with a linear heat density > 2 MWh/(a*m) are generally considered attractive in the final expansion and with year-round operation. General conditions such as revenue from heat sales, favourable fuel costs, low heat losses (high insulation standard, low network temperatures) or favourable construction conditions as well as investment subsidies enable economic operation even with lower connection densities.

The connection of small consumers in the vicinity or along a route is generally desirable and normally not critical in terms of connection density. However, if a small consumer is located far away from the next main or branch pipeline, it reduces the connection density, which is why a corresponding connection can be unattractive and must be examined on a situational basis. The connection can be linked to a contribution to the additional connection costs or an increased heat price.

More detailed explanations are described in the Handbook on Planning of District Heating Networks [19] in chapter 6.4.4.

12.2.7 Specific investment costs

The specific costs of heat distribution show a wide range and are mainly determined by construction conditions, pipe type, local prices, development progress and connection density.

In rural areas, the costs for laying district heating pipes are generally lower than in urban areas. In urban areas, existing service pipes, building structures, the condition of the subsoil, high reconstruction costs (asphalting, paving, etc.) as well as difficult traffic conditions prevent an optimal pipe routing, which sometimes causes considerable additional costs.

If the target value of the specific investment costs cannot be achieved in a quality monitoring according to QM for Biomass DH Plants, higher values can be agreed upon in consultation with the investor and the capital providers. In this case, it must be examined how the higher specific investment costs of heat distribution affect the economic viability in the long term, especially with regard to possible price increases, for example due to higher fuel prices. In both cases, the economic viability should be demonstrated with a business plan and a budgeted balance sheet and budgeted income statement. More detailed explanations are described in chapter 10.

12.2.8 Heat distribution losses

Heat distribution losses are, like the connection density, an important parameter that influences economic efficiency. They depend on the following factors:

- Dimensioning of the pipelines
- Performance of the pipeline insulation (U-value)
- Temperature level of flow and return
- Temperature profile during operation (constant, sliding or constant-sliding)
- Connection density
- Duration of operation (year-round or seasonal operation).

In operation, heat distribution losses are determined as the difference between the heat quantity supplied to the district heating network by heat generation and the heat quantity drawn from all connected customers (see Handbook on Planning of District Heating Networks [19] chapter 7.1.4). The heat distribution losses can be considered in absolute or relative terms, usually in relation to the amount of heat fed into the system. In relative terms, the heat losses in summer are significantly higher than in winter, whereas in absolute terms the difference is almost negligible.

Figure 12.3 shows the relative (percentage) annual heat distribution losses as a function of the linear heat density for different operating modes and flow temperatures. For efficiency reasons, according to QM for Biomass DH Plants, heat distribution losses should not exceed a target value of 10 % of the useful heat demand. In order to meet the target value according to Figure 12.3 different connection densities must be achieved depending on the operating mode, temperature level and investment costs.

In an operating heating network, the relative heat distribution losses can be reduced in the first instance by increasing the connection density (compression), which improves the overall economic efficiency.

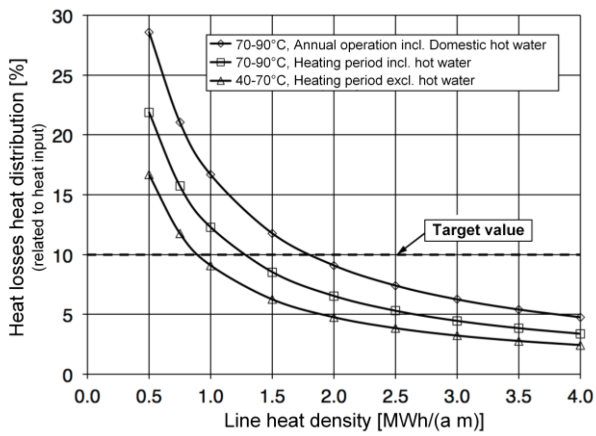


Figure 12.3 Heat distribution losses as a function of linear heat density for different operating modes and flow temperature levels of the heating network.

12.2.9 Deviation from efficiency criteria

As already described in chapter 12.2.6, cost-effective construction and operating conditions enable an economic operation of a heating network even with lower connection densities.

When considering unavoidable waste heat (e.g. processes and industry), there are also conflicting goals in terms of efficiency (low heat distribution losses) and cost-effectiveness (low investment). Since the waste heat sources are often not located in the immediate vicinity of connected customers, it would make sense if lower connection densities were also permitted for waste heat utilisation, for example by accepting higher heat losses for the connection or transport line.

No conclusive answer or recommendation can be given to this question at this point. In principle, however, it should be possible under certain circumstances to allow lower efficiency requirements as long as the use is based on a resource-conserving application and mainly on CO_2-neutral energy sources. The assessment should therefore always be made on a situational basis and adapted to the respective framework conditions on the part of the legislator, acceptance in the population and more.

12.3 Project procedure

A heating network comprises heat generation, heat distribution and heat transfer to the customers. The following description of the project process includes the planning tasks for heat distribution from heat generation to and including heat delivery to customers and is described in detail in chapter 6 of the Handbook on Planning of District Heating Networks [19]. A basic distinction is made between a planning phase and an operating phase.

Table 12.2 lists the planning phases and the corresponding activities and tasks. The dimensioning of the pipe diameters is dealt with in the next chapter.

Table 12.2 Planning phases and activities according to the Handbook on Planning of District Heating Networks (see [19], page 103 ff.).

Planning phase	Activity / Task
Pre-study	Determine potential heat supply area
	Determine key customers
	Update heat supply area
	First economic feasibility study
	Decision for further development
Design planning	Specify the key customers
	Survey of small customers
	Determine heat supply area
	Second economic efficiency analysis
	Decision on implementation
Tender planning	Design of heat network
	Specification transfer stations
	Building permit
	Tender and submission
	Third profitability analysis
	Award, execution and acceptance

12.4 Dimensioning of pipe diameters

The pipe diameters are always dimensioned on the basis of the specific pressure loss per metre of pipe length in Pa/m. Figure 12.4 shows the recommendations for maximum flow velocities according to ÖKL-Merkblatt 67 [101] and according to the Swedish District Heating Association DHA [77]. For comparison, the flow velocities corresponding to a constant specific pressure loss of 100, 200 and 300 Pa/m are drawn [121].

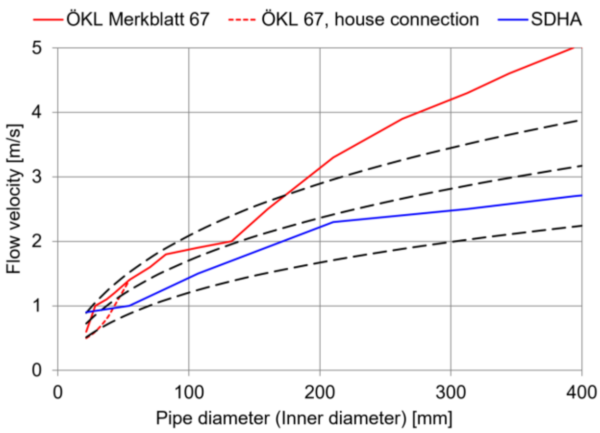


Figure 12.4 Flow velocities as a function of the internal pipe diameter with recommendations for maximum flow velocity according to ÖKL-Merkblatt 67 [101] and the Swedish District Heating Association (DHA) [77].
In addition, the flow velocities at constant specific pressure drops of 100, 200 and 300 Pa/m are shown [121].

Results of the practical survey

A practical survey of 52 district heating networks showed that about 80 % of the main and sub-pipes were larger than would have been effectively necessary [121]. The oversizing usually corresponds to one or two, but in some cases up to four nominal diameters, and it causes significantly higher heat losses and costs compared to a heating network with the smallest possible pipe diameter.

12.4.1 Recommendations for Dimensioning

The dimensioning of the pipe diameters is based on the planned or expected final expansion. Due to the long service life, a long-term strategic consideration is indispensable, but also associated with corresponding uncertainties and difficulties. A careful balance must be struck between a precautionary expansion potential with increased investment costs and heat losses and a generally tight dimensioning of the pipelines.

In addition, the appropriate choice of pipe system and insulation standards, the pressure rating, the installation situations and methods, as well as data transmission and leakage monitoring must be taken into account. In addition, there are pipe static and operational temperature specifications such as continuous operating temperature in winter and expected return temperature.

Based on the boundary conditions listed above, the pipe diameters are dimensioned according to the following **recommendations:**

- Hydraulic pipe roughness k ≤ 0.01 mm
- Design of individual sub-pipelines for a specific pressure drop of 250 Pa/m to 300 Pa/m

- Control variable for longer pipeline sections with different nominal diameters (e.g. critical node) with average specific pressure drop of 150 Pa/m to 200 Pa/m

For an initial estimate and dimensioning, the transmission capacities at different temperature spreads and specific pressure losses are shown graphically for different pipe systems in the Handbook on Planning of District Heating Networks (see [19], page 191 ff.).

12.4.2 Dimensioning procedure

The procedure for dimensioning the heating network is described in detail in chapter 7.3 of the Handbook on Planning of District Heating Networks (see [19], page 130 ff. and design tables page 191 ff.).

The starting point is a pipeline plan or a pipeline diagram in which the pipes are divided into sections. A section is defined as a pipe without a branch and a change in nominal diameter. For the design, the following information must be defined for the sections:

- Numbering of the section
- Heat capacity of the section
- Flow of the section
- Length of the section
- Individual resistances of the section (consideration of changes in direction and fixtures)
- First pipe dimensioning of the section.

Important: Determining the optimum nominal diameter is an iterative process.

12.4.3 Calculation methods

The calculation of the pressure loss and the resulting dimensioning of the pipeline can be done in different ways, either by hand with the help of tables, charts and forms for pipe network calculation or using special calculation programs.

There are a large number of pipe network calculation programs available for this purpose (e.g. from building and installation technology). Some of them are only used to calculate pressure losses, such as the pressure loss Excel tool from the Lucerne University of Applied Sciences and Arts [122].

There are also more comprehensive calculation programmes specifically for district heating applications that are suitable for calculating large heating networks. These often have comprehensive interfaces for importing and exporting data (e.g. GIS data) and cover all district heating-relevant aspects of the calculation such as pressure loss, heat loss, critical node, dimensioning, optimisation, network analysis and others. There are a variety of commercially available calculation programs such as:

- STANET of the engineering office Fischer-Uhrig [123]
- ROKA GS of the computer centre for supply networks Wehr GmbH [124]
- SIR-3S from 3S-Consult GmbH [125]
- THENA from Verenum AG [106]

Most programmes have preset values (e.g. for pipe roughness), but these should not be used without careful verification. All relevant calculation parameters are usually freely configurable and should always be carefully checked and set.

12.5 Developments in heat network technology

Classical district heating networks transfer heat from the source (heat generator) with flow temperatures of > 60 °C and sometimes up to > 150 °C to the sink (heat consumers) [77] and are called “high-temperature networks” according to Figure 12.5. They serve to supply buildings with space heating and domestic hot water as well as processes.

Low-temperature networks refer to networks for the exchange of heat that operate at temperatures below 60 °C. This allows direct supply for space heating down to a lower limit of around 30 °C. Decentralised heat pumps are required for domestic hot water preparation. At flow temperatures below 30 °C (see Figure 12.5), decentralised heat pumps are required for both space heating and domestic hot water preparation. Low-temperature networks can also be used as a source for decentralised heat pumps that supply downstream conventional high-temperature distribution networks.

At temperatures below 20 °C, the grid can also serve as a heat sink and thus supply cooling. In the latter case, the application is also referred to as district cooling. Applications for heat distribution below 30°C are sometimes also referred to as “cold district heating” or “anergy network”. Since “anergy network” is physically imprecise, this term is not used in this document.

Thermal networks serve as a generic term for networks for the transfer of heat at all temperature levels (see Figure 12.5). As described above, they are differentiated on the basis of **flow temperature**. In addition, there are also different **operating modes** with regard to the direction of flow of the water (directional or non-directional) and the energy flow in the system (unidirectional or bidirectional; see [126]).

The trend in the development of district heating technology, especially also for existing high-temperature grids, is towards lower system temperatures in order to enable low-loss and efficient heat distribution, to increase the efficiency and yield of renewable heat sources and to develop new low-temperature heat sources. However, which system temperatures and network technology are chosen depends very much on the available heat sources and the framework conditions of the respective project. Accordingly, low-temperature grids are not always more suitable than high-temperature grids.

Typical fossil heat sources for district heating supply (fossil CHP plants, gas boilers) will no longer be available as heat sources in the medium term. Other high-temperature heat sources for district heating, such as CHP waste heat from waste incineration and wood-fired heating and CHP plants, will increasingly be supplemented by other **renewable energy sources** and other waste heat sources in the future:

- Environmental heat as a heat source for central and decentralised heat pumps for heating or as a heat sink for passive cooling of buildings (free cooling) with use of:
  - Surface water (lakes and rivers)
  - Groundwater (various depths)
  - Geothermal energy (especially borehole heat exchangers).
- Waste heat from various energy sources, including thermal power plants, fossil or electrically powered industrial processes as well as waste heat from refrigeration plants, buildings and waste water and, depending on the region, also from geothermal power plants.
- Fossil fuels (for peak load and redundancy, limited in the future)

In addition, ambient air and solar radiation are available as heat sources. For heat pumps, heat sources other than air (for example seawater or geothermal heat) are more efficient for the required temperatures and outputs. Depending on the region and general conditions, solar thermal energy is already being used in various forms and its use will continue to increase.

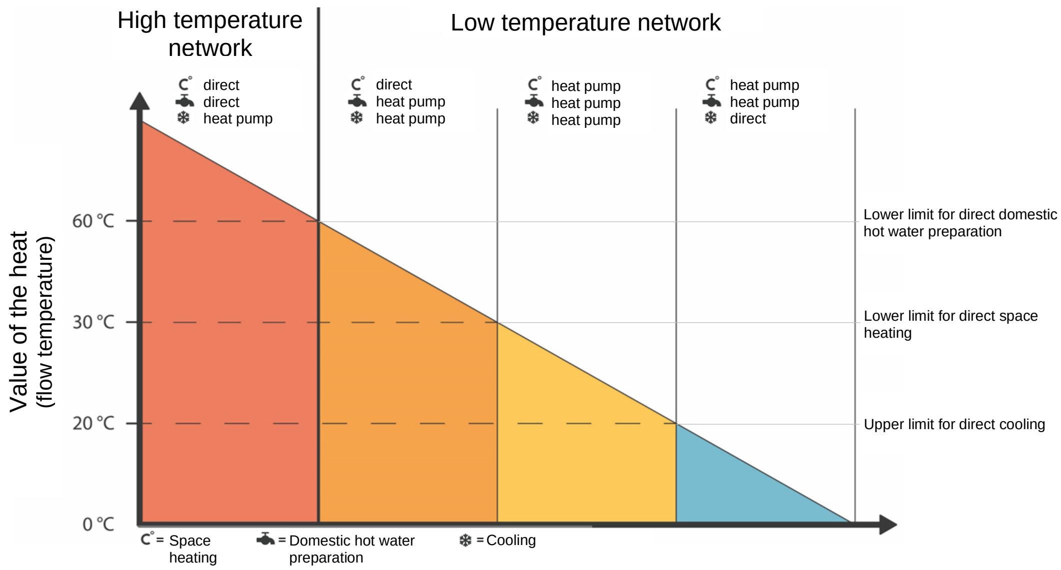


Figure 12.5 Classification of thermal networks as a function of flow temperature (according to [126] with additions).

Energy from biomass as a renewable resource will continue to play an important and supporting role in the future heat supply due to its regional availability, storability and flexibility (see chapter 1.3.2). Special advantages of low heat network temperatures arise for biomass DH plants due to the reduced transmission losses and especially in combination with flue gas condensation, where significantly higher yields can be achieved at low supply temperatures (see chapter 13).

Biomass DH plants can be integrated into low-temperature concepts in a wide variety of ways. For example, cascading heat utilisation can be achieved by decoupling heat from the return for low-temperature sub-networks. Conversely, a low-temperature heat source can be integrated into a heat network via a low-temperature transport pipeline and a central heat pump.

There are many current and planned projects for the further development of concepts and technologies in the area of thermal grids. Some of these are pilot and demonstration plants, which are not always fully developed for the market or are too specialised. The aim of QM for Biomass DH Plants and of this Planning Handbook is an efficient, resource-saving and low-emission operation of biomass DH plants and thermal networks. Based on this, the following general principles can be formulated for thermal networks and the interaction of different renewable heat sources:

- Best possible and resource-saving use of all regionally available heat sources
- Use of local sources before non-local sources
- System configuration and dimensioning of the individual heat generators and heat storage tanks done in such a way that all heat sources are operated within optimal and permissible operating conditions (capacity, temperature).
- Minimising heat losses in the heating network

As soon as biomass DH plants are part of an overall system, the principles and recommendations of this Planning Handbook for efficient and low-emission operation of biomass boilers should be applied mutatis mutandis or as far as possible (see chapter 13.7). Furthermore, no generally valid recommendations can be derived from the current state of knowledge as to which concepts are sustainable and which are not. It can be assumed that, given the large number of concepts, not all of them will be successful in the long term.

To analyse the current situation, around 1,000 networks were recorded in the “Thermische Netze” programme of EnergieSchweiz [115]. In addition to two classic district heating networks, the analysis also describes seven case studies of thermal networks with flow temperatures below 40 °C [127]. The “Low-Temperature District Heating Implementation Guidebook” of the International Energy Agency (IEA) [128] offers further literature on the topic of low-temperature networks and a large number of demonstration examples.

13 System selection of heat generation

13.1 Introduction

After important basic data such as annual heat production and total heat capacity demand are known from the demand assessment and the design of the heat distribution, chapter 13 deals with heat generation design. Depending on the total heat demand and the desired distribution of the heat demand among the heat generators, a basic variant of the heat generation systems is selected. The inclusion of other renewable heat sources and renewable heat generator systems, the use of efficiency-increasing measures and the possibilities of combined heat and power (CHP) should also be examined. The selection of heat generators in turn influences the design of the heating system, the hydraulics and the chimney system. Legal issues, safety, noise protection and emission requirements must be ensured.

13.2 Ecological comparison with other heat sources

13.2.1 Overview

When choosing a heating system today, environmental compatibility or sustainability are always in the foreground as well as costs. Although a precise and generally valid assessment of environmental compatibility is not possible, various parameters and methods are available that can be used for a qualitative comparison of different variants within the framework of system planning.

If only the local influence, for example on noise or the ambient air, is to be assessed, corresponding surveys can be carried out on the operation of the system. In the case of air quality, a comparison of the emissions of different heating systems is useful. Emission factors for individual types of installations are collected by the environmental authorities, regularly updated and, for example, made available in Switzerland by the Federal Office for the Environment in the “Factsheet on Emission Factors for Furnaces” [129].

For a more detailed assessment, however, the effects of upstream and downstream processes such as construction of the plant, procurement of the fuel, auxiliary energy consumption and disposal must be taken into account over the entire process and the expected lifetime of the plant. A comprehensive assessment is carried out using a life cycle assessment (LCA).

Particularly important for the assessment of energy plants are energy efficiency and climatic impact, which can be quantified as follows:

- **Assessment of energy efficiency** (mostly related to primary energy):
  Cumulative energy demand (mostly stated as primary energy factor) and optionally derived from this the energy payback period as well as the energy harvesting factor.
- **Assessment of the climatic impact:**
  Determination of the total greenhouse gas emissions (CO_2 or GHG equivalent)

Although the collection of this data requires life cycle accounting, the data obtained describes a single physical entity that can be quantified without subjective weighting of different effects.

If a comprehensive assessment of various environmental impacts is required, individual environmental areas can be assessed separately (e.g. “critical volumes” in the form of indicators for critical air volume, critical water volume, waste volume and energy equivalent). In Germany, the evaluation method of the “UBA impact indicators” developed by the Federal Environment Agency (UBA) is used for this purpose. The aim of this method is to rank various environmental impacts, which requires a subjective evaluation of individual impacts.

In other methods, the environmental impacts are aggregated into a single indicator. This is done, for example, by using the “ecological scarcity method” used in Switzerland to so-called “environmental impact points” (EIP), which also requires a subjective weighting of individual environmental impacts. In Switzerland, the determination of the EIP is used to assess sustainability in the building sector. Corresponding data are made available in a recommendation of the “Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren” - Coordination Conference of Building and Real Estate Bodies of Public Builders (KBOB). This shows data on the primary energy factor, greenhouse gas emissions and environmental impact [130].

The box below describes the characteristics of the methods mentioned.

Assessment of energy efficiency

Cumulative energy demand (CED)

The CED comprises the energy input for the production, use and disposal of a system or product [131]. As a rule, the primary energy is assessed and the CED is then also referred to as the "**primary energy factor**". The energy payback period can be determined from the CED and the annual energy production.

Harvesting factor HF = CEP/CED

If an expected lifetime is also assumed for the system, the energy harvesting factor (HF) can also be determined from the CED and the cumulative energy production (CEP) during the lifetime. According to this definition, HF < 1. The HF value can be used, for example, to compare two systems for the energetical use of biomass. For a comparison of an oil heating system with a wood heating system, however, this definition is not useful. For this purpose, a harvesting factor can be determined under the condition that non-renewable primary energy is counted as demand, while renewable primary energy is not considered.

With index RE for renewable energy applies:

$\mathbf{HF_{RE}} = CEP/CED_{RE}$

With index NR for non-renewable energy applies:

$\mathbf{HF_{NR}} = CEP/CED_{NR}$

As a rule, the following applies for fossil energy sources:
$HF_{NR} = HF < 1$ and for renewables:
$HF_{NR} > 1 > HF$.

This method enables a comparison of the resource efficiency of different energy systems, with $HF_{NR} > 2$ to > 10 possible for renewable energy sources and EFNE < 1 for non-renewable energy sources.

For CED, the following also applies:
$\mathbf{CED_{RE} + CED_{NR}} = CED$

Assessment of climatic impact

Green house gases (GHG) equivalent

Water vapour, CO_2, methane (CH_4) and numerous other gases and particles in the atmosphere influence the Earth's radiation budget, which is described as the greenhouse effect. The CO_2 equivalent or GHG equivalent serves as a measure of a change in the greenhouse effect. This describes the contribution of a compound to the greenhouse effect compared to CO_2 over a certain period of time. A period of 100 years is usually considered. For 100 years, for example, 1 kg of methane (CH_4) has a CO_2 equivalent of 28 kg of CO_2. For nitrous oxide ("laughing gas", N_2O) this value is 265. If all greenhouse-relevant emissions of a process are added up over the life cycle, the GHG equivalent can be determined. For fossil fuels, the GHG equivalent is usually dominated by CO_2. For other processes, CH_4 (e.g. biogas) or N_2O (e.g. crop cultivation) can also be important.

Life cycle assessment with evaluation of various environmental impacts in different impact categories

Examples are the CML method with 14 categories or the Eco-Indicator method with 9 categories (radioactivity, ozone depletion, heavy metals, carcinogenicity, summer smog, winter smog, pesticides, greenhouse effect, acidification and eutrophication). These methods allow a summary comparison of numerous environmental impacts. However, if, for example, wood is to be compared with petroleum in a single figure, a weighting of the greenhouse effect is necessary.

Life cycle assessment with evaluation according to ecological scarcity

Here, the assessment is made in relation to regional or country-specific targets and by summing up environmental impact points (EIPs). This method allows a simple assessment of the sensitivity of important influencing factors such as emissions from wood heating systems. However, the overall assessment is oriented towards a subjective target definition such as exceeding or falling below national limit values.

13.2.2 Examples

Table 13.1 shows a comparison of the harvesting factor HF_{NR} (without evaluation of the renewable energy used) of different heating systems, in which the influence of a district heating network was also examined. The highest values of automatic wood heating systems of 13.0 are achieved by systems without a district heating network. The inputs and losses of the grid lead to somewhat lower harvesting factors of around 9 for typical connection densities. At low connection densities, the harvest factor decreases.

Table 13.1 Harvesting factor HF_{NR} of different heating systems given in TJ useful heat per TJ non-renewable primary energy. For district heating, the influence of the linear heat density is also shown in MWh/(a*m). Data according to [131].

Supply chain	HF_{NR} [TJ/TJ]
Wood pellets	8.3
Wood chips with district heating at 0.6 MWh/(a*m)	7.9
Wood chips with district heating at 1.5 MWh/(a*m)	9.0
Wood chips with district heating at 3 MWh/(a*m)	9.4
Wood chips without district heating	13.0
Lump biomass boiler	13.8
Fuel oil boiler with flue gas condensation	0.71
Natural gas heating with flue gas condensation	0.74

As oil and gas heating systems achieve a harvest factor between 0.71 and 0.74, wood heating systems achieve a substitution effect for non-renewable energy sources that is higher by a factor of 10 to 20. The substitution potential results from the ratio of the harvest factors of wood heating systems and fossil heating systems (e.g. 14/0.7 = 20). This means that one litre of petroleum invested in the construction and operation of wood heating systems substitutes 10 to 20 litres of petroleum required for an oil heating system with equivalent benefits. Since fossil energy sources cause CO_2, this factor is also an indicator for the substitution of fossil CO_2 emissions.

Figure 13.1 shows an example of a life cycle assessment according to the eco-indicator method. As all environmental effects are combined into one indicator, the order of the variants examined depends on the weighting of the greenhouse effect. With a "high" weighting of the greenhouse effect, wood heating is rated significantly better than fossil heating, while with a "low" weighting of the greenhouse effect, gas heating performs best, which illustrates the problem of aggregated weighting.

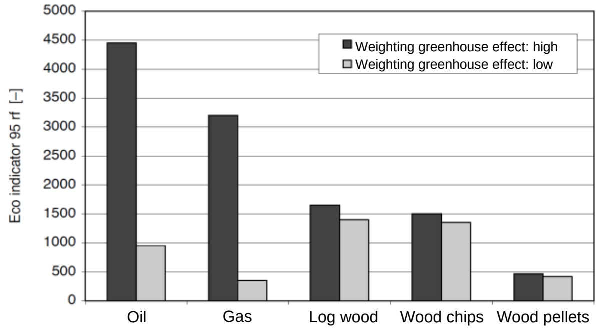


Figure 13.1 Environmental impact as eco-indicator points per TJ of useful energy for oil, gas and wood heating systems for the weighting variants of the greenhouse effect "high" and "low" according to data from [132].
More than 80 % of the values for logs and wood chips are due to fine dust and nitrogen oxide emissions. For modern wood chips heating systems with fine dust separators, the value would be about one third.

Table 13.2 shows an extract from the *Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren* (KBOB Recommendation) [130] for assessing sustainability in the building sector in Switzerland. The data on the primary energy factor and the cumulative energy expenditure are shown in Figure 13.2 (left) where only the non-renewable primary energy is assessed (index NR). The data show that the energy wood systems achieve high harvesting factors and can reduce the consumption of non-renewable energy by around 80 % to 90 % compared to heating oil and natural gas. A similar effect is achieved in terms of greenhouse gas emissions, as shown in Figure 13.3 (left).

In contrast, Figure 13.3 (right) shows that the differences in the environmental impact points are smaller than the differences when considering the primary energy or the greenhouse effect. By taking all environmental impacts into account, the advantage of natural gas over heating oil becomes greater, while the advantages of wood heating systems over fossil heating systems become smaller.

For the coming decades, however, the highest priority must be given to greenhouse gas emissions, as the most important challenge is to achieve climate targets. As Figure 13.3 (left) shows, biomass heating and solar thermal systems are particularly advantageous in terms of greenhouse gas emissions. Heat pumps are also of interest, provided they are operated with low CO_2 electricity. The data for heat pumps shown in Table 13.2 apply to an electricity purchase from the grid in Switzerland with 0.102 kg CO_2 per kWh electricity. For other countries the corresponding CO_2 intensity of the electricity has to be considered. Table 13.2 shows the data for Austria, Germany and Italy. Electricity in these countries has a higher CO_2 intensity by a factor of about 2, 4 and 6. For factor 2, the advantage of heat pumps over fossil heating is reduced, factor 4 results in similarly high GHG emissions, while for CO_2-intensive electricity with factor 6, heat pumps result in higher CO_2 emissions than fossil heating.

Table 13.2 Primary energy factor or cumulative energy demand (CED), harvesting factor (HF), greenhouse gas emissions (GHG) and environmental impact points (EIP) of different heating systems related to the useful heat produced. The harvesting factor HF_{NR} was calculated as the reciprocal of CED_{NR}. The data for the heat pumps apply to the Swiss electricity mix, whose characteristic values are given at the end of the table. Data according to [130] except data on electricity in Austria, Germany and Italy according to [133].

	Primary energy (Oil-equivalent) = cumulative energy demand CED			Harvesting factor	Greenhouse gas emissions	Environmental impact points
	Non-renewable (CED_{NR})	Renewable (CED_{RE})	Total (CED)	Non-renewable (HF_{NR} = $1/CED_{NR}$)	GHG	EIP
Boilers[1)]	kWh/kWh Q_u			kWh Q_u/kWh	kg CO_2/kWh Q_u	EIP/kWh Q_u
Heating oil extra light	1.300	0.007	1.31	0.77	0.322	251.0
Natural gas	1.160	0.005	1.17	0.86	0.249	151.0
Log wood	0.194	1.580	1.77	5.2	0.045	152.0
Log wood with particle filter	0.198	1.580	1.78	5.1	0.046	144.0
Wood chips	0.097	1.420	1.52	10.3	0.020	116.0
Wood chips with particle filter	0.100	1.420	1.52	10.0	0.020	106.0
Pellets	0.210	1.320	1.53	4.8	0.038	108.0
Pellets with particle filter	0.213	1.320	1.53	4.7	0.038	103.0
Biogas	0.330			3.0	0.142	121.0
Heat pump air/water (annual COP 2.8)	0.908			1.1	0.063	149.0
Heat pump earth collector (annual COP 3.9)	0.665			1.5	0.046	110.0
Flat plate collector DHW SFH	0.275			3.6	0.037	102.0
Flat plate collector SH+DWH SFH	0.221			4.5	0.034	90.0
Flat plate collector DHW MFH	0.086			11.6	0.014	40.7
Vacuum tube collector SH+DHW SFH	0.193			5.2	0.031	76.5
District heating[2)]	kWh/kWh_{end}			kWh_{end}/kWh	kg CO_2/kWh_{end}	EIP/kWh_{end}
Biomass heating plant	0.143	1.580	1.72	6.99	0.050	120.0
Biomass CHP plant	0.128	1.330	1.46	7.81	0.042	102.0
Heating plant waste water heat pump (annual COP 3.4)	0.894			1.1	0.041	124.0
Heating plant ground water heat pump (annual COP 3.4)	0.963			1.0	0.062	155.0
District heating from waste incineration (average CH)	0.452			2.2	0.089	75.5
Biogas CHP plant	0.207			4.8	0.079	72.9
Electricity from the grid[2)]	kWh/kWh_{end}			kWh_{end}/kWh	kg CO_2/kWh_{end}	EIP/kWh_{end}
Switzerland (CH-consumer mix)	2.520	0.488	3.01	0.40	0.102	347.0
Austria[3)]	0.820	0.980	1.80	1.22	0.202[4)]	170.0
Germany[3)]	1.760	0.830	2.59	0.57	0.427[5)]	400.0
Italy[3)]	2.760	0.320	3.08	0.36	0.610	489.0

Abbreviations: COP: coefficient of performance, Q_u: useful heat, DHW: domestic hot water, SH: space heating SFH: single-family house, MFH: multi-family house

[1)] For boilers, the reference value is 1 kWh of useful heat.
[2)] For district heating and electricity, the reference quantity is 1 kWh end (final) energy (trading unit).
[3)] Source: [133], all other data according to [130].
[4)] Current figures and applicable values for CO_2 emissions in Austria are provided by the Federal Environment Agency https://www.umweltbundesamt.at/
[5)] Current figures and applicable values for CO_2 emissions in Germany are provided by the Federal Environment Agency https://www.umweltbundesamt.de/

For heating oil, natural gas and wood fuels, KBOB shows values for CED that are greater than 1 and comparable with each other. For biogas and refuse-derived fuels, CED < 1 is shown, as their primary energy share is not or only partially assessed. These values for CED = CED_{RE} + CED_{NR} are not comparable with others and are not listed in the table.

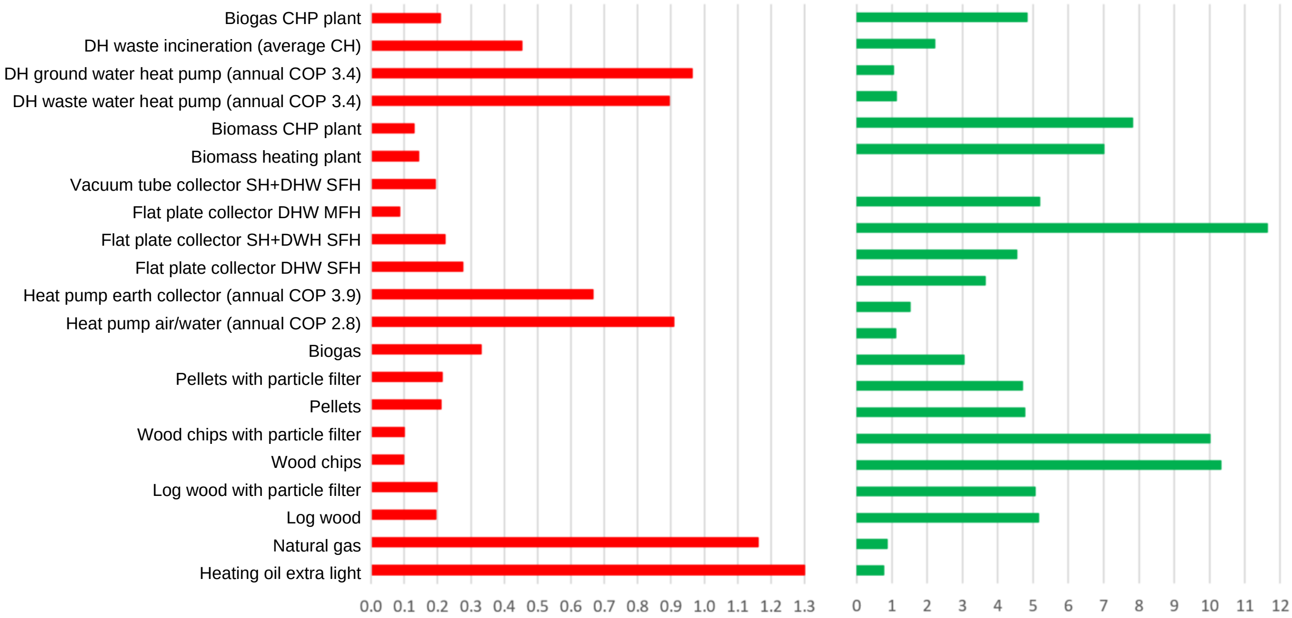


Figure 13.2 Left (red): Primary energy factor of non-renewable energy or cumulative energy demand CED_{NR}
Right (green): Non-renewable energy harvesting factor $HF_{NR} = 1/CED_{NR}$ according to Table 13.2.

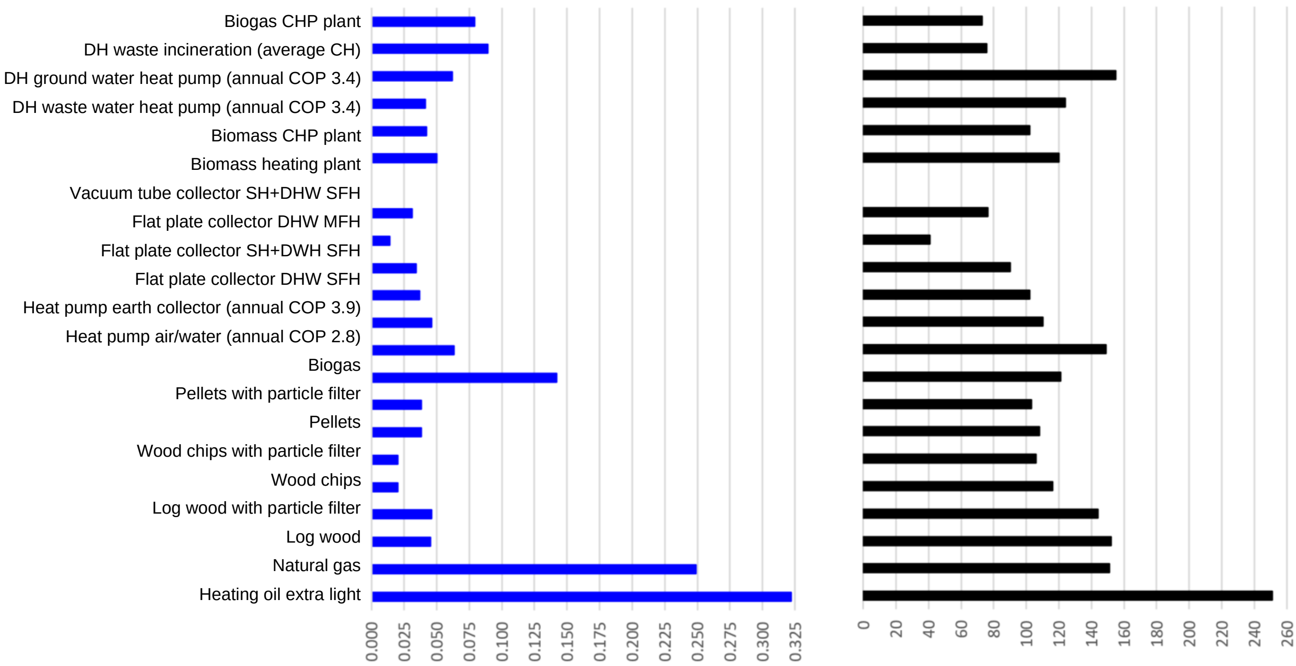


Figure 13.3 Left (blue): Greenhouse gas emissions in [kg CO_2-eq/kWh useful heat]
Right (black): Environmental impact points [EIP/kWh useful heat] according to Table 13.2.

13.3 General requirements and definition of important terms

Biomass DH plants must be operated with low emissions and economically. This requires an appropriate firing system for the fuel assortment, correct recording of the heat output of individual heat generators, a fuel storage volume (silo net volume) adapted to the fuel logistics and optimal hydraulic integration into the overall system. The objective is to achieve proven and economical installations by focussing on the essentials and simple concepts.

Depending on the progress of the project (milestone), the following should be defined as **objectives** with an increasing degree of accuracy:

1. Annual total heat demand[1)] or required annual heat production of heat generation
2. Total required heat capacity[1)]
3. Heat generation system (circuit, control concept)
4. Firing system of the biomass boiler
5. Allocation of the total heat capacity demand to the heat generators of the individual energy sources (fuels) including their heat production share[1)]
6. Dimensioning of the other components in the heating system (volume of fuel storage and heat storage, etc.)

[1)] according to Excel tool for demand assessment and appropriate system selection

When designing a biomass heating plant, the following specific characteristics must be considered:

- Long reaction time after changing the boiler output setpoint due to sluggish burning behaviour of the fuel depending on the water content and compaction (e.g. pellets)
- Biomass boilers can usually be operated in the output range from 30% to 100% in continuous combustion with uninterrupted combustion air supply and continuous fuel supply. An extension of the lower power range down to 15% is possible with suitable measures (e.g. combustion air preheating).
- Minimum required average daily heating load for low-load operation in the range of 10 % - 30 % of the rated biomass boiler output.

The optimal design of a biomass heating plant requires specific expertise and thus places increased demands on the planner. It is recommended that people or planning offices who are designing and planning a biomass heating plant for the first time consult experienced specialist planners for advice. In order to achieve the quality objectives of QM for Biomass DH Plants, the heat generation system must fulfil the following requirements and target values:

- **Low emissions**: The legally applicable limit values must not be exceeded during the stationary operating phase of a biomass combustion plant. This applies to all fuel assortments as well as in the entire output range of the firing system and therefore requires suitable control concepts.
- **Odour emissions** during the transient operating phases in low-load operation during the start-up phase, burn-out phase and firebed maintenance are to be avoided with the measures described in chapter 13.5 (Note Table 13.4).
- **High annual efficiency η_a > 85 %:** Prerequisites for a high annual efficiency (see chapter 20.12) are:
  - Excess air in the entire power range (30 % to 100 %) with $\lambda < 1.7$
  - Flue gas temperatures on average < 140 °C and low radiation losses of the boiler
  - Monovalent biomass combustion plant: Minimum number of full load operating hours after expansion stage 1 per year > 1,400 h and with full expansion per year > 2,000 h
  - Bivalent biomass combustion plant: Full load operating hours are significantly higher according to Table 13.5 (in AT target value according to ÖKL-Merkblatt > 4,000 h/a)
  - Low standby operation or firebed maintenance (ratio of annual standby to operation time < 0.2)
  - As few start-up and burn-out phases as possible
  - Compliance with the light load conditions according to Table 13.4
- **Low system investment costs**: No oversizing of the heat generation system, simple heating plant with a clear system structure and as few boiler units with as wide a power range as possible. Multi-boiler systems with standard series equipment are an exception.
- **Low maintenance and servicing costs**: Use of automatic ash removal and boiler tube cleaning, ensuring low-fault operation through the use of system components with a long service life, a charging and firing system adapted to the agreed fuel range and regular servicing. Uniform utilisation of the biomass boiler with a low number of start-up and burn-out phases (biomass boiler continuously follows the average load curve without short-term sharp changes in output).
- **Cost-effective fuel storage**
  - The volume of the fuel storage for **wood chips** with automatic discharge system (silo net volume) should hold five to seven daily demands of the biomass boiler plant at rated power operation à 24h plus the transport volume of the delivery vehicle in case of direct supply chain (see chapter 4.5.5.5). This dimensioning allows the fuel supply company a logistics interval to easily bridge holidays such as Christmas and New Year or short-term interruptions in the supply chain. In the indirect supply chain (see chapter 4.5.5), the required fuel storage volume can be reduced in consultation with the fuel supplier. Security of supply under extreme conditions such as snowfall, freezing rain and the like must be coordinated with the fuel supplier.
  - The fuel storage volume for **pellets** should have about ten daily requirements at design temperature plus a minimum delivery capacity of the pellet

vehicle of 25 to 30 m³ of pellets. This allows for the reaction time of the fuel supplier from order to delivery with the necessary logistical leeway. Further information can be found in chapter 14.2

- **Optimum utilisation of biomass boiler**:
  - Biomass boiler should continuously follow the average load curve at the lowest possible output level.
  - Frequent start-up and burn-out phases are to be avoided by long operating times, i.e. by a high utilisation of the biomass boiler.
  - Biomass boiler should be able to handle slow load changes of the heating network (e.g. depending on the outside temperature).
  - Short-term changes in output should be avoided, as the fuel bed needs a long time to adapt optimally to the new firing output.
  - The power input to the biomass boiler must be slower than the reaction time. This usually requires a heat storage, which can compensate for short-term load peaks and load reductions.
- **Annual share of heat production with the biomass boiler system:**
  - Monovalent biomass combustion plant: 100%
  - Bivalent biomass heating system with oil/gas boiler for peak load operation and low-load operation in summer: 80% to 85%.
  - Bivalent biomass heating system with oil/gas boiler for peak load operation: 90% to 95%.
- **Security of supply**: Security of supply or redundancy in the event of a biomass boiler failure can be ensured by the following measures:
  - Peak load boiler with oil or gas (bio-oil/biogas), boiler output ≤ total required heat capacity for heat generation
  - Connection pipe for mobile heating system for monovalent biomass combustion system
  - Load shedding from large connected customers with redundant oil/gas boiler system
  - Connection pipes for mobile heating systems at the central heating plant or at selected large connected customers (e.g. industrial companies with critical production processes).

Terms:

Firebed maintenance
To ensure that a biomass combustion system can restart without external ignition after a few hours without a power demand, the firebed (embers) is maintained during this standby period by periodically adding small amounts of fuel.

Low-emission and controlled firebed maintenance operation
Periodically, a small amount of fuel is added to the grate and burnt down to an ember bed in a controlled manner with the combustion air fans switched on. After switching off the combustion air fans, the renewed ember bed should no longer contain any fuel particles that emit smouldering gases in the pyrolysis process.

Automatic ignition
When the fuel is dry (water content M < 35% to a maximum of M < 40%), the firing is switched off with low emissions by burning down the fuel bed to an ember bed in the burnout phase with the combustion air fans switched on. When the combustion air fans are switched off, this should no longer contain any fuel particles that still emit smouldering gases. After the standstill phase, the combustion process is started with automatic ignition (ignition fan or ignition rods) when needed.

Switched-on time
The switched-on time comprises the regular operating time and the standby time (firebed maintenance or operating phase without load demand) of a combustion plant between the beginning and the end of the heating period.

13.4 Fuel quality and firing system

System selection involves choosing the firing system of the biomass boiler according to the fuel quality.

The classification of fuels and particle sizes of QM for Biomass DH Plants are based on the specifications according to EN ISO 17225-1, the classification of particle sizes were supplemented with the S-classes of EN ISO 17225-4.

QM for Biomass DH Plants has additionally supplemented the fuel classification with quality wood chips fine/coarse and further restricted the cross-section of oversized particles compared to the standard. The fuel classification is described in detail in chapter 4. With Table 13.3 as a guide, the recommended firing system in the corresponding output range can be assigned to a given fuel quality.

Table 13.3 Recommended range of use of wood fuels (according to fuel classification for combustion systems and output ranges (see also FAQ 36).

Fuel classification	Firing system	Power range	Comments
WS- and IS-P16S-M20	Small firing systems, standard series units Underfeed, fixed grate firing*	20 kW - 200 kW	Quality wood chips finely sieved with F05
WS- and IS-P31S-M20	Standard series units Underfeed, fixed grate firing*	> 100 kW	Quality wood chips coarsely sieved with F05
WS- and IS-P31S-M35	Underfeed and feed grate firing	> 200 kW	
WS- and IS-P31S-M50	Underfeed and feed grate firing	> 200 kW	
WS- and IS-P31S-M55+	Feed grate firing	> 200 kW	
P31-M35	Feed grate firing	> 200 kW	PWK, LH, DH
P31-M50	Feed grate firing	> 200 kW	PWK, LH, DH
P31-M55+	Feed grate firing	> 200 kW	PWK, LH, DH
WS- and IS-P45S-M35	Feed grate firing	> 500 kW	
WS- and IS-P45S-M50	Feed grate firing	> 500 kW	
WS- and IS-P45S-M55+	Feed grate firing	> 500 kW	
P45-M35	Feed grate firing	> 1,000 kW	PWK, LH, DH, AH
P45-M50	Feed grate firing	> 1,000 kW	PWK, LH, DH, RZ
P45-M55+	Feed grate firing	> 1,000 kW	PWK, LH, DH, RZ
P63-M35	Feed grate firing	> 3,000 kW	PWK, LH, DH, AH
P63-M50	Feed grate firing	> 3,000 kW	WS, IS, PWW, PWK, LH, DH, RZ
P63-M55+	Feed grate firing	> 3,000 kW	WS, IS, PWW, PWK, LH, DH, RZ

It is assumed that the requirements for the storage capacity (Q-Guidelines; Table 19) and for the minimum average daily heating load during off-peak operation (Q-Guidelines; Table 20) are met.

*Fixed grate firing: Grate firing without active movement/conveying of the fuel on the grate (e.g. flat grate, inclined grate). The fuel is conveyed over the grate with the charging screw, the ash can be removed, for example, by tilting the grate segments.

Specifications for residual wood from wood processing (RHH-M10-20), wood chips and shavings with a high dust content):

- For underfeed and grate firing, a maximum of 50% dust content is permissible; above this, provide for dust injection firing.
- To avoid slag formation in the fuel bed, the use of a primary flue gas recirculation system should be considered (see chapter 5.3.2).
- The lumpiness (proportions of wood chips, shavings and dust) and the chemical composition based on fuel analyses are the key factors regarding the guarantee provided by the furnace manufacturer.

13.5 Selection and design of heat generation system

The following key data must be known for the selection and design of the heat generation system:

- Annual total heat demand[1)]
- Required heat capacity[1)] and load characteristic[1)] of the entire system
- Annual duration curve of the required heat capacity with biomass boiler and base load share[1)]
- Future development of heat sales (thermal refurbishments, climate, expansion potential, “risk customers”)
- Minimum average daily heating load for low-load operation in the expansion stages according to Table 13.4
- Flow temperature as a function of outdoor temperature
- Main return temperature
- Fuel supply and quality depending on fuel logistics: direct or indirect supply chain
- Waste heat and heat source potentials

[1)] according to Excel tool for demand assessment and appropriate system selection

Chapter 13.3 lists the requirements that are decisive for the choice of a monovalent or bivalent biomass boiler system. The requirements for the operating mode and the utilisation of the biomass boilers determine the design of the nominal output and the number of boilers.

Procedure

- Selection of heat generation system as the basic variant:
  - According to total required heat capacity class as per Table 13.5
  - Distribution of the heat output of the individual heat generators in bivalent systems and determination of the fuel requirement
- Selection of the firing system depending on the fuel quality and the fuel logistics (direct or indirect supply chain).
- Design of system components:
  - Combustion plant with additional components (fuel storage, fuel transport system, flue gas cleaning, etc.)
  - Hydraulic integration including volume of heat storage
  - Heating system
  - Chimney (flue gas system)
- Checking compliance with safety, noise protection and emission requirements
- Checking the defined basic variant including the additional variants (chapter 13.6) and additional options (chapter 13.7)
- Determination of investment and annual costs, assessment of economic viability (chapter 10).

13.5.1 Basic variants of heat generation systems with biomass combustion system

Heat generation systems with biomass combustion can be designed as single or multiple boiler systems, monovalent or bivalent with storage. Once the required total heat capacity demand has been determined, taking into account the load characteristic and annual duration curve of the heat capacity demand of the overall system and expansion stages, and all the requirements placed on the biomass combustion system have been precisely defined, one of the basic variants of heat generation systems summarised in Table 13.5 is selected.

All listed basic variants have a heat storage tank to fulfil the general requirements according to chapter 13.3.

Basic variants without a storage tank can only be selected if the biomass combustion system is operated with a base load.

For the selection of the heat generation system, the following **Q-requirements and influencing factors** must be taken into account in addition to the performance class:

- **Number of full load operating hours** biomass boiler Table 13.5; prerequisite for high annual full-load operating hours without increased wear is a uniform utilisation (low number of start and stop phases, slow power changes, stable fuel bed) and an industrial design of the boilers.
- **Switched-on time**: All year round or during the heating period.
- **Low load condition** according to Table 13.4
For year-round operation, the low load condition must be fulfilled in summer. For operation during the heating period, it applies in the transition period.
- **Load changes:**
  - Large, rapid load fluctuations (load peaks and load reductions) occur in the following situations: morning heating peaks, evening reduction of the heating demand (night reduction), water heating in summer (especially with flow-through water heaters, fresh water modules), special load profiles (for example, winter sports resort, sports hotel), switching on a heat exchanger with network separation in the heating plant, raising or lowering the flow temperature of the district heating network, etc.
  - Diurnal variation with high load fluctuations (load peaks and load drops) occurs in the following situations: Greenhouses (no load reduction when the sun is shining, high load reduction when the night is clear), morning heating of outdoor pool, uneven load profiles for process heat, etc.
- **Base load** e.g. process heat, base load operation as a result of small rated biomass boiler output in relation to heat capacity demand
- **Fuel assortment** places demands on the feeding and firing system.
- **Plant investment**
- **Security of supply/redundancy**: The susceptibility to failure of the fuel transport or firing system and thus the security of supply depends largely on how well the specified fuel quality is maintained. The redundancy corresponds to the heat capacity (as a percentage of the required heat capacity) that can still be provided in the event of a failure of the largest boiler.
- **Biomass share**
- **Fuel price**: When fuel prices are low, year-round operation of the biomass combustion system is preferred.
- **Flexibility/expansion reserve**: Multi-boiler systems enable optimum utilisation of the individual biomass boilers when developing a heat supply area in stages.
- **State of the art**: Firing systems with a nominal output of up to about 500 kW can be operated with automatic ignition at a water content in the fuel of < M35 - M40, for example, without firebed maintenance. This enables low-load operation with low emissions and reduced energy losses and is especially important for monovalent biomass combustion systems.
- **Minimum required constant load**: For biomass combustion systems with pusher feeding systems, a minimum constant load is required to prevent back fires in the insertion duct. The following guide values apply for this:

- dry fuel < M35: 30 % of the rated biomass boiler output
- wet fuel > M40: 20 % of the rated biomass boiler output

- The **number of full load operating hours of the biomass boiler** in h/a is defined as the division of the annual heat production in kWh/a of the biomass boiler by the nominal heat output of the biomass boiler in kW.

Table 13.4 Minimum average daily heating load for low-load operation based on the Q-Guidelines [15] (Table 20).

Firing type → **Recommendations ↓**	**Feed grate firing systems**					**Underfeed and fixed grate firing systems**		
	with automatic ignition		with firebed maintenance			with automatic ignition		with firebed maintenance
Water content	≤ M35	M35-40	≤ M35	M35 - 50	> M50	M ≤ M35	M35 - 40	≤ M50
Minimum average daily heating load as a percentage of the nominal boiler output for heat generation with heat storage tank	15 %	20 %	15 %	20 %	30 %	10 %	15 %	15 %

Important note: Depending on the biomass boiler manufacturer, the values may vary slightly. The values and recommendations of the biomass boiler manufacturer are always decisive.

Low load condition

Adhering to the low load condition avoids the following serious problems with insufficient load reduction:

- Odour nuisance
- Periodically visible smoke
- Danger of soot accumulation in the biomass boiler
- Limited effectiveness of the particle separator because it does not reach the operating temperature and thus has only limited or no effect in low-load operation. This results in reduced or at best insufficient availability of the separator.
- Electro-particle separator: If the temperature falls below the dew point, there is a risk of moist particle caking in the housing, on the insulators and on the separator electrodes. Consequences: Short circuit across insulators, failure of automatic cleaning and ash discharge.
- Fabric filter: If the temperature falls below the dew point, there is a risk of moist particle caking on the filter fabric. Consequences: Failure of automatic cleaning up to destruction of the filter fabric.
- Details on the separation processes can be found in chapter 5.8

The following framework conditions must be observed:

- Due to the larger fuel bed (ember bed), moving grate furnaces must be operated with a higher minimum output than underfeed or fixed grate furnaces.
- The advantage of automatic ignition is that it enables automatic sequencing and eliminates the minimal heat loss associated with firebed maintenance. In low-load operation, this can result in advantages over a system with firebed maintenance.
- In systems with heat storages and automatic ignition, the storage tank can be completely filled and then completely emptied again during low-load operation without the occurrence of short-term, high load fluctuations with minimum boiler output. This means that longer continuous operation with minimum boiler output can be achieved.

Example

Maximum biomass boiler output = 200 kW; heat demand in summer operation = 300 kWh per day; storage and transmission losses in summer operation = 180 kWh per day.

- Daily heating load as a percentage of the nominal boiler output = (300 kWh/d + 180 kWh/d)/(24 h/d x 200 kW) = 0.10 = 10%.
- When using dry wood chips of good quality (M ≤ 35 %), summer operation with underfeed or fixed grate firing should be possible with this system if automatic ignition and a heat storage are available.
- For systems without summer operation, operation during the transition period must meet the same requirements. It is therefore often necessary to initially operate the oil/gas boiler (if present) or the small biomass boiler (for monovalent systems) during low-load operation.

13.5.1.1 Influence of total required heat capacity

The total required heat capacity determines the output class of the basic variants divided into the following groups:

- 100 kW to 500 kW
- 501 kW to 1,000 kW
- > 1,000 kW

In the case of bivalent systems, the output of the biomass boiler or biomass boilers must be distributed on the basis of the annual duration curve according to Figure 13.5 so that the minimum number of full load operating hours of the biomass boiler or the biomass boilers is achieved taking into account the minimum required average daily heating load in low-load operation.

Table 13.5 Overview of the basic variants of heat generation systems with storage depending on the total heat capacity demand based on Table 19 of the Q-Guidelines [15]. In the Standard hydraulic schemes Part I [62] the circuits WE1 to WE8 are described in detail and in the Standard hydraulic schemes Part II [71] the circuits WE12 to WE16.

Circuit	Description	Total required heat capacity		
		100 - 500 kW	**501 - 1,000 kW**	**> 1,000 kW**
1 Biomass boiler with storage tank WE2 (WE12)	Annual heat produced with biomass	100 %		
	Design biomass boiler output	100 % without load peaks		
	Number of full load operating hours biomass boiler	> 2,000 h/a		
	Low-load operation	Summer operation possible if sufficient summer load according to Table 13.4		
	Automatic ignition?	Yes		
	Fuel	Maximum P31S; with automatic ignition M40≤		
	Expansion reserve	Only possible in exceptional cases due to low load problems		
	Storage capacity	≥ 1 h related to nominal output of biomass boiler		
1 biomass boiler + 1 oil/gas boiler with storage tank WE4 (WE14/16 with 1 biomass boiler)	Annual heat produced with biomass	80 – 90 %		For systems without summer operation, it may also make sense to have only 1 biomass boiler + 1 oil/gas boiler above 1,000 kW.
	Design biomass boiler output	50 – 60 %*		
	Design oil/gas boiler capacity	At least 70 %, maximum 100 %.		
	Number of full load operating hours biomass boiler	> 3,500 h/a Target 4,000 h/a		
	Low-load operation	If Table 13.4 not fulfilled, by oil/gas boiler		
	Automatic ignition?	Yes		
	Fuel	Maximum P31S; with automatic ignition M40≤	No restriction; with automatic ignition M40≤	
	Expansion reserve	Possible through oil/gas boiler (with corresponding reduction of wood coverage)		
	Storage capacity	≥ 1 h related to nominal output of biomass boiler		
2 biomass boilers with storage tank WE6	Annual heat produced with biomass	→ Realisation of monovalent summer operation may be only possible with two biomass boilers	100 %	
	Design biomass boiler output 1		33 % without load peaks	
	Design biomass boiler output 2		67 % without load peaks	
	Number of full load operating hours biomass boiler 1 + 2		> 2,000 h/a	
	Low-load operation		Compliance with Table 13.4 usually possible with small biomass boilers	
	Automatic ignition?		For small biomass boiler	
	Fuel		Max. P31S; with automatic ignition M40≤	No restriction; with automatic ignition M40≤
	Expansion reserve		Possible with correspondingly high investment costs (expensive biomass boilers)	
	Storage capacity		≥ 1 h related to 2/3 of the total nominal output of biomass boilers	

Circuit	Description	Total required heat capacity		
		100 - 500 kW	501 - 1,000 kW	> 1,000 kW
2 biomass boilers + 1 oil/gas boiler with storage tank WE8 (WE14/16 with 2 biomass boilers)	Annual heat produced with biomass			80 - 90 %
	Design biomass boiler output 1			17 - 20 %*
	Design biomass boiler output 2			33 - 40 %*
	Design oil/gas boiler capacity			Min. 100 % - small biomass boiler, max. to 100%.
	Number of full load operating hours Biomass boiler 1 + 2			> 3,000 h/a Target 4,000 h/a
	Low-load operation			Compliance with Table 13.4 with small biomass boiler or oil/gas boiler
	Automatic ignition?			For small biomass boiler
	Fuel			No restriction; with automatic ignition ≤ M40
	Expansion reserve			Possible with oil/gas boiler (reducing use of biomass)
	Storage capacity			≥ 1 h related to 2/3 of the total nominal output of biomass boilers
* Indicative value for systems with predominantly space heating				

13.5.1.2 Determination of the required total boiler output

The determination of the required total boiler output is done as follows:

- For **bivalent** biomass boiler systems on the basis of the total heat capacity demand. This corresponds to the blue square of the extracted load characteristic in Figure 13.4 (total thermal power demand including load peaks).
- For **monovalent** biomass boiler systems with storage, based on the average total heat capacity demand. This corresponds to the black rhombus of the dotted load characteristic in Figure 13.4 (daily average value of the total heat capacity demand without load peaks). This prevents over-dimensioning of the biomass boilers, whereby short-term load peaks (3 to 4 hours) are to be covered by the heat storage tank.

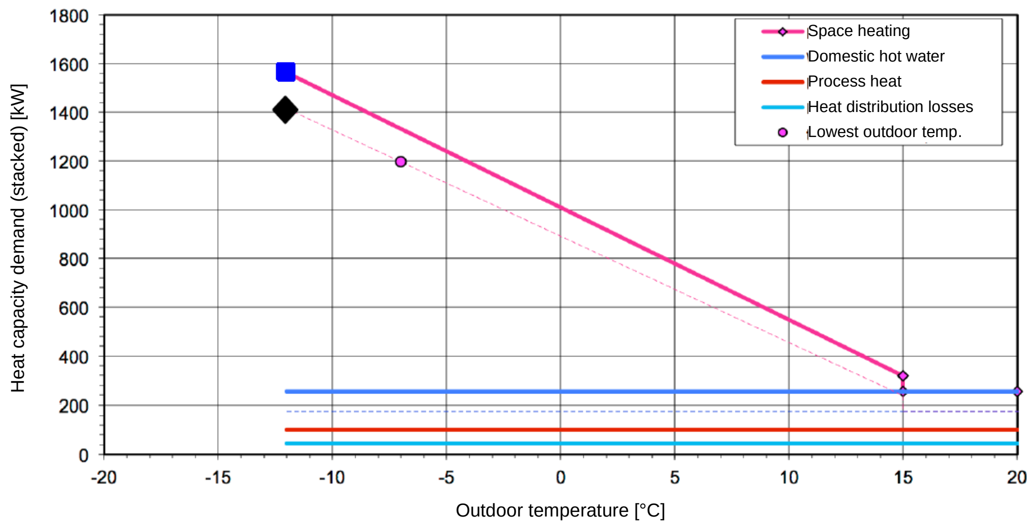


Figure 13.4 Determination of the required total boiler output for a mono- or bivalent biomass heating system using the load characteristic.

13.5.1.3 Allocation of total biomass boiler output to smaller and larger biomass boilers

In monovalent or bivalent biomass heating systems with two or three biomass boilers, the ratio of the nominal output of the small biomass boiler to the nominal output of the large biomass boiler should not exceed 1:2 (recommended range 1:1 to 1:2) (Figure 13.5). This allows a **common transition range,** i.e. a common output range, which enables optimum operation for both biomass boilers in individual operation. This division must also be observed for multi-boiler systems with standard series units.

The common transition area is required,

- so that after commissioning of the larger biomass boiler during the transition to the cold season, its minimum required utilisation according to Table 13.4 can be ensured even during an unexpected warm weather period without switching off the larger biomass boiler again with renewed commissioning of the smaller biomass boiler.
- so that after switching off the larger biomass boiler and starting up the smaller biomass boiler during the transition to the warm season, even during a short cold weather period, it is not necessary to start up the larger biomass boiler and switching off the smaller biomass boiler again.

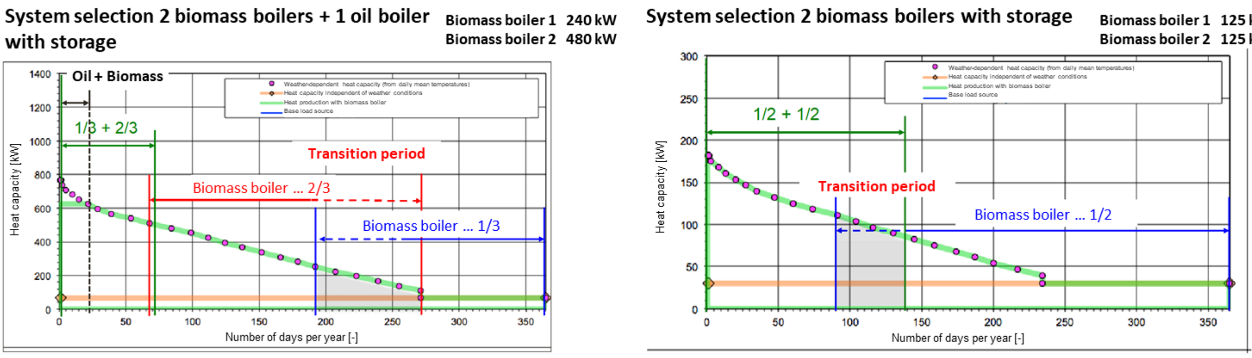


Figure 13.5 Operating phases and transition range for systems with two biomass boilers using the example of the annual duration curve (left with fossil boiler, right without fossil boiler).

The detailed data for the annual duration curve on the left “Bivalent three-boiler system with storage tank” are:

- Minimum average daily heating load during off-peak operation effectively 67 kW
- Small biomass boiler 240 kW, minimum required average daily heating load at low load operation 48 kW (assumption 20 % of boiler output according to Table 13.4, moving grate firing, M35 to M50).
- Large biomass boiler 480 kW, minimum required average daily heating load at low load operation 96 kW (assumption 20 % of boiler output according to Table 13.4)

The detailed data for the annual duration curve on the right “Monovalent two-boiler wood heating system with storage tank” are:

- Minimum average daily heating load for low-load operation effectively 30 kW
- Biomass boiler 1 and biomass boiler 2 125 kW each, minimum required average daily heating load at low load operation 13 kW (assumption 10 % of boiler output according to Table 13.4, underfeed and fixed grate firing systems, ≤ M35).

13.5.2 Description of the basic variants

13.5.2.1 Monovalent biomass heating system with storage tank 100 to 500 kW

Description

Systems with a nominal heat output up to a maximum of 500 kW can be operated with a monovalent single boiler system (a biomass boiler with storage tank WE2). The storage tank serves to balance the boiler operation and to cover peak loads. These systems are relatively inexpensive and save room. They can also be used as a basis for further expansion stages.

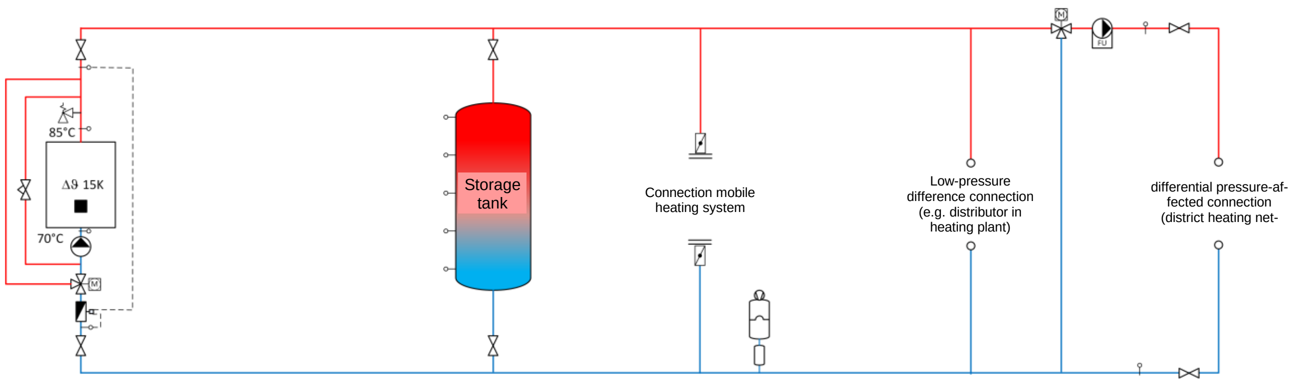


Figure 13.6 Principle scheme of a system with a biomass boiler with storage tank (WE2).

The most important **features** are:

- Short-term peak loads and load reductions are balanced out by the storage system.
- Designing the boiler output without taking peak loads into account (black rhombus in Figure 13.4)
- Year-round operation with exclusive heat demand for space heating and domestic hot water only possible with sufficiently high summer load (low load conditions Table 13.4)
- In transition period, maximum water content in fuel is limited to ≤ M40 (automatic ignition required).
- Cost-effective variant
- Extension possible by upgrading to WE4, 6, etc.
- Control strategy: The biomass boiler is operated at the lowest possible output so that the boiler output just corresponds to the average required heat capacity. The storage tank charging state determines the output specification to the boiler. In the transitional period or in summer operation, if there are no short-term high load fluctuations, the storage tank is charged at minimum boiler output in on/off mode. For detailed control description, see Standard hydraulic schemes Part I [62].

Solution WE2 is unsuitable:

- when short-term high load fluctuations occur that cannot be absorbed by the storage system.
- if the low-load conditions cannot be met during summer operation.
- for systems in partial expansion.

Design principles

Annual heat production with biomass	100 %
Design biomass boiler output	100 % without load peaks (black rhombus in Figure 13.4)
Number of full load operating hours biomass boiler	> 2,000 h/a
Low-load operation	Summer operation possible if sufficient summer load according to Table 13.4
Automatic ignition?	Yes
Fuel	Maximum P31Swith automatic ignition ≤ M40
Storage capacity	≥1 h related to nominal output of biomass boiler

13.5.2.2 Bivalent biomass heating system with storage tank 100 to 1,000 kW

Description

To increase the security of supply and/or in the case of a gradual expansion, a bivalent system achieves significantly more stable operation at low additional cost. Bivalent systems with a biomass boiler with storage tank are recommended up to a nominal required heat capacity of 1,000 kW (a biomass boiler with storage tank and fossil fuel boiler WE4). The heat storage tank serves to balance the boiler operation. The fossil boiler covers the peak loads and, if necessary, also the summer operation. With the fossil fuel boiler, short-term load fluctuations that cannot be compensated for by the heat storage system can also be covered. In addition, the fossil fuel boiler guarantees security of supply in the event of a failure or malfunction of the biomass boiler. These systems are relatively inexpensive and can be operated very efficiently.

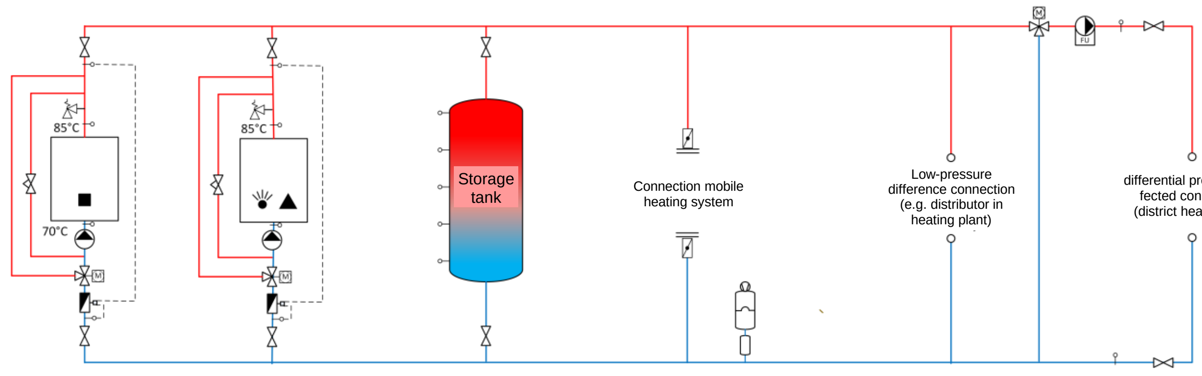


Figure 13.7 Principle scheme of a system with a biomass boiler with storage tank and fossil fuel boiler (WE4).

The most important **features** are:

- Short-term peak loads and load reductions are compensated for by the heat storage unit
- Design of the total boiler output including load peaks (blue square in Figure 13.4)
- The output of the biomass boiler corresponds to the average required heat capacity up to the bivalence point and then to a proportion of the average daily heating load
- Peak load coverage with fossil auxiliary boiler
- Low-load operation in the transition period and in summer with biomass boiler if load is sufficient, otherwise with fossil boiler (Table 13.4)
- For automatic ignition, maximum water content in the fuel is limited to ≤ M40
- Cost-effective variant for guaranteed year-round operation and supply
- Good utilisation of the biomass boiler with a correspondingly high degree of coverage with biomass
- Reserves are covered by the fossil plant part
- Heat generation hydraulics and control can be extended, for example to WE8
- Control strategy: The biomass boiler is operated at the lowest possible output so that the boiler output meets the average required heat capacity. The storage charging status determines the output specification for the biomass boiler. For peak load operation during the coldest winter days, the fossil boiler is switched on and supports the biomass boiler. In the event of a malfunction or failure of the biomass boilers, the fossil heating system takes over automatically. Summer operation is carried out with the biomass boiler or the fossil boiler, depending on whether the low load condition is met. If no short-term high load fluctuations occur, the storage tank is charged by the biomass boiler at minimum boiler output in on/off mode (automatic ignition mandatory). If the biomass boiler is not suitable for low-load operation, summer coverage is provided by the fossil boiler. For detailed control description, see Standard hydraulic schemes Part I [62].
- Systems without summer operation or with high process heat demand can possibly also above 1,000 kW be operated with only one biomass boiler and one fossil boiler.

Solution WE4 is unsuitable

- when 100 % fossil-free heat generation is required.

Design principles

Annual heat production with biomass	80 - 90 %
Design biomass boiler output	50 to 60 % total required heat capacity including load peaks (blue square in Figure 13.4)
Design of fossil boiler output	70 to 100 % total thermal power requirement (high redundancy)
Number of full load operating hours Biomass boiler	> 3,500 h/a (target 4,000 h/a)
Low-load operation	If not fulfilled: Summer operation with fossil boiler
Automatic ignition	Yes
Fuel	up to 500 kW maximum P31S; with automatic ignition ≤ M40
Storage capacity	≥ 1 h related to nominal output of biomass boiler

13.5.2.3 Monovalent biomass heating system with storage tank 501 to 1,000 kW

Description

By dividing the boiler output between two biomass boilers, larger systems can be operated with biomass all year round (two biomass boilers with storage WE6). It is recommended to split the output 1/3 to 2/3. This usually allows the smaller boiler to cover the low load in summer and a balanced operation of both heat generators throughout the year. The small boiler should be equipped with automatic ignition. A storage tank must be installed to balance the boiler operation and to cover peak loads.

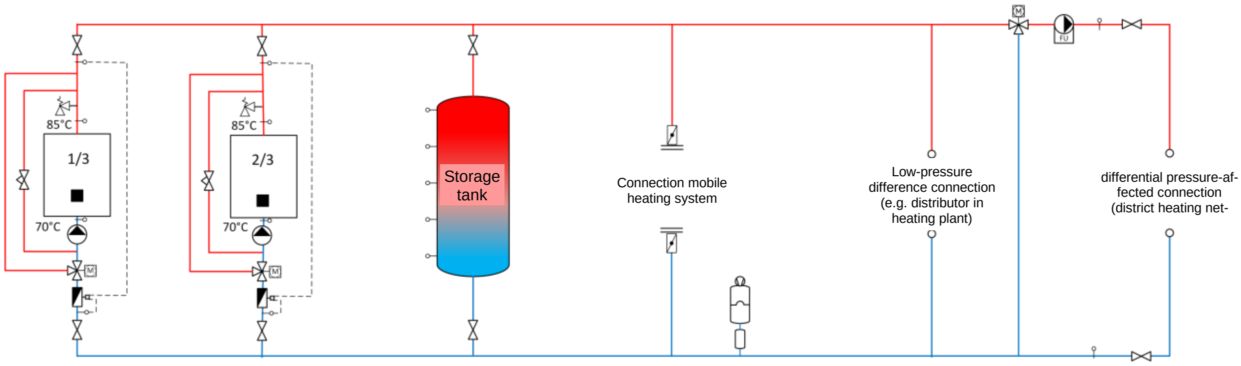


Figure 13.8 System with two biomass boilers and with storage tank (WE6).

The most important **features** are:

- Short-term load peaks and load reductions are compensated by the storage system.
- Design of the total boiler output without load peaks (black rhombus in Figure 13.4)
- Distribution of boiler outputs in the ratio 1/3 to 2/3 according to chapter 13.6.1
- Low-load operation in the transitional period and in summer with small boiler usually possible (Table 13.4)
- Small boiler with automatic ignition maximum water content in fuel limited to ≤ M40
- Fossil-free year-round operation
- In the event of a malfunction of one biomass boiler supply is conditionally guaranteed by the second biomass boiler. For maximum reliability a connection to a mobile heating system should be provided.
- Step by step connection of customers possible (at relatively high investment costs)
- Heat generation hydraulics and control can be expanded
- Control strategy: Both biomass boilers are operated at the lowest possible output (common same output specification) so that the sum of the boiler outputs meets the average required heat capacity. The storage charging state determines the output specification for the boilers. The boiler cascade (sequential circuit) determines the operation of the boilers. In summer operation, if there are no short-term high load fluctuations, the storage tank is charged at minimum output of the smaller biomass boiler in on/off mode. The smaller biomass boiler is switched over to the larger one manually when the smaller biomass boiler can no longer cover the daily average heat demand. The larger biomass boiler is switched over to the smaller one manually if the daily heat production of the larger biomass boiler (heat production in 24 hours at minimum output) is less than 25 % of its maximum possible daily heat production (heat production in 24 hours at nominal output). The smaller biomass boiler is switched on with automatic sequencing and peak load operation with the automatic ignition when the larger biomass boiler can no longer cover the heat demand on an hourly average. The smaller biomass boiler is only switched off again when the heat capacity demand falls below the sum of the minimum outputs of the two biomass boilers. In the event of a malfunction of the larger biomass boiler, the smaller biomass boiler is switched on with the automatic ignition. For a detailed description of the control system, see Standard hydraulic schemes Part I [62].

Solution WE6 is unsuitable:

- when short-term high load fluctuations occur that cannot be absorbed by the storage system.
- if the low-load conditions in summer operation cannot be met with the small boiler.

Design principles

Annual heat production with biomass	100 %
Design biomass boiler output 1 and 2	33 % respectively 67 % without load peaks (black rhombus in Figure 13.4)
Number of full load operating hours biomass boiler	> 2,000 h/a
Low-load operation	Compliance with Table 13.4 with small boiler
Automatic ignition?	Yes, for small boiler
Fuel	up to 1,000 kW max. P31S with automatic ignition ≤ M40
Storage capacity	≥ 1 h related to at least 2/3 of total nominal output of biomass boilers (recommended, however, ≥ 1 h at 100% of total nominal output).

13.5.2.4 Monovalent biomass heating system with storage tank ≥ 1,000 kW

Description

Monovalent multi-boiler systems with more than two biomass boilers can be realised, for example, as an extension of two-boiler systems WE6 in the case of step-by-step expansion or if the low-load conditions cannot be met with the small boiler (multi-boiler system wood with storage tank). The partial output ranges of the boilers are to be selected in such a way that both easy boiler switching and summer operation are possible. By dividing the nominal boiler output (e.g. 1/5 to 2/5 to 2/5), operation can be ensured all year round. The smallest boiler should be equipped with automatic ignition. A storage tank should be installed to balance boiler operation and to cover load fluctuations.

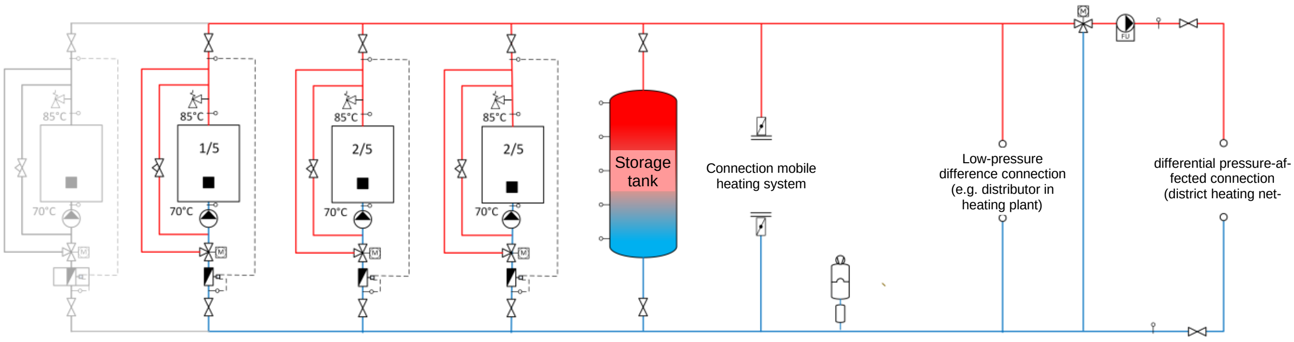


Figure 13.9 System with several biomass boilers and with storage tank (WE6+).

The most important **features** are:

- Short-term load peaks and load reductions are compensated by the storage system
- Design of the total boiler output without load peaks (black rhombus in Figure 13.4)
- Distribution of boiler outputs in such a way that summer operation and boiler switching are guaranteed (see chapter 13.6.1).
- Low-load operation in transition period and in summer with smallest boiler (Table 13.4)
- Smallest boiler (≤ 500 kW) with automatic ignition, maximum water content in fuel limited to ≤ M40
- Fossil-free year-round operation
- In the event of a malfunction of one biomass boiler, supply is conditionally guaranteed by the other biomass boilers. For maximum reliability a connection to a mobile heating system should be provided.
- Step-by-step connection of customers possible
- Heat generation hydraulics and control can be expanded
- Control strategy: The biomass boilers are operated at the lowest possible output (common equal output specification) so that the sum of the boiler outputs meets the average required heat capacity. The storage charging state determines the output specification for the boilers. The boiler cascade (sequential circuit) determines the operation of the boilers. In summer operation, if there are no short-term high load fluctuations, the storage tank is charged at minimum output of the smallest biomass boiler in on/off mode. The biomass boilers are usually switched manually. If the heat capacity demand exceeds the sum of the nominal outputs of the biomass boilers in operation, either a small biomass boiler is switched off and a large biomass boiler is switched on, or another biomass boiler is switched on. If the required heat capacity falls below the sum of the minimum outputs of the biomass boilers in operation, either a small biomass boiler is switched off or a small biomass boiler is switched on and a large biomass boiler is switched off. The smallest biomass boiler with automatic ignition can be switched on automatically with automatic sequential switching. In the event of a malfunction of a larger biomass boiler, the smallest biomass boiler with automatic ignition is also switched on. For a detailed description of the rules, see Standard hydraulic schemes Part I [62].

The solution WE6+ is unsuitable

- when short-term high load fluctuations occur that cannot be absorbed by the storage system.

Design principles

Annual heat production with biomass	100 %
Design	Total boiler output without load peaks (black rhombus in Figure 13.4) smallest boiler according to Table 13.4, design other boilers for problem-free boiler changeover (e.g. 1/5 to 2/5 to 2/5)
Number of full load operating hours biomass boiler	> 2,000 h/a
Low-load operation	Compliance Table 13.4with smallest boiler
Automatic ignition?	Yes, for small boiler
Fuel	up to 1,000 kW maximum P31S with automatic ignition ≤ M40
Storage capacity	≥ 1 h related to 2/3 of the total nominal output of the biomass boilers (recommended, however, ≥ 1 h at 100% total nominal output).

13.5.2.5 Bivalent biomass heating system with storage tank ≥ 1,000 kW

Description

Bivalent multi-boiler systems with two or more biomass boilers usually allow summer operation with biomass even in larger systems (two biomass boilers with storage tank and fossil boiler WE8). They can also be built as an extension of bivalent systems WE4 or of two-boiler systems WE6. Bivalent systems are characterised by maximum reliability with low additional costs. The storage tank serves to balance the biomass boiler operation. With the fossil fuel boiler, short-term load fluctuations that cannot be compensated for by the heat storage system can also be covered. These systems can be operated relatively inexpensively and very efficiently.

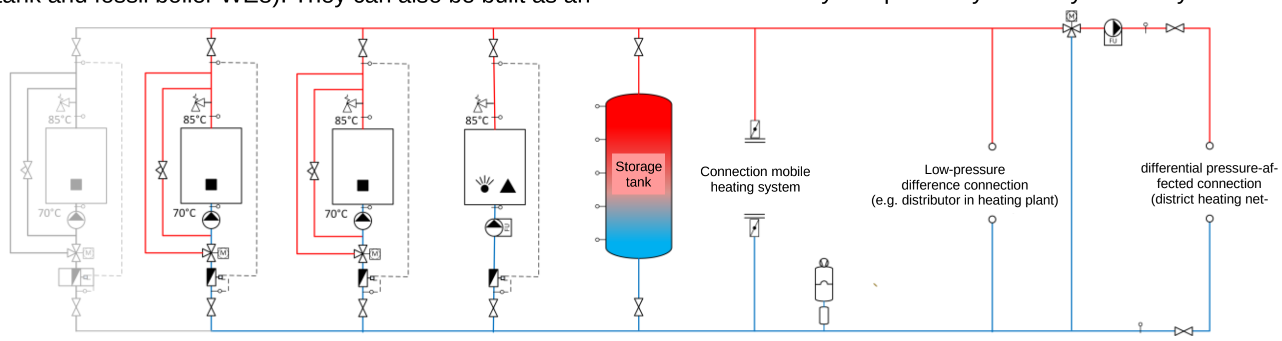


Figure 13.10 System with two biomass boilers with storage tank and fossil fuel boiler (WE8).

The most important **features** are:

- Short-term load peaks and load reductions are compensated by the storage system.
- Design of the total boiler output including load peaks (blue square in Figure 13.4)
- Division of the boiler output in such a way that summer operation and boiler changeover are guaranteed (cross-reference to design of multi-boiler systems)
- Low-load operation in the transition period and in summer with smallest biomass boiler (Table 13.4)
- Smallest biomass boiler (≤ 500 kW) with automatic ignition, maximum water content in fuel limited to ≤ M40
- Maximum supply reliability
- Good utilisation of the biomass boiler plant with a correspondingly high degree of coverage with biomass
- Reserves covered by fossil fuel boiler
- Step-by-step connection of customers possible
- Heat generation hydraulics and control can be expanded
- Control strategy: The biomass boilers are operated at the lowest possible output (common equal output specification) so that the sum of the boiler outputs meets the average required heat capacity. The storage charging state determines the output specification for the boilers. The boiler cascade (sequential circuit) determines the operation of the boilers. In summer operation, if there are no short-term high load fluctuations, the storage tank is charged at minimum output of the smallest biomass boiler in on/off mode. The biomass boilers are usually switched manually. If the heat capacity demand exceeds the sum of the nominal outputs of the biomass boilers in operation, either a small biomass boiler is switched off and a large biomass boiler is switched on, or another biomass boiler is switched on. If the required heat capacity falls below the sum of the minimum outputs of the biomass boilers in operation, either a small biomass boiler is switched off or a small biomass boiler is switched on and a large biomass boiler is switched off. The smallest biomass boiler with automatic ignition can be switched on automatically with automatic sequential switching. The fossil fuel boiler is used for peak load operation during the coldest winter days and possibly for low load operation in summer. In the event of a malfunction of a larger wood-fired boiler, the smallest biomass boiler with automatic ignition is added. In the event of a complete failure of the biomass heating system, the fossil boiler takes over the heat supply. For a detailed description of the control system, see Standard hydraulic schemes Part I [62].

Design principles

Annual heat production with biomass	80 - 90 %
Design	Total boiler output 60 % including peak loads (blue square in Figure 13.4) smallest boiler according to Table 13.4, design other boilers for problem-free boiler changeover (e.g. 1/3 to 2/3 or for three biomass boilers 1/5 to 2/5 to 2/5)
Number of full load operating hours biomass boiler	> 3,000 h/a
Low-load operation	Compliance with Table 13.4 with smallest boiler or fossil fuel boiler
Automatic ignition?	Yes, for small boiler
Fuel	up to 1,000 kW maximum P31Swith automatic ignition ≤ M40
Storage capacity	≥ 1 h related to 2/3 of total nominal output of biomass boilers (recommended, however, ≥ 1 h at 100% total nominal output).

13.5.3 Procedure for the design of a bivalent system

When designing the heat generators of a bivalent biomass heating plant, the following boundary conditions must be taken into account:

- The **annual duration curve** of the heat output of a district heating network shows a relatively short peak load phase in relation to the course of the outdoor temperature (see Figure 13.11).
- The **cost structure of** heat generator systems is different. The investment costs of biomass boilers are high and the fuel costs are low, while oil and gas boilers have comparatively low investment costs but high fuel costs.

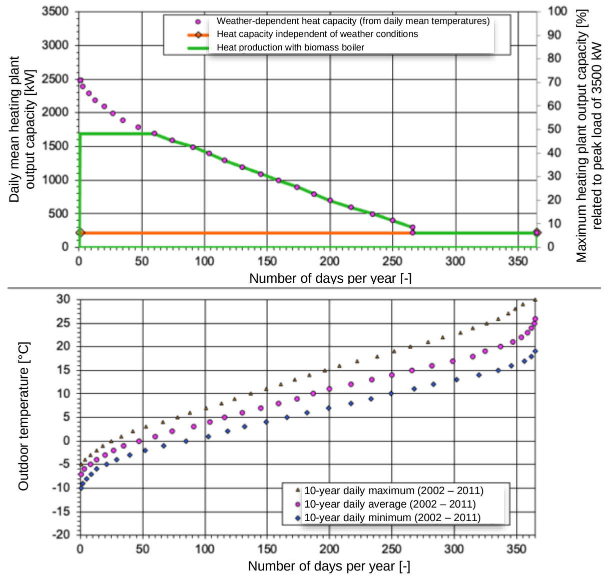


Figure 13.11 Example of the annual duration curve of a bivalent biomass heating system.

Top: Annual duration line of the heat output in the daily mean.
Bottom: Annual duration curve of the daily mean outdoor temperature

Table 13.6 Cost structure of different heat generator systems.

Combustion plant	Investment costs (fixed costs)	Fuel costs (variable costs)
Biomass	high	low
Heating oil, gas	low	high

- From these boundary conditions it can be deduced that it is recommendable to divide a bivalent system between a biomass combustion plant to **cover the base load** (base and medium load) and an oil/gas plant to **cover the peak load** and as a stand-by unit. CO_2-neutral heat generation can only be achieved with this system variant if the fossil energy source is replaced by a renewable energy source such as biogas (liquid), bio heating oil or high-quality wood fuel (pellets, quality wood chips).

  In principle, the heat output of a bivalent system should be divided up by determining the cost optimum. However, other framework conditions must also be taken into account, such as the maximum share of fossil fuels allowed by the funding agency, the declining acceptance of the use of fossil fuels among the population and the building owner (heat transition to CO_2-neutral heat generation).
- For larger systems, it makes sense to divide the system into two biomass boilers. The following criterion is important here:
  - The cost degression of the investment costs represents an important decision criterion in this context, i.e. a division into two biomass boilers with a sum of the rated biomass boiler outputs of less than approx. 2 MW should be carefully examined from an economic point of view.

The experience of QM for Biomass DH Plants shows that compliance with the Q-requirements according to Table 13.4 not only ensures technically flawless operation with low emissions, but that these plants are also the most interesting economically.

13.5.4 Selection of the firing system

Based on the selection of the heat generation system and the corresponding design principles, the required boiler output for one or more boilers is determined.

The various firing systems are more or less suitable for the different areas of application. The most important criteria for the selection of the firing system are:

- Boiler output
- Biomass assortment according to chapter 13.4
- Operating mode for base load and low load operation (see requirements Table 13.4).

13.5.5 Dimensioning of the heat storage tank

So that the output setpoint for the biomass boiler can be changed slower than its reaction time, a heat storage tank with the following functions is usually necessary:

- Compensation of short-term load peaks and reductions that are faster than the reaction time of the biomass boiler (according to the specified storage capacity).
- Reaction to the load trend due to the change of the storage charging state.

As a **storage volume,** a storage capacity of ≥ 1 h related to the nominal output of the biomass boiler is generally recommended. In addition, any legal requirements must be taken into account. However, if high (short-term) load peaks and load reductions occur during the course of the day, such as the load pattern of greenhouses, process heat or air heaters, these can only be compensated for with a significantly larger storage capacity. The following recommendations should therefore be observed for the following cases:

- **Greenhouses**: In order to compensate for peak loads in greenhouses (at night due to cold radiation) and load reductions (during the day when the sun is shining) during the day, the storage capacity should be increased to 4 to 6 h of the nominal output of the biomass boiler. The nominal output of the biomass boiler should be designed for approx. 50% of the maximum heat capacity demand. This results in a corresponding increase in the utilisation or the number of full load operating hours.
- **Process heat** 2 h - 8 h
- **Air heater** 1.5 h - 2 h
- **Domestic hot water preparation** 1.5 h - 2 h (e.g. fresh water stations)
- Heating **outdoor swimming pool** 1.5 h - 2 h

In order to prevent over-dimensioning of the biomass boiler of a **monovalent biomass boiler system with storage tank**, short-term load peaks (3 to 4 h) are to be covered by the storage tank according to the solid line load characteristic. The storage volume must have a storage capacity that is capable of balancing the load curve in such a way that the biomass boiler system can follow the average load reduction or the dotted line load characteristic (Figure 11.1).

For **two or more biomass boilers**, the minimum storage volume of ≥ 1 h storage capacity can be based on 2/3 of the total nominal output of the biomass boilers.

The required storage volume is calculated in the Excel tool for demand assessment and appropriate system selection. The storage capacity is determined directly via the temperature difference across the storage tank. QM for Biomass DH Plants specifies that the temperature spread across the storage tank should be > 30 K. With a temperature difference of 40 K, the storage capacity can be increased considerably compared to 30 K for an existing storage volume. For optimal storage management, a constant high flow and constant low return temperature is necessary.

Further information on the function of heat storage systems, including prerequisites for optimal heat storage management, can be found in chapter 7.5.

13.5.6 Fuel demand

The annual fuel demand for biomass (t/year or LCM/year) is calculated from the annual primary energy demand (energy content of the fuel e.g. in MWh/a) and the energy content of the fuel.

In the case of monovalent heat generation, the annual primary energy demand for biomass corresponds to the annual heat demand of the entire system divided by the annual efficiency η_a of the biomass boiler system.

In the case of bivalent heat generation, only the share of the annual heat demand that is covered by biomass boilers (biogenic share of the annual heat production) is relevant for determining the primary energy demand for biomass. This depends on the power allocation made and the annual duration curve of the entire plant and usually corresponds to 80 to 90 % of the annual heat demand of the entire plant. Dividing this share by the annual efficiency η_a of the biomass boiler plant results in the annual primary energy demand for biomass. In the Excel tool for demand assessment and appropriate system selection, this is shown in the worksheet "*Figures* or *Q-plan table".*

The **heat generation losses** Q_{VWE} are calculated from the annual efficiency of heat generation η_a. The determination of the annual efficiency for biomass systems is described in chapter 20.12. Heat generation losses Q_{VWE} are influenced by:

- Operating losses, respectively boiler efficiency
- Standby losses
- Capacity utilisation
- Average load level.

13.6 Further variants of heat generation systems

13.6.1 Multi-boiler systems with standard series equipment

Low-cost biomass boilers as standard series devices up to a nominal boiler output of about 500 kW, with exceptions up to 1,500 kW, enable as monovalent multiple boiler systems ("cascade systems", for example 3 to 6 biomass boilers) to cover the heat capacity demand of a biomass heating plant up to about 2 MW and larger.

In conjunction with a heat storage tank, which enables optimal output specification and optimal cascade control with automatic switching on and off (with automatic ignition) of the individual biomass boilers, the individual biomass boilers can be operated continuously throughout the year, especially during low-load operation in the transition period and in summer (see Table 13.4), with high utilisation and low standby losses. This enables a high overall annual efficiency η_a.

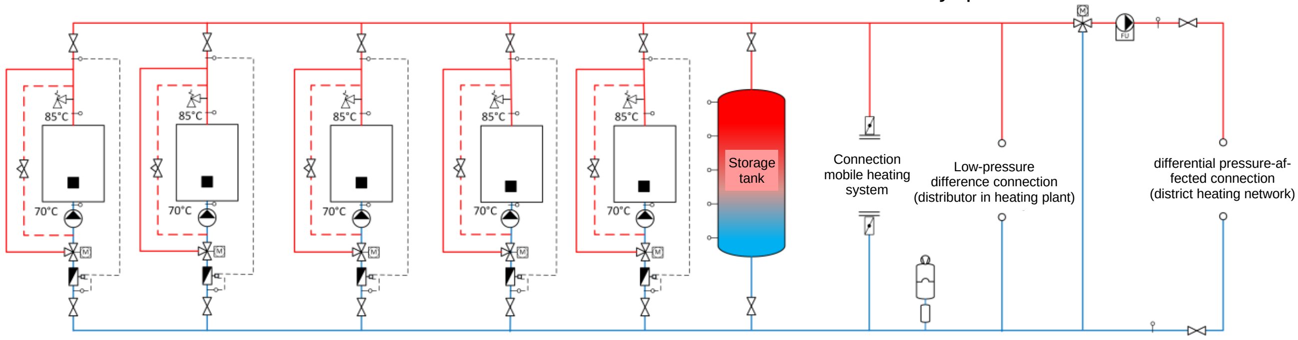


Figure 13.12 Schematic diagram of a multi-boiler system ("cascade system") with standard series devices.

It should be noted that biomass boilers as standard series appliances with fixed grate firing and underfeed firing carry out an automatic **ash removal and cleaning interval of** the fixed grate (with tilting grates) or the rotating grate after a specified operating time of, for example, 6 to 8 operating hours. In this process, the fuel on the grate is completely burnt down to ash in the burnout phase. The grate is then cleaned mechanically before the biomass boiler is restarted with the automatic ignition. The cleaning interval is around 30 to 45 minutes.

During the cleaning interval of a biomass boiler, it must be prevented that another biomass boiler is started up to bridge the cleaning process with a cold start in order to be switched off again as soon as the cleaned boiler is back in the stationary operating phase.

In the event of the failure of one biomass boiler, the remaining biomass boilers provide a reliable back-up (redundancy).

Multi-boiler systems with standard series devices result in a high degree of flexibility when expanding a heating network, as the required utilisation of the individual biomass boilers in low-load operation is already made possible in the basic expansion.

Requirements for the **fuel** (see also chapter 13.4):

- Pellets
- Quality wood chips WS- and IS-P16S-M20* as well as WS- andIS-P31S-M20
- WS- and IS-P31S-M35 (from boiler output > 200 kW with moving grate firing)

The required high fuel quality significantly increases operating costs due to the higher fuel price. This has a particular effect on the economic efficiency of multi-boiler systems with a high total nominal boiler output.

Design principles

Annual heat production with biomass	100 %
Design	Total boiler output without load peaks (black rhombus in Figure 13.4) Smallest boiler according to Table 13.4, Other boilers for problem-free boiler changeover (e.g. 1/5 to 2/5 to 2/5)
Number of full load operating hours biomass boiler	> 2,000 h/a
Low-load operation	Compliance with Table 13.4 with smallest boiler
Automatic ignition?	Yes, for small boiler (< 500 kW)
Fuel	Pellets, quality wood chips WS- and IS-P16S-M20* as well as WS- and IS-P31S-M20 or WS- and IS-P31S-M35 (from boiler output > 200 kW with moving grate furnace)
Storage capacity	≥ 1 h related to 2/3 of the total nominal output of the biomass boilers (recommended, however, ≥ 1 h at 100% total nominal output).

13.6.2 Additional biomass boiler with high fuel quality for summer operation

In the case of low heat demand in the transitional period or in summer, a monovalent system with two biomass boilers sometimes does not achieve the necessary utilisation (the minimum average daily heating load required for low-load operation according to Table 13.4) for the larger biomass boiler(s), as these have a higher minimum load requirement due to their size and the reference fuels typically used.

In order to have more flexibility in the design and operation of systems, an additional biomass boiler (summer boiler) with a low output can be a useful addition to cover summer or low-load operation flexibly and efficiently (see Figure 13.14). As a rule, series devices are used here that are designed for operation with high fuel quality (pellets or quality wood chips) and have automatic ignition. They represent a sensible alternative to fossil boilers as well as bio-oil and biogas boilers in order to enable 100% CO_2-neutral heat generation.

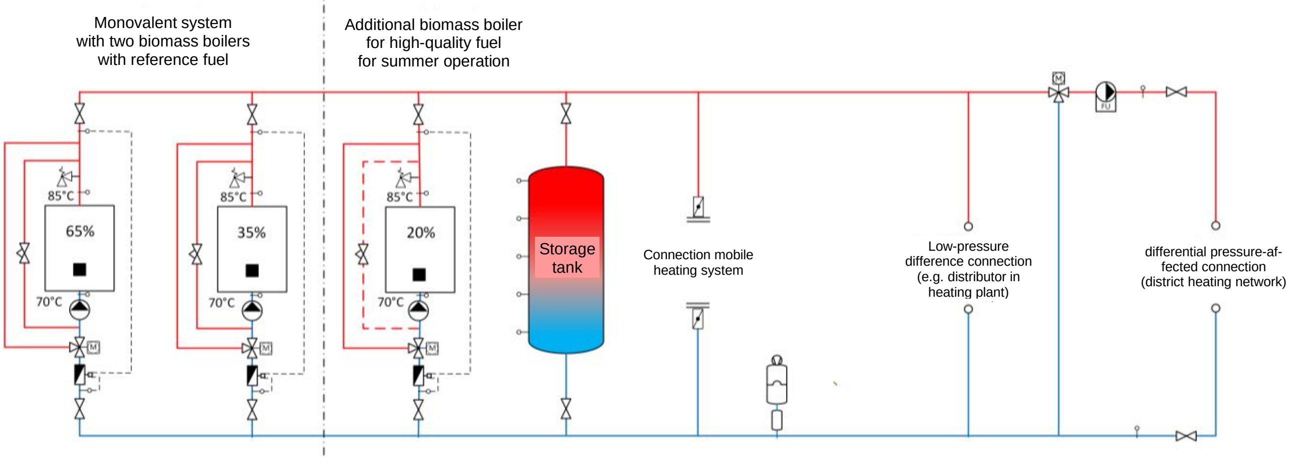


Figure 13.13 Schematic diagram of a monovalent system with two biomass boilers and an additional biomass boiler for high-quality fuel for summer operation.

The aim of the design of the auxiliary biomass boiler is to achieve optimum utilisation of the biomass boiler in heat production for the domestic hot water supply in summer.

For this purpose, the boiler output or the total boiler output of one or more additional biomass boilers should be dimensioned to at least twice the maximum average daily heating load required in summer operation. In a system with only one large biomass boiler and one additional biomass boiler, the system should possibly be dimensioned for three times the maximum average daily heating load required in summer operation. This is based on the assumption that storage capacity is available to compensate the daily load in such a way that the additional biomass boiler can cover the average daily load during summer operation. This makes it possible for the additional biomass boiler (see Figure 13.5) to cover the transitional range, in which the larger biomass boiler could then be used as well.

For series appliances, **special fuel requirements** must be taken into account as for multi-boiler systems with standard series appliances (see chapter 13.6.1).

If there is no separate fuel storage and supply, it must be ensured that the fuel storage contains the required high-quality fuel when the auxiliary biomass boiler starts up. If there is a malfunction in the fuel supply, none of the boilers can be operated.

With separate fuel storage and supply, the additional biomass boiler can be operated at the same time as the other boilers and used as peak load cover and for redundancy or to guarantee supply in the event of a malfunction.

When using pellets for the auxiliary boiler, an additional pellet storage must be created, e.g. a fabric silo.

If a central solar thermal system is available, auxiliary biomass boilers with automatic ignition and high flexibility offer the possibility of a back-up for the solar thermal system. However, the question of the usefulness and economic efficiency of an auxiliary biomass boiler arises, as the heat production and thus the utilisation of the auxiliary biomass boiler is severely limited. The required utilisation of the auxiliary biomass boiler according to Table 13.4 cannot be guaranteed at all times. Therefore, such operating phases should be kept to a minimum (see chapter 13.7.4.3). When the auxiliary biomass boiler is switched on, it should have a long continuous operating time of > 8 hours at minimum boiler output. The storage tank should only be partially charged so that the solar thermal system can be used to the maximum again the following day.

13.6.3 Combined heat and power

For a future-oriented, energy efficient use of the biomass potential, the installation of combined heat and power (CHP) plants should also be examined. In Germany and Austria, the term “Kraft-Wärme-Kopplung” is used, in Switzerland “Wärme-Kraft-Kopplung”.

When producing electricity from biomass, the maximum quantity of heat produced should always be used to save resources. Otherwise, the use of biomass for electricity production is not recommended. The modulation range of these plants is relatively small, so as a rule they should always be operated at nominal power for electric and thermal base load supply. The following technologies are suitable for biomass CHP plants:

- Steam turbine
- Steam engine
- Organic Rankine Cycle (ORC)
- Gas engine
- Hot gas turbine

The individual CHP technologies are described in more detail in the Handbook on Planning of District Heating Networks (see [19], chapter 2.9).

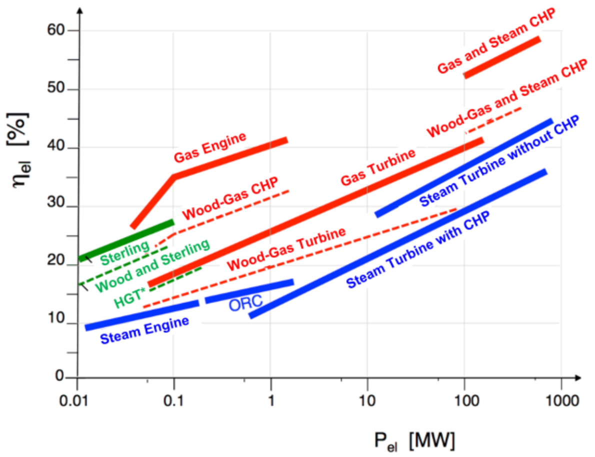


Figure 13.14 Net electrical efficiencies of different technologies for electricity generation as a function of electrical output [19]. CCGT = combined cycle gas turbine, HGT = hot gas turbine (with biomass combustion).

Figure 13.14 shows that CHP technologies cover a range from a few kW to over 1 GW of electrical capacity. The achievable net electrical efficiencies cover a range from less than 10 % up to 60 %. For the established processes of steam power technology, the electrical efficiencies show a pronounced scale dependency from less than 10 % for outputs from 10 kW_{el} up to around 45 % for large-scale plants. Other technologies such as biomass gasification and the Stirling engine achieve higher electrical efficiencies in the small and medium output range. Electricity production with biomass is independent of the weather and the season and is suitable for base-load operation and electricity grid stabilisation.

With biomass gasification, care must be taken to ensure a high fuel quality. As a rule, a homogeneous and dried fuel such as quality wood chips WS/IS-P16S/P31S-M10 is required. Depending on the plant manufacturer, design and technology as well as the size of the plant, the range of fuels that can be used must be clarified in each individual case. In addition to electricity and heat production, the production of charcoal is also possible with biomass gasification technologies.

Biomass CHP plants have the following electricity production costs as orientation values:

- Steam process with steam boiler and steam turbine: 10 - 20 ct. /kWh (15 - 30 Rp/kWh)
- ORC process with thermal oil boiler and ORC module:
  15 - 25 ct. /kWh (20 - 35 Rp/kWh)
- Biomass gasification process with gas engine:
  15 - 30 ct. /kWh (25 - 40 Rp/kWh)

The economic viability must be examined in detail according to the market conditions (achievable feed-in tariffs/own power coverage vs. electricity production costs) and technical framework conditions (partial load operability, plant utilisation, heat output optimised operation/overall plant efficiency, etc.). and, if applicable, to compare the achievable electricity production costs with those of other renewable electricity sources.

13.7 Complementary heat sources and heat generation systems

13.7.1 General remarks

The demand for future CO_2-neutral heat generation is a challenge that must be accepted. For peak load and low load coverage, additional options to the basic variants of heat generation systems with biomass combustion (chapter 13.5.1) can be required. Another possibility is the integration of decentralised existing boilers, if available. Depending on the required infrastructure, measurement and control technology, it must be checked in each individual case whether existing heat generators (e.g. pellet or gas boilers, CHP units) can be integrated into a planned network.

Fossil peak load coverage cannot meet the decarbonisation requirement. Heat generation for heating networks (thermal grids) should therefore increasingly be carried out with several renewable energy sources in the future.

Complementary heat sources can be:

- Waste heat from exhaust gases of biomass combustion plants for direct and indirect use with heat pump
- Waste heat from refrigeration plants for direct and indirect use with heat pump
- Waste heat from waste water and waste water treatment plants (WWTP) for indirect use with heat pump
- Waste heat from industrial processes for direct and indirect use with heat pump
- Ambient heat from near-ground air layers, surface waters and near-surface geothermal energy for indirect use with heat pump
- Geothermal energy down to a depth of approximately 500 metres as well as geothermal energy at greater depths for direct or indirect use with heat pumps, including groundwater utilisation.

Complementary heat generation systems are:

- Heat pumps
- Solar thermal systems
- Biogas/bio-oil boiler
- Biogas/bio-oil CHP (combined heat and power plants)

The interaction of biomass combustion systems with the supplementary heat sources / heat generation systems is determined by the availability of the heat source or the heat generation system.

The requirements regarding the minimum average daily heating load for low-load operation according to Table 13.4 and the annual utilisation of the biomass boilers (number of full load operating hours) determine the area of application at which the biomass combustion system can be operated in an energy-efficient and low-emission manner.

The following objectives must be observed when combining a biomass system with supplementary heat sources or supplementary heat generation systems:

- Substitution of fossil energy sources for CO_2-neutral heat production
- Energy efficient use of the biomass potential. The limited potential is to be used optimally.
- Substitution of biomass with other renewable energy sources, where possible and appropriate. The potential of renewable energy sources is to be expanded and these are to be used optimally.
- Avoiding “competitive situations” between the different renewable energy sources - combining instead of competing!

For the successful implementation of the listed complementary heat sources and heat generation systems, the basic requirements of the selected technologies must always be taken into account. For example, in order to increase efficiency, some technologies require low return temperatures in the heating network with a target value of 40 °C or lower flow temperatures in the heating network with a target value of 70 °C.

With additional heat generation systems, it has be considered in the boiler design that the biomass boilers must be operated at the required minimum utilisation according to Table 13.4. The use of the additional heat generation systems can reduce the number of full load operating hours of the biomass boilers, so that the values required in Table 13.5 cannot longer be met.

The overall system should be designed and operated in a way that the basic requirements listed in chapter 13.3 can be met at all times.

13.7.2 Heat recovery from exhaust gas

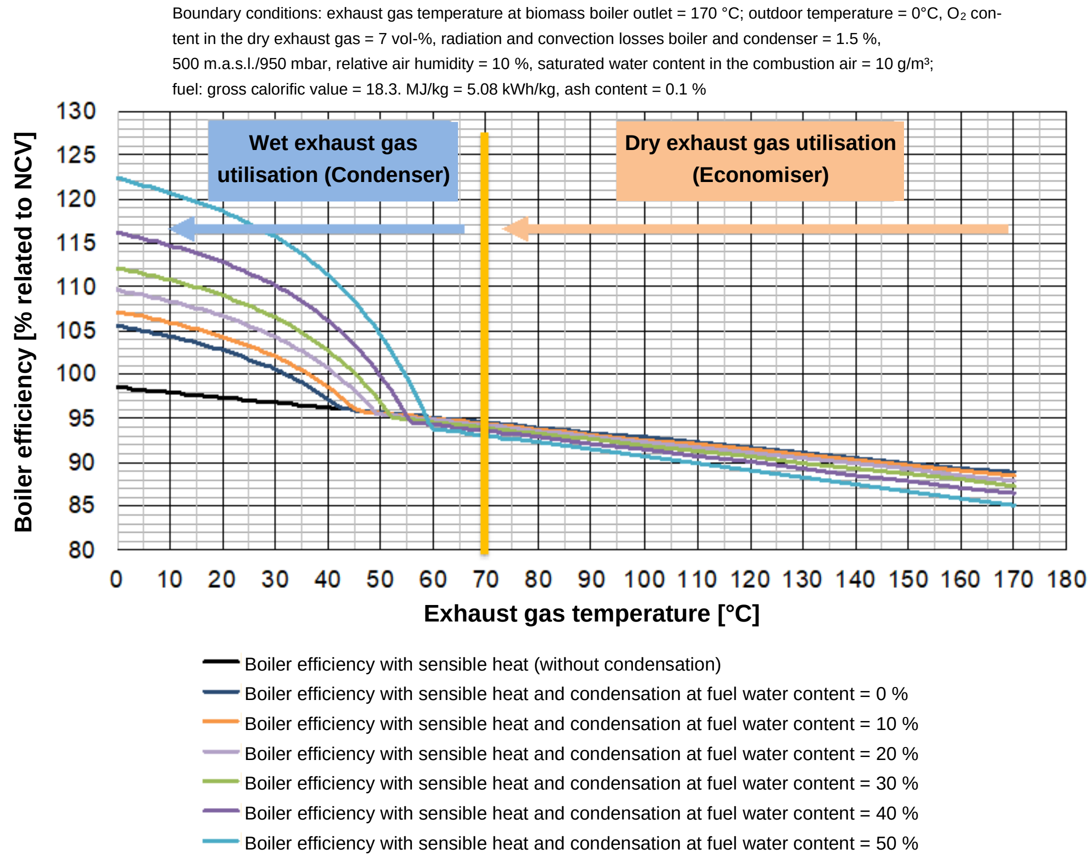


Figure 13.15 Boiler efficiency as a function of exhaust gas temperature and water content of the fuel. Dry exhaust gas utilisation with economiser, wet exhaust gas utilisation with exhaust gas condensation (source Verenum AG).

13.7.2.1 General remarks

After leaving the boiler or the flue gas cleaning system, the flue gas can still have temperatures of 120 to >160°C and a correspondingly high energy content, depending on the design and operating condition.

Figure 13.15 shows the potential for increasing the boiler efficiency through the use of economisers and flue gas condensation systems. Accordingly, the variants of heat recovery from the flue gas described below should be examined for efficient energy utilisation from biomass. Further information can be found in chapter 5.9.

13.7.2.2 Economiser

At the outlet of the particle separator, the flue gases have temperatures ranging from 120 °C at partial load to 160 °C at nominal boiler output. In the economiser, the sensible heat is recovered by cooling the flue gases to about 70 °C (about 15 K above the dew point). With a high annual boiler utilisation, an additional WRG share of 5 to 7 % of the produced heat quantity of the biomass boiler can be achieved.

Hydraulically, the economiser is usually connected in series to the main return after the storage tank (on the boiler side) (see Figure 13.16, diagram on the left). A hydraulic integration of the economiser in parallel to the biomass boiler (see Figure 13.16, diagram on the right), thus like an additional heat generator, should be considered if the main flow temperature is < 85 °C, the main return temperature > 65 °C or the heat transfer medium of the biomass boiler (e.g. thermal oil, steam or hot water) is > 110 °C and the heat generated by the economiser can be transferred to a hot water system.

FAQ 17 describes in detail the advantages and disadvantages of the different variants of integrating the economiser on the heating water and exhaust gas side.

Further information can be found in chapter 5.4 and in chapter 5.9.

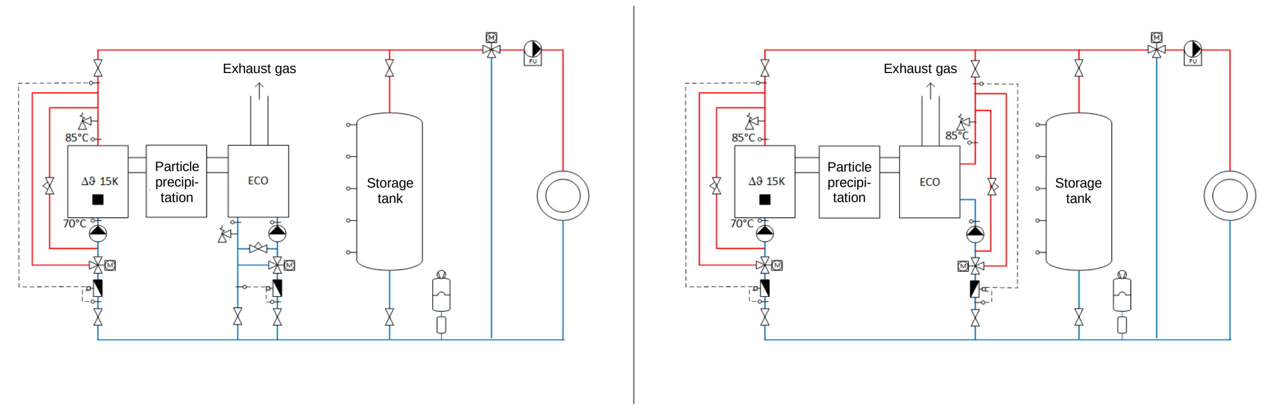


Figure 13.16 Schematic diagram of a system with the integration of an economiser in series in the return (left) or in parallel (right).

13.7.2.3 Flue gas condensation

In the flue gas condensation system, the latent heat in the flue gas is also recovered along with the sensible heat. The flue gases are cooled well below the dew point to achieve maximum heat recovery.

In order to be able to achieve a WRG share > 10 % or a target value > 15 %, the following framework conditions must be met:

- Low return temperature of the heating system
- Excess air ratio λ in the stationary operating phase over the entire output range of the boiler 30 % to 100 %: < 1.5 wet base
- Flue gas recirculation and optimum utilisation of the biomass boiler system required (full load operating hours > 3,000 h/a, few start-up and burn-out phases).
- Average fuel water content at least M40
- Heat exchanger temperature difference between flue gas temperature at the outlet and return temperature of the heating system < 4 K in the design case at maximum heat recovery capacity and < 2 K over the entire operating time.

The **return temperature** determines the heat recovery rate. **Every Kelvin** that the flue gas can be cooled below the dew point **increases** the heat recovery rate **by 1 %**.

Table 13.7 Basic requirements for the efficient operation of an exhaust gas condensation system.

Average water content	Fuel type	Return temperature
M 40	Wood chips from forest residues	< 45 °C
M 40	Wood chips from forest residues (> 1,000 kW nominal boiler output)	< 50 °C*
M 50	Industrial waste wood from a sawmill	< 50 °C

* with combustion air humidification

As a basic variant, the flue gas condensation system is hydraulically integrated in series into the main return (see Figure 13.17). To ensure the lowest possible return temperature, the volume flow for the condensation must be determined upstream of the storage tank. To ensure the volume flow via the condensation, the return must be between the storage tank and the boiler. Due to the simultaneity of boiler and condensation, the function of the hydraulics can thus be guaranteed without overflow.

It is also possible to install the condensation in the main return between the storage tank and the boiler (see Figure 13.18). If the volume flow in the main return is low, the volume flow in the circuit of the flue gas condensation system must be reduced by reducing the pump capacity so that an overflow of the flue gas condensation system flow into the inlet of the flue gas condensation system can be excluded. The installation of a non-return valve or a non-return flap constitutes an additional measure to prevent the undesired overflow.

In exceptional cases, e.g. in the case of a network separation between heat generation and heating network or in the case of a line with low return temperatures, the flue gas condensation can be integrated into the network-sided return (see Figure 13.19). In this case, the simultaneity of the heat production of the flue gas condensation system with the heat demand in the network and the corresponding mass flows in the return must be taken into account.

FAQ 17 describes in detail the advantages and disadvantages of the different variants for integrating the flue gas condensation system on the heating water and flue gas side.

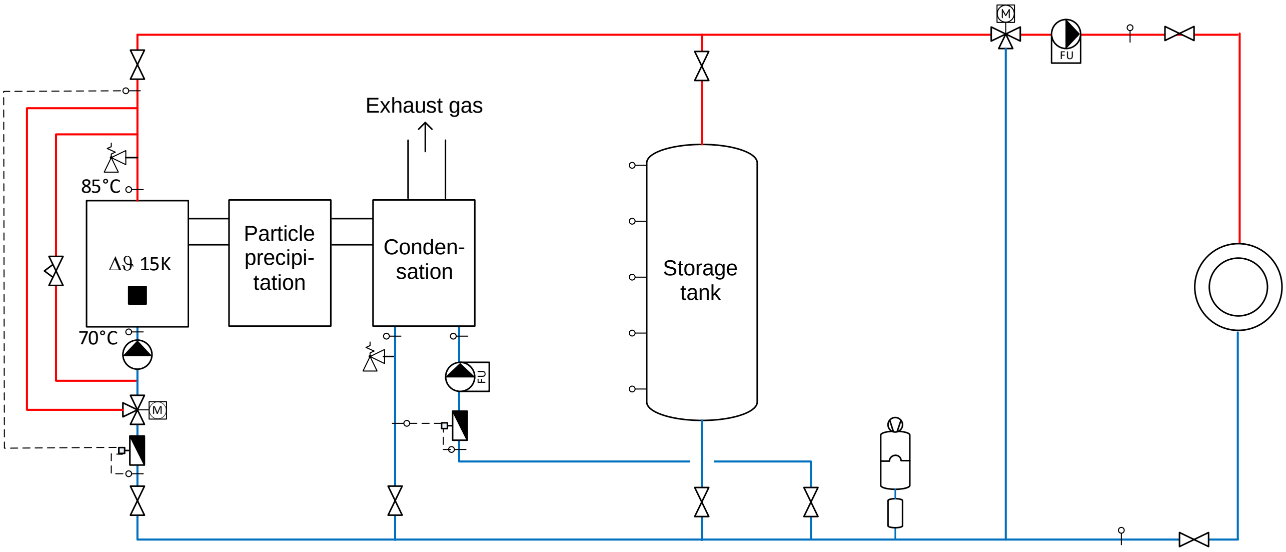


Figure 13.17 Schematic diagram of a system with flue gas condensation integrated into the main return: Flue gas condensation inlet upstream of the storage tank, flue gas condensation outlet between storage tank and boiler.

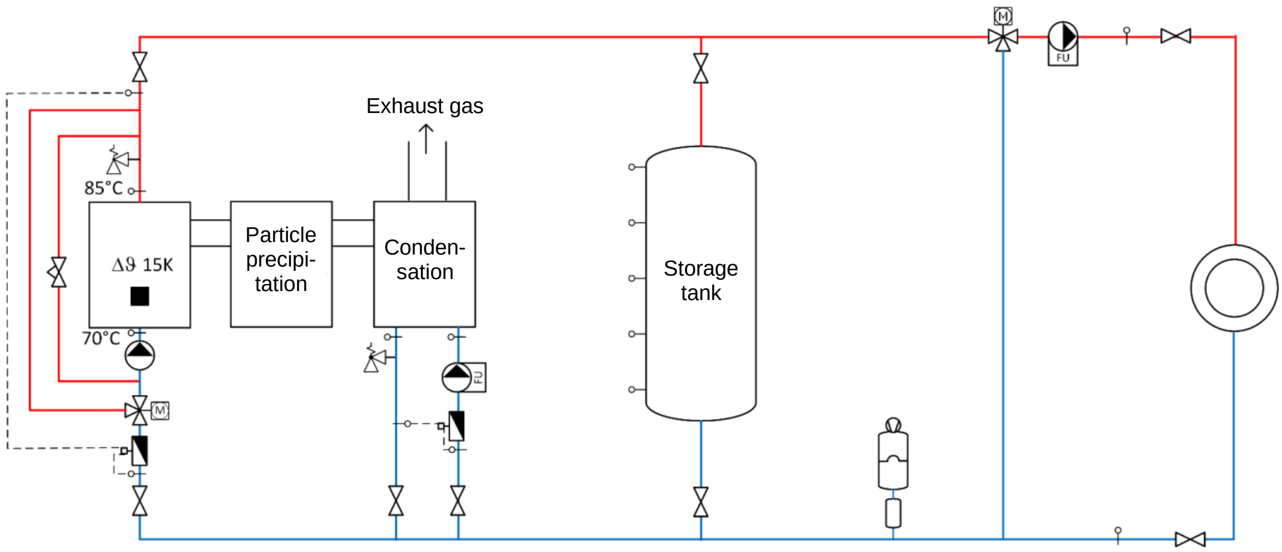


Figure 13.18 Schematic diagram of a system with flue gas condensation integrated into the main return: Flue gas condensation inlet and flue gas condensation outlet between storage tank and boiler.

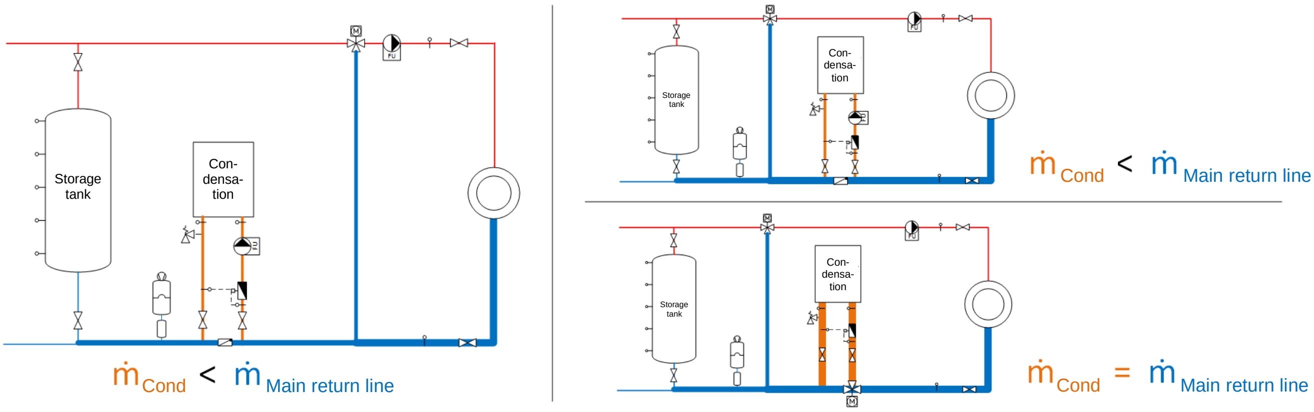


Figure 13.19 Schematic diagram with integration of flue gas condensation in the main return upstream of the storage tank.

13.7.2.4 Heat recovery with flue gas condensation for a low-temperature network

If consumers with low return temperatures and also low temperature requirements can be tapped via a separate low-temperature network, the low-temperature network can only be supplied with waste heat from the flue gas condensation. Due to the low temperature level, a significantly higher heat yield can be achieved from the flue gas condensation.

Note: For peak load coverage or for hygienic reasons, the grid temperatures can be temporarily raised with heat from the primary system. Due to the significantly lower flue gas temperature during normal operation than in the event of a malfunction of the flue gas condensation system, special attention must be paid to the dimensioning of the cross-section of the chimney (see section 13.10.4.2) and the operating mode in the event of a malfunction.

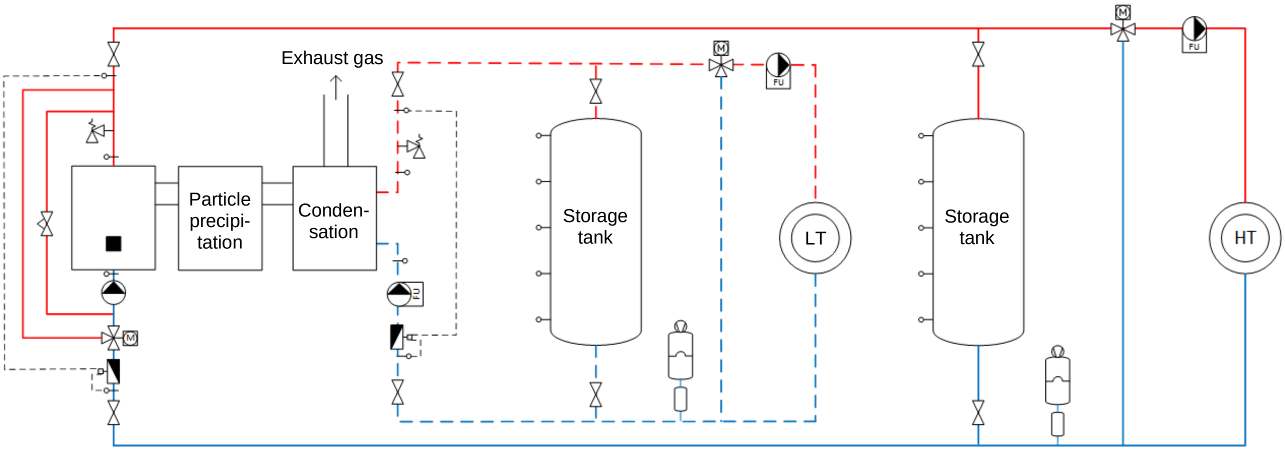


Figure 13.20 Schematic diagram of the integration of flue gas condensation into a low-temperature network.

13.7.3 Heat pumps

13.7.3.1 General information

A heat pump extracts heat from a heat source with a lower temperature level in order to raise this heat to a higher temperature level. The heat at a higher temperature level can be used for heating purposes. The working principle of the heat pump cycle and the definition of the corresponding key figures are assumed to be known.

The **efficiency** of a heat pump system is defined by the coefficient of performance (**COP**) and the **annual COP**.

The **quality grade** shows how the coefficient of performance COP of the real machine differs from the COP of the ideal CARNOT thermodynamic cycle (Carnot-COP).

The basic requirements for a heat pump system are:

- The refrigerant (working medium) of the heat pump has a high environmental compatibility with regard to ozone depletion potential (ODP) and global warming potential (GWP).
- The refrigerant must be suitable for the entire temperature application range.
- The design of the heat pump must correspond to the load of the unit. A heat pump with 8,000 full load operating hours per year must be realised in the industrial building standard.
- The legal requirements for the construction of a heat pump system must be observed. All relevant standards and directives must be complied with (approved refrigerants, noise emissions, hazard potential, ventilation of installation room, gas warning, etc.).

13.7.3.2 Energy efficiency of a heat pump system

The heat pump system must be operated with a high coefficient of performance (COP) and a high annual COP respectively. The following points must be taken into account when designing the system:

- Operation at the smallest possible temperature lift (temperature difference between sink and source). The generated heat should be used at the lowest possible temperature level. The optimum utilisation of the waste heat from the hot gas must be taken into account with regard to the possible temperature lift.
- Selection of a heat pump with high COP or high quality grade (see Figure 13.22 and Figure 13.23).
- Continuous operation of the system at the optimum operating point with variable heat output with few start/stop phases to reduce wear. For this purpose, several heat pumps, speed-controlled heat pumps or a combination of both variants can be used.
- Hydraulic integration of the heat pump system for raising the temperature of the main return:
  - The main return temperature of the heating network must be kept constant at the lowest possible temperature level.
  - The heat feed of the heat pump system for the return temperature increase must be carried out

according to the smallest possible temperature difference depending on the transfer capacity in the variable volume flow of the heat pump circuit.

- In the following operating conditions, the heat pump system must feed heat into a storage tank that is connected in series to the main return (see Figure 13.21 left) or into the lower part of a storage tank that is connected in parallel to the heat generators (see Figure 13.21 right):
  - The heat production curve of the heat pump system is not identical to the curve of the load reduction in the heating network:

    1-stage heat pump
  - The heat input from the heat source (e.g. flue gas condensation system, refrigerating machine) is time-delayed in relation to the load demand in the heating network. In the short term, high load fluctuations can occur in the heating network.

    This hydraulic integration enables a constantly low return temperature in the heat pump circuit despite varying load patterns of the heating network in relation to the heat production pattern of the heat pump.

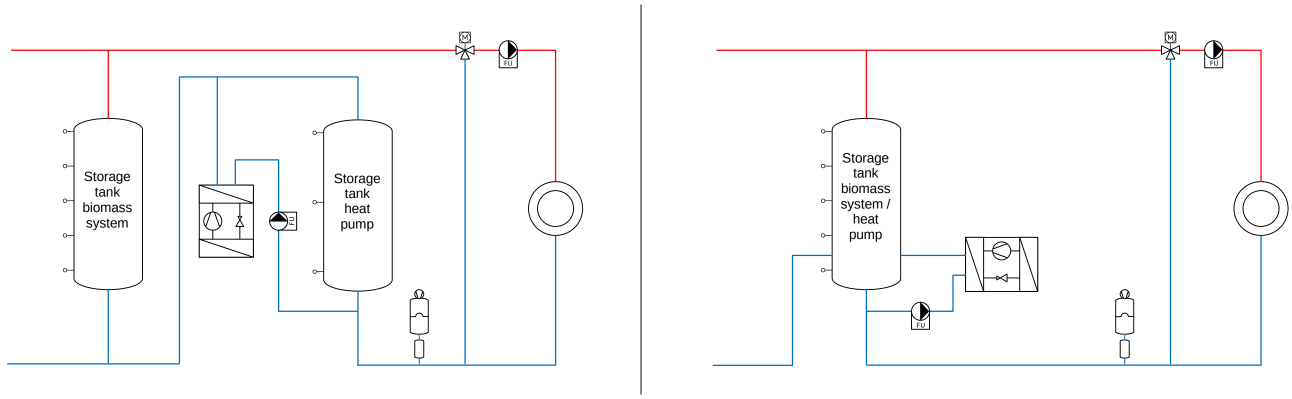


Figure 13.21 Schematic diagram for integrating heat pumps.

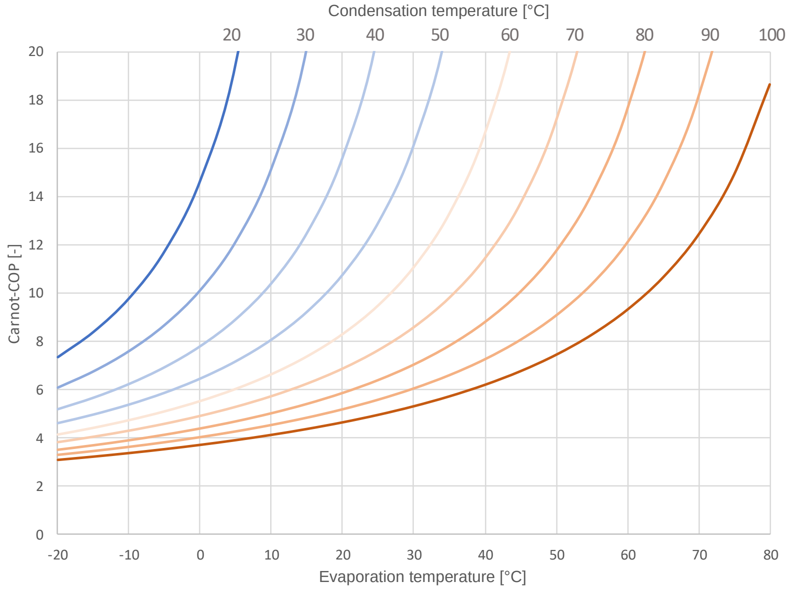


Figure 13.22 COP of the Carnot process. The diagram is based on a quality grade of 1 of an ideal machine or heat pump. In real operation, heat pumps have a quality grade of 0.4 to 0.6.

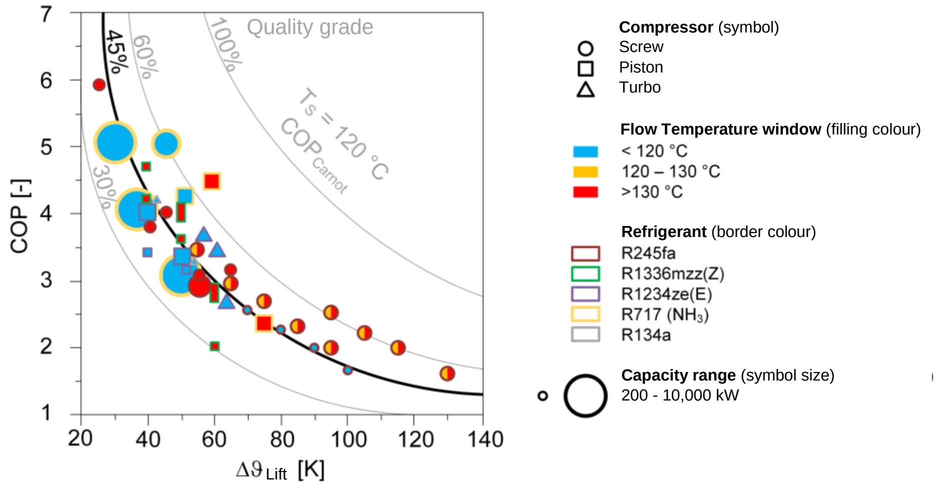


Figure 13.23 Quality grade and COP of real machines as a function of the external temperature lift, i.e. the temperature difference between sink outlet and source inlet temperature [134].

For the economic and energy-efficient operation of a heat pump system for a heating network with a biomass heating plant, a target value of the **annual COP > 4** must be observed. The annual performance factor or the coefficient of performance COP is directly related to the temperature lift that the heat pump system has to achieve (see Figure 13.22). The state of the art of industrial heat pump systems is:

- Temperature lift 30 K, COP 6 to 7*
- Temperature lift 40 K, COP 4 to 5*
- Temperature lift 60 K, COP 3 to 4*
  (e.g. 15 °C to 75 °C)

  *Heat pumps with high quality grade

When selecting the **refrigerant,** an ODP value of 0 and a low GWP value must be ensured (see Chemicals Risk Reduction Ordinance, ChemRRV [135]). As far as possible, natural refrigerants should be considered

13.7.3.3 Hydraulic integration of a heat pump system for summer operation

If the flow temperature of the heat pump in summer operation (when heat is generated only with the heat pump system) corresponds to the supply flow temperature of the district heating network, the heat pump can charge the storage tank of the biomass boiler system (see Figure 13.24). When the heat pump system is operated together with the biomass combustion system, the heat pump feeds heat into the main return upstream of the storage tank or into the lower part of the storage tank to raise the return temperature.

Note: In principle, the basic QM requirements must always be complied with!

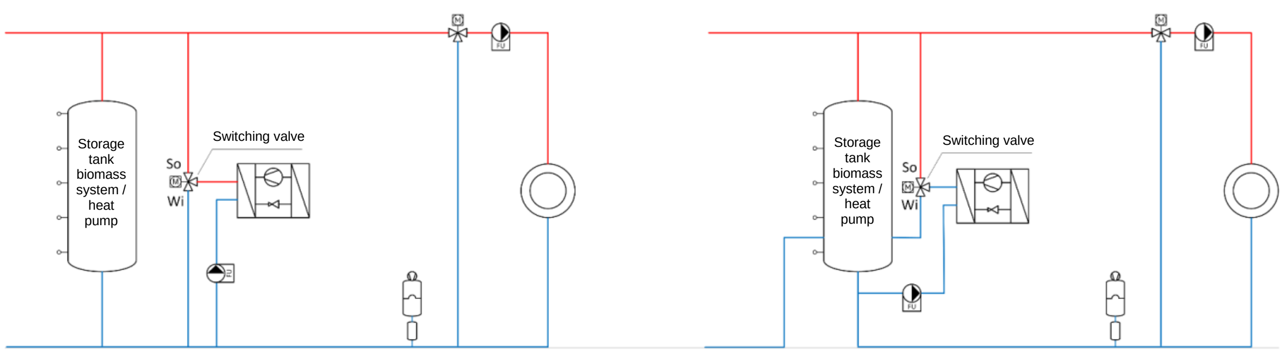


Figure 13.24 Schematic diagram for integrating a heat pump for summer operation.

13.7.3.4 Heat pump in combination with flue gas condensation

The heat recovery share of the flue gas condensation can be increased up to 30 % if the flue gases, after cooling with the main return temperature of the heating network, are additionally cooled down to < 30 °C with the help of heat pumps.

The heat pump system must be installed hydraulically in such a way that the heat produced is fed in series into the main return (see Figure 13.25). This achieves a high COP which becomes greater the smaller the temperature lift.

In order to keep the temperature lift of the heat pump system low, a low main return temperature must be ensured. It should be noted that the direct part of the heat recovery through the flue gas condensation system already leads to an increase in the main return flow.

The economiser must be hydraulically integrated into the main return after the temperature increase by the heat pump system.

When using **compression heat pumps**, a COP > 4 should be aimed for and the system should be designed in such a way that it can be operated at constantly optimal operating conditions despite fluctuating exhaust gas volume flows by modulating the boiler output.

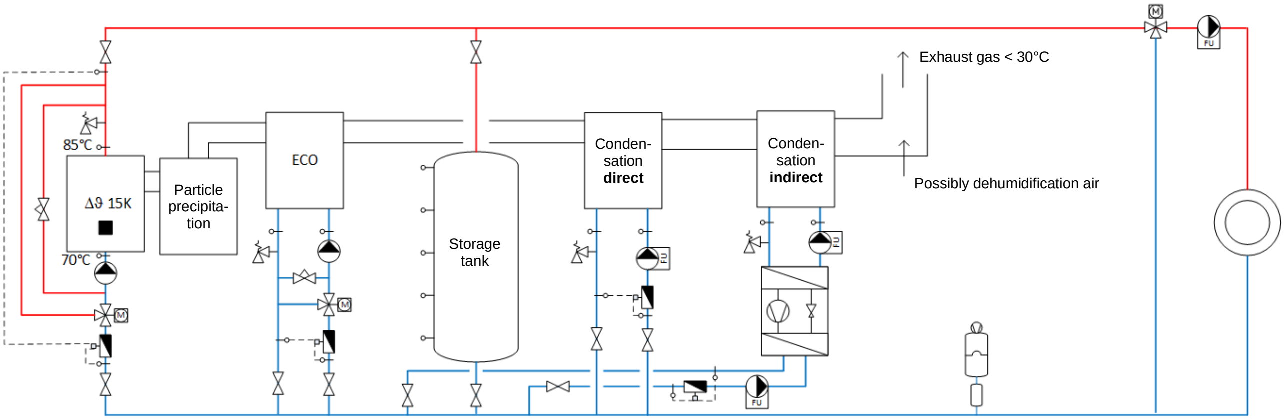


Figure 13.25 Schematic diagram of heat pump integration into flue gas condensation.

This can for example be achieved by using several compression heat pumps, a speed-controlled heat pump with speed-controlled pumps for the heat source circuit and the useful heat circuit, or with a combination of the two options. The additional heat output that the heat pump system gains by using the flue gas condensation system increases the total heat output of the heat generation considerably. When selecting the heat pump, it should be ensured that it is suitable for both a low temperature lift and a relatively high source temperature.

Absorption heat pumps are operated with a hot water boiler in the temperature range of 150 °C. Around 30 % of the hot water boiler output of the biomass boiler (the biomass boilers) is required for the driving heat of the absorption heat pump. As an option, the total boiler output of the biomass boilers can be divided into 70 % warm water and 30 % hot water boiler output with a shared flue gas condensation system. The hot water (30 % of the total volume flow of the boiler circuit) is cooled from approx. 150 °C to approx. 130 °C in the absorption heat pump. A COP of about 1.7 results for 80 °C flow and 55 °C return temperature on the condenser side (used for raising the district heating main return temperature) and a flue gas temperature after flue gas condensation of < 30 °C (Figure 13.26).

Here, the fuel efficiency can be increased by approx. 20 % through flue gas condensation at a fuel water content of M 50. The additional yield of a economiser is not taken into account.

Absorption heat pumps for heat recovery systems with flue gas condensation are used in biomass DH plants with a total required heat capacity > 5 MW. Ideally, some customers (maximum approx. 50 %) also require hot water, as is the case with dairies, laundries and other process heat consumers.

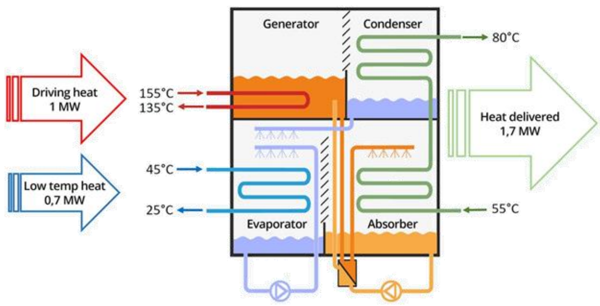


Figure 13.26 Absorption heat pump (LiBr, single-stage; source: STEPSAHEAD).

The area of application for **rotary heat pumps** for heat recovery with flue gas condensation is in biomass DH plants with a total required heat capacity > 5 MW.

Advantages of rotary heat pumps:

- No problematic refrigerant
  ODP = 0, GWP = 0, non-flammable, non-toxic (noble gas)
- Wide range of use from -20 °C to 150 °C with one and the same machine and work equipment

- Temperatures and outputs very flexibly adjustable
- Advantages for high temperature applications < 100°C.

Disadvantages of rotary heat pumps:

- moderate COP
- high costs
- high space requirement.

13.7.3.5 Heat recovery with flue gas condensation for cold district heating

Feeding the heat from the flue gas condensation system into a network with a flow temperature of about 15 °C enables the flue gases to be cooled down to < 20 °C resulting in a high heat recovery share of the flue gas condensation. The heat is distributed as cold district heating and is raised to the required temperature by decentralised heat pumps (annual COP > 4). This allows a high energy efficient use of biomass.

13.7.4 Solar energy

13.7.4.1 Objectives

Objectives of the use of solar energy in connection with the operation of a biomass heating plant are listed below:

- Efficient direct solar energy use makes it possible to reduce the demand for biomass in the months with high solar radiation. Biomass should be used in the months with low solar radiation.
- Avoiding the operation of a biomass boiler in summer with insufficient utilisation in low-load operation.
- Reduction of the use of fossil fuels (heating oil, gas) in summer when there is insufficient utilisation of the biomass boiler in low-load operation.

13.7.4.2 Solar thermal systems for heating networks

A solar thermal system for a district heating network is designed on the basis of the average summer load, i.e. the average daily heating load of the heating network in summer as the weather-independent heat capacity demand according to Figure 13.27. The hydraulic integration of the solar thermal system into the heating network can be centralised or decentralised.

With a thermal solar collector array, which is dimensioned according to the average daily heating load of the heating network in summer, 100 % of the heat demand can be covered in summer and part of it in the transition period. The biomass boiler system is only put into operation at the beginning of the heating season.

If a limited collector field area prevents 100% summer coverage, the required residual coverage must be provided by a biomass boiler with high fuel quality or, as an alternative, with a boiler that is ideally operated with bio-oil or biogas (see chapter 13.6.2).

Various examples and possibilities for integrating solar thermal systems can be found on the website of Solar District Heating or Euroheat&Power (https://www.solar-district-heating.eu and https://www.euroheat.org/).

The following empirical formula, taking into account the values in Table 13.8 allows a rough estimate of the necessary total collector area. The detailed dimensioning of the total collector area has to be done taking into account the effective framework conditions. Simple applicable tools, which are available free of charge, facilitate the dimensioning (e.g. www.scfw.de).

*Collector area = collector area factor [m²/kW$_{summer\ demand}$] * average daily heating load in summer [kW$_{summer\ demand}$].*

Table 13.8 Estimation of collector area and storage volume for different solar fractions (basis: 10 realised plants in CH, DE and AT)

Collector area factor [m²/kW$_{summer\ demand}$]	**Storage volume** [l/m²$_{collector}$]	**Annual coverage*** [%]	**Solar fraction summer** [%]
20	100	approx. 20	100
4	200	approx. 6	40
2	300	approx. 3	20

* Annual heat demand for domestic hot water assumed 25 % of the total heat demand, and heat demand outside the heating period (summer) around 10 % of the annual heat demand (heat demand for domestic hot water plus heat distribution losses of the district heating network). The higher the share of the annual heat demand for domestic hot water, the higher the possible annual coverage.

Assuming an annual collector yield of 400 to 500 kWh/m², the following orders of magnitude result:

- With a collector area of about 20 m²/kW and a storage volume of about 100 litres/m² collector area, a solar fraction of up to about 20 % can be achieved with respect to the total annual heat demand of the heating network. In summer, the solar fraction in this case can be almost 100 %.
- With approximately 4 m²/kW collector area and a storage volume of 200 litres/m² collector area, a solar fraction of up to 6 % can be achieved with respect to the total annual heat demand of the heating network.
- With a collector area of 2 m²/kW and a storage volume of 300 litres/m² collector area, a solar fraction of up to 3 % can be achieved with respect to the total annual heat demand of the heating network.

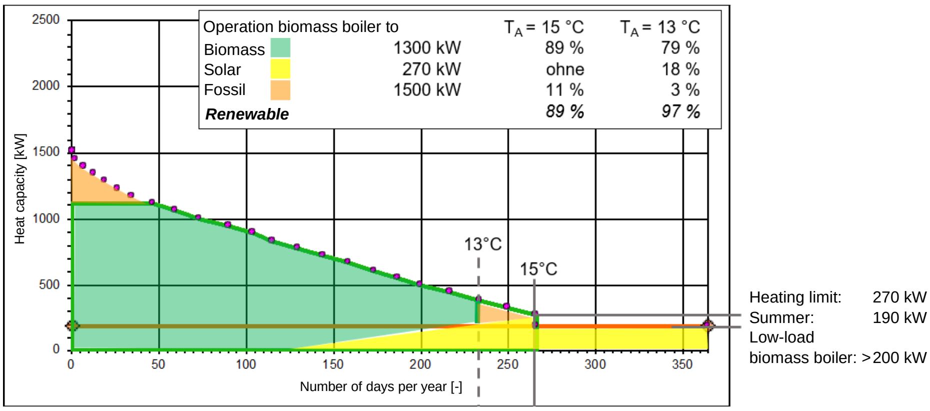


Figure 13.27 Annual duration curve of a biomass heating plant with a biomass boiler, a fossil-fired boiler and a solar thermal system.

A prerequisite for a sensible energy efficient integration of a solar thermal system into the network of a biomass heating plant is that the biomass boilers can be operated with a high overall annual efficiency η_a > 90 %. This requires optimal utilisation of the biomass boilers, combined with energy-efficient heat recovery from the flue gases.

- The additional heat yield from the installation of an economiser is around 6 % of the heat production of the biomass boiler. This corresponds to the yield of a solar thermal system with 4 m² of solar collector surface per kW of average daily heating load in summer and a solar annual coverage of up to 6 %.
- The additional heat yield from the installation of a flue gas condensation system is around 15 to 20 % of the heat production of the biomass boiler. This corresponds to the yield of a solar thermal system with 20 m² of solar collector surface per kW of average daily heating load in summer and a solar fraction of up to 20 %.

Note: If the solar thermal system cannot cover the entire summer demand, the utilisation of the biomass boiler in operation is considerably limited by the heat yield of the solar thermal system. If the utilisation is significantly lower than the minimum average required daily heating load for the biomass boiler according to Table 13.4, this results in a strong reduction of the annual efficiency η_a of the biomass boiler in operation. Under these circumstances, the combination of a solar thermal system with a biomass boiler to cover the heat demand in summer can have an unfavourable effect in terms of energy efficiency.

The **utilisation of the biomass boiler** is also significantly reduced in the transition period by the heat yield of the solar thermal system. This problem can be seen in the annual duration curve of Figure 13.27. With a solar fraction in summer of almost 100 % (e.g. substitution of fossil fuel in summer), the heat yield of the solar thermal system results in a significantly reduced load for the biomass boiler in the transition period. The system selection “one biomass boiler with storage tank (monovalent or bivalent)” results in an unfavourable operation of the biomass boiler in the transition period with reduced annual efficiency η_a due to a too low load (significantly below the minimum average daily heating load requested for the biomass boiler).

An additional biomass boiler with a small output for operation with high fuel quality (e.g. with pellets or quality wood chips) in summer and possibly in the transitional period can prevent the problem of insufficient utilisation of the biomass boiler by the heat yield of the solar thermal system (see chapter 13.6.2).

Therefore, for optimal operation of the biomass combustion system in the transitional period with the required utilisation with additional heat yield from the solar thermal system, the following system selection variants should be examined: 2 biomass boilers (division of boiler output 1 to 2) or multiple boiler system with storage tank.

The common storage volume is to be used as follows:

- In summer, the heat yield of the solar thermal system and the heat production of the biomass boiler system are fed into the main flow.
- In the transition period, the heat yield of the solar thermal system is fed into the lowest third of the storage tank for raising the main return. The upper two thirds of the storage tank are managed by the biomass boiler system according to the standard QM biomass heating plant circuit.
- Supplementary information can be found in FAQ 32 “How should solar collectors be integrated? “.

13.7.4.3 Decentralised solar thermal system at consumer

With a connection density in the heating network of < 1 MWh/(a*m), it should be examined whether the domestic hot water preparation in summer can be decentralised with thermal solar collector systems at the consumers, since during this time the heat losses of the heating network are significantly higher than the heat demand of the domestic hot water preparation.

In this variant, the heating network is only operated during the heating period. The heat losses of the heating network in summer are omitted and do not have to be covered by a central solar thermal system with corresponding electricity demand for the pumps of the solar thermal system and the heating network.

The solar thermal system is designed according to the domestic hot water consumption of each customer. It would also be possible to heat water at the customer's premises in summer using a heat pump (heat pump boiler in combination with photovoltaic system).

13.7.4.4 Photovoltaics with heat pump

The heat demand of a heating network can be completely covered by a heat pump in summer. If the electricity for the heat pump is generated with a photovoltaic system (PV system), this heat production is also renewable. Furthermore, the heat pump can be additionally integrated in winter for peak load coverage or in flue gas condensation.

A photovoltaic module area totalling 5 to 7 m² per kW of average daily heating load in summer demand results in an annual electricity production that corresponds to the electricity demand of the heat pump for covering the heating demand in summer.

The photovoltaic module surface can also be arranged on several existing roof surfaces.

The following assumptions can be made:

- Summer heat demand: 10 % of the total annual heat demand
- Heat source outside air on average > 15 °C, flow temperature heat network 70 °C
- Annual performance factor (APF) of the heat pump > 3 (up to 4 for heat pump with high quality grade).

In contrast to solar thermal, the heat pump can be switched off at the beginning of the transition period in order to start up the biomass boiler. In this way, the biomass boiler can be operated during the transition period with the required utilisation and without loss of annual efficiency (see chapter 13.7.4.2). PV electricity that is not used directly can be fed into the grid.

With the system choice "one biomass boiler with storage monovalent", the heat pump should be designed larger. Switching the heat pump on and off makes it possible to design the indirect use of solar energy with the photovoltaic system more flexibly, taking into account the required utilisation of the biomass boiler. The use of solar energy and heat production are separated in time.

The heat pump can also be used for heat recovery with flue gas condensation.

13.7.5 Waste heat utilisation

13.7.5.1 Preliminary remarks

Waste heat is the term used to describe heat flows that occur as a by-product of processes and are released into the environment unused and often with additional energy expenditure for pumps, fans, re-cooling heat exchangers or refrigeration systems, contributing to unwanted heating. Waste heat utilisation (heat recovery) refers to measures that use this waste heat for other processes or purposes and thus increase energy efficiency.

In contrast to heat from a heat generator, waste heat is not demand-related, but process-related. Qualitative (temperature) and quantitative (heat quantity) fluctuations in the waste heat supply due to seasonal conditions, working hours or process sequences and other reasons, as well as temporal shifts between waste heat supply and heat demand, must be taken into account when designing the systems and especially the heat storage tanks. In the Excel tool for demand assessment and appropriate system selection from QM for Biomass DH Plants, waste heat utilisation can be taken into account under "Maximum average daily base load capacity" when designing the system.

Note: Industrial plants usually work one to two shifts from Monday to Friday and do not produce over Christmas and New Year. It is therefore possible that waste heat from industrial plants is not available for space heating during this time.

13.7.5.2 Direct waste heat utilisation

Waste heat sources > 80°C

Heat from waste heat sources > 80 °C (e.g. waste heat from CHP plants, deep geothermal energy) is usually at the same temperature level as the biomass heating system and can be integrated directly into the main flow or the heat storage system in parallel to the biomass boiler system.

When integrating waste heat sources with relatively low power and consequently low mass flow, it should be noted that the flow rate at the customer end should be adapted to this mass flow. Otherwise, there is a risk that the temperature in the flow of the waste heat utilisation is mixed by the high mass flow and the heat storage tank is charged from the bottom.

Waste heat sources > 60°C

For heat sources > 60 °C (industrial waste heat, compressed air waste heat, desuperheater heat or medium-depth geothermal energy), the heat should be fed directly into the main return of the heating network. This way, the main return temperature is raised and less heat > 80 °C has to be added to reach the setpoint temperature of the heating network. In this case, however, the simultaneity of waste heat generation and waste heat demand of the customers or the heating network as well as the mass flows of the main return to be raised must be matched with the waste heat output. If necessary, an additional heat storage tank is useful in order to compensate for the temporal shift from heat demand to heat supply. If this waste heat is fed directly into the heat storage tank of the biomass heating system, the corresponding heat quantity and its influence on the storage temperature must be taken into account when designing the heat storage tank. The storage tank must be dimensioned accordingly and it must be ensured that the maximum return temperature of all heat generation components can be maintained.

13.7.5.3 Indirect waste heat utilisation with heat pump

Waste heat sources < 50°C
Waste heat from heat sources with a temperature that is lower than the main return temperature of the heat consumers cannot be used directly. If no heat sink is available for direct waste heat utilisation, this waste heat can be raised to a usable temperature level with the help of a heat pump and fed into the heating circuit.

With regard to the application possibilities, application limits and requirements for the design of heat pumps, the basic conditions mentioned in chapter 13.7.3 must be observed.

The following additional heat sources for condensation waste heat from exhaust gases can be used, for example, with a heat pump:

- Waste heat from refrigeration systems
- Industrial waste heat/industrial exhaust air
- ARA waste heat (waste water treatment plants)
- Groundwater (lake or river water)
- Near-surface geothermal energy (geothermal probes).

Waste heat from refrigeration systems (20 to 40°C)
The condensation temperature of refrigeration systems is usually between 30 °C and 40 °C. This temperature level can often not be used directly in the heat network but as a source for a heat pump. Depending on the refrigerant and the design of the system, the refrigerant can be directly compressed to a higher pressure in a second stage or raised to the usable temperature with a separate system.

Depending on the purpose of the cooling application, the heat demand varies seasonally. If mostly air-conditioning cooling is produced, the heat pump can be used well to cover the domestic hot water demand in summer. In winter, the flue gas condensation system of the biomass heating can be used as a source for the heat pump. Cooling applications that run relatively stable all year round can accordingly also be used all year round for waste heat utilisation.

Due to the relatively high source temperature, good COP values and also high useful temperatures are possible with these systems.

Process-dependent industrial waste heat (5 to 80 °C)
Waste heat from industrial plants can be of very different origins and occurs at different temperature levels. The first priority in the use of industrial waste heat is that it should be used as close as possible to the location where it is produced. An analysis of all processes in the plant using the pinch method helps to identify heat sources and sinks and enables the creation of a “heat exchanger network”. Waste heat that is not used in the company can be transferred to the central heating system.

Due to the temperature, directly usable heat is to be integrated according to chapter 13.7.5.2. Waste heat at a lower temperature level can be raised to a usable temperature with a heat pump and integrated into the system:

- In a low-temperature network, waste heat from machines (turbine plant with generator, machine tools, etc.), industrial or commercial waste heat and geothermal energy, e.g. from thermal springs, can be transferred.
- The use of the heat pump must be coordinated with the temporal occurrence of the waste heat or balanced with a heat storage tank.

Waste heat from waste water treatment plants (5 to 20 °C, varies seasonally)
In wastewater treatment plants (WWTPs), residual heat of 5 °C to 20 °C accumulates throughout the year and can be usefully utilised for flue gas condensation in the biomass boiler system. A flow temperature of around 15 °C for the wastewater treatment plant enables the flue gases to be cooled to < 20 °C and thus a high grade of heat recovery. In the winter months, the reduced waste heat potential of the WWTP can be compensated by lower waste water temperatures due to lower waste water volumes.

The heat pump system is operated to cover the base load. In summer, the heat pump supplies the flow temperature for the district heating network. During the heating period, it serves to raise the main return temperature.

The biomass boiler system serves to cover the medium load and, if there is sufficient storage volume, also to cover the peak load. The peak load can also be covered with biogas or bio-oil boilers.

Groundwater and surface water with seasonally varying temperatures
These include the following sources:

- Groundwater has a source temperature of 8 to 12 °C.
- The source temperature of surface water: ranges between 5 to 20 °C. There are relatively significant seasonal differences.

These heat sources can be used sensibly in the flue gas condensation system of the biomass boiler system. A flow temperature of 15 °C allows the flue gases to be cooled down to < 20 °C and results in a high grade of heat recovery. The reduced potential of groundwater and surface water in the winter months can be compensated by lower water temperatures.

The heat pump system is operated to cover the base load. In summer, it provides the flow temperature for the district heating network. During the heating period, it serves to raise the main return temperature.

The biomass boiler system serves to cover the medium load and, if there is sufficient storage volume, also to cover the peak load. The peak load can also be covered with biogas or bio-oil boilers.

Outside air (- 10 °C to + 30 °C)

For only summer operation of the heat pump outside air at a temperature of 10 °C to 30 °C as the heat source can be used.

Heat pumps with larger heat outputs require evaporators with a correspondingly large capacity, which need considerable space. In addition, sound insulation must be taken into account - especially in summer operation.

13.8 Provision of process heat

Process heat is heat that is required for an industrial process. In contrast to the demand for space heating, the demand for process heat is usually not dependent on the outside temperature, but directly on the process to be supplied.

Due to the high temperatures of combustion, biomass firing systems are also suitable for providing process heat at high temperatures. Depending on the required temperature level, process heat can be generated with biomass for the following media:

- Warm water system < 110°C
- Hot water system > 110°C
- Steam
- Thermal oil
- Hot air or other hot gas processes

Biomass boilers for steam, thermal oil or hot air are state of the art and available (see also chapter 5.4), but in contrast to warm and hot water boilers, they are only used for CHP or process heat plants. Unlike the flue gas from gas boilers, direct use of the hot flue gas from biomass boilers for processes (e.g. drying) is generally not possible due to the dust load. For high-temperature applications, special attention must be paid to safety engineering, inertia due to the large thermal mass of biomass furnaces and corrosion issues. This Planning Handbook does not go into detail about construction types, plant and safety technology. Specialised manufacturers and planners experienced in this field should be involved.

Load profile and process heat storage

Process heat demand, which occurs as a base load, can be supplied by a biomass combustion system, even if the temperature level is high.

Process heat demand with high short-term load fluctuations and an uneven daily load profile (e.g. no heat consumption outside working hours, such as during the night and at weekends) can hardly be covered monovalently with a biomass combustion system while maintaining the required utilisation. In order to enable the necessary load balancing via a heat storage tank without resorting to fossil fuel boilers, the following must be considered:

- In advance, possible measures should be carefully examined to reduce peak loads as far as possible by adjusting production.
- The heat storage tank and the storage tank charging management must then be designed in such a way that the largest load peaks, which occur for example in the morning at the beginning of the week, can be safely covered by the storage tank and the biomass combustion system together. The maximum storage tank discharge capacity and the maximum heat output of the biomass boiler are limiting factors. It must be taken into account that both maximum outputs can only be used simultaneously if the system operation is planned with foresight, as the biomass boiler requires a certain start-up time and the storage tank can only deliver the maximum discharge output for a limited time.
- Production planning may have to be incorporated into storage management.
- With a reduced (process) heat demand at the weekend, the storage design must ensure the heat production of the biomass boiler at minimum output (according to the low load condition in Table 13.4). The high storage charging state on Monday morning can be used to cover the start-up peak.
- In the case of steam, thermal oil or air as heat transfer media, the storage options are extremely limited due to various factors (achievable storage capacity, costs, safety aspects, ...). As a rule, no or only minor storage capacities can be implemented for these heat transfer media.

Design

For the system selection and design of the heat generation plant for the supply of process heat plants, the Excel tool for demand assessment and appropriate system selection of QM for Biomass DH Plants is sometimes not sufficient. Hourly load profiles based on measurements are often required. The influence of the weather is often of secondary importance, so that the design can be based on a few selected, typical weekly profiles. However, the temperature requirements of the processes are decisive for the plant selection.

Possible system variants:

- Base load coverage (if available) by biomass combustion plant with heat storage and peak load coverage with fossil gas boiler, which in future will be operated with biogas obtained from the gas grid and of natural gas quality.
- Biomass gasification system that produces a combustible product gas that is used as a substitute for natural gas in a gas boiler. It should be noted that the calorific value is significantly lower than that of natural gas and that adjustments to the gas pipes and burners are therefore necessary. As yet, there is hardly any practical experience of this. At the same time, the use for process heat supply requires either modulating operation practically in the range from 0 % to 100 % or a gas storage tank. For this variant, hardly any commercial products are available yet and high investment costs and operating costs (high fuel quality, increased maintenance and servicing costs) are to be expected. However, biomass gasification plants also enable the additional production of charcoal or “vegetable charcoal” (vegetable charcoal is charcoal produced from biomass that is not used for energy but for material purposes).

13.9 Design of system components

13.9.1 Selection of dust precipitation technology

Dust fractions
With regard to environmentally relevant aspects, dust emissions from the combustion of biomass are of great importance as well as NO_x emissions. When assessing dust emissions from biomass heating systems, a basic distinction must be made between two fractions. **Coarse fly ash is composed of** ash particles that are swirled up from the fuel bed during combustion and are discharged with the exhaust gas. The particle size ranges between a few µm and around 100 µm. The second fraction consists of **fine particles**, so-called aerosols, with diameters clearly <1 µm, which are formed by condensation of inorganic substances in the biomass that evaporate during combustion.

Legal requirements
In the discussion about fine dust, the term PM 10 is often used. PM 10 stands for “particulate matter < 10 µm” and corresponds to the total mass of solid and liquid particles, so-called aerosols, which have a particle size smaller than 10 µm. Most European countries have both emission and immission limits for PM 10. Since the limit values for respirable fine particles have been reached or exceeded in many places, also biomass heating systems must contribute to their reduction. In addition to particle mass, the number of particles, which is more relevant to health, will be of importance in the future.

Limit values for total dust in biomass combustion plants are country-specific (see Table 13.9 and chapter 19). With the Medium Combustion Plant Directive (MCPD) of 2015, new minimum emission standards were set within the EU for combustion plants up to 50 MW thermal with regard to dust, nitrogen oxides, carbon monoxide and sulphur dioxide, which were implemented country-specifically. Germany, for example, has implemented the MCPD far more strictly in the 44. BImSchV.

Table 13.9 Country-specific particulate matter emission limit values depending on the fuel or rated thermal input; for better comparability, the limit values of the individual countries are converted to 11 and 13 % O_2.

Fuel heat output		Total dust [mg/m³]	
		at 11 % O_2	at 13 % O_2
CH	70 - 500 kW		50
	0.5 - 1 MW		20
	1 - 10 MW	20	
	> 10 MW	10	
EN	< 1 MW	25	20
	1 - 5 MW	23	19
	> 5 MW	13	11
AT	< 1 MW	150	120
	1 - 2 MW	33	27
	> 2 MW	20	16

Significantly stricter limits apply to other biomass fuels (culm, waste wood).

Dust precipitation technologies
The following dust collection methods, described in detail in chapter 5.8.1, are available:

- Gravity dedusting (settling chambers)
- Centrifugal separation (cyclone, multicyclone)
- Electric field forces (electrostatic precipitator, wet electrostatic precipitator)
- Filtration (fabric filter, packed bed filter, ceramic filter)
- Wet dedusting (Venturi scrubber, radial flow scrubber, exhaust gas condensation).

Procedure for the selection of the separation process

1. Examine possibilities to reduce dust content already in raw gas (primary measures, see chapter 5.7): fuel selection, combustion design, adjustment of control parameters.
2. Determine degree of separation necessary to meet emission requirements
3. Selection of appropriate separation process for fly ash and fine particles.

Multicyclones are always applied or used as pre-dedusting and spark separation for a downstream dust collection process. As a rule, emission dust limits of 150 mg/m³ (at 11 vol.% O_2) can be complied with. Dust values < 100 mg/m³ (at 11 vol.% O_2) usually cannot be guaranteed without further measures (primary measures or downstream dust separation process). Dust values < 50 mg/m³ (at 11 vol.% O_2) require a downstream dust separation process.

The necessary degree of separation is determined from the dust content in the raw gas and the limit value to be complied with.

Table 13.10 used to select the appropriate separation method.

The following points are important or critical for the use of dust precipitation technologies:

- Water vapour content in the flue gas (water content of the fuel, changing water content)
- Exhaust gas temperature
- Temperature drop below dew point
- Load changes and shutdowns (nightly shutdown phases, weekend shutdown, summer operation)
- Operating phases with high oxygen content caused by incorrect air supply or by too high combustion air quantities
- High proportion of unburnt material in the fly ash.

Table 13.10 Criteria for the selection of dust collection methods.

Criteria	Assessment		
	Fabric filter	Electro-separator	Wet electric separator
Dry fuel	++1)	++	- –
Wet fuel	–2)	+	++
Base-load operation	++	++	++
Discontinuous operation	- –	+	+
Clean gas dust content mg/m³ at 11 vol.% O_2	1 - 5	5 - 50	5 - 20
Separation efficiency	> 95 %	90 % – 95 %	90 % – 95 %
Absorbent addition (additive) for reduction of HCl, SOx and PCDD/F 3)	++	- –	- –
Pressure loss (typical values) in mbar	high 10 - 20	deep1 .5 - 3.0	medium5 - 10
Auxiliary energy demand (typical values) in kWhel/MWhth	high14 - 17	deep2 - 5	medium5 - 10
Space requirement	medium	high	high
Operating range exhaust gas temperature	140 - 220 °C	80 - 250 °C	40 - 60 °C4)
Bypass necessary	yes	optional	optional
Sensitivity to ember particles, flying sparks	high	deep	deep
Investment costs	medium	high	high
Operating costs (maintenance and auxiliary energy)	high	deep	medium

Assessment ++ Very well suited, typical field of application
+ suitable
- – Not suitable

1) base-load operation advantageous
2) suitable to a limited extent for base-load operation
3) necessary, e.g. for waste wood
4) Dehumidification usually necessary, suitable in combination with flue gas condensation

Fabric filters prove their worth in biomass combustion plants that are operated to cover the base load (one start and one burnout phase over a long operating time of the plant). The use of a fabric filter in biomass combustion plants with discontinuous operation at low utilisation (many starts and burnout phases, frequent standby operation, interruptions of operation due to short boiler cleaning intervals) is problematic due to the cooling of the fabric filter during standby operation, as the flue gases can cool below the dew point in the start phase, which leads to humidification of the fabric. Moisture and dust form a coating on the fabric that cannot be removed with the compressed air shock cleaning and leads to clogging of the fabric filter. The moister the fuel, the higher the tendency of the fabric filters to clog.

Electrostatic precipitators for biomass combustion plants with discontinuous operation at low utilisation need trace heating (electrical or via the heating system) in the area where the dust particles accumulate, in order to prevent wetting of the particles in the start-up phase and thus the build-up of a deposit which can no longer be discharged automatically. The effectiveness of an electrostatic precipitator cannot be checked at present by continuous fine dust measurement. Optical measuring devices can be used to detect breakthroughs, for example in fabric filters (function check). However, an accurate, continuous measurement of the fine dust concentration is not possible. The effectiveness of an electrostatic precipitator over a specified operating time can be determined on the basis of “FAQ 38: How is the availability of electrostatic precipitators determined? The interval for demonstrating the availability of the electrostatic precipitator is determined by the authority. The availability must be shown at least each time an emission measurement is required by the authorities, for example with FAQ 38 Form 1 or 2.

13.9.2 Selection of nitrogen oxide reduction technology

The term nitrogen oxide includes nitrogen monoxide NO and nitrogen dioxide NO_2, the sum of which is often referred to as NO_x. The NO_x reduction processes are based on converting already formed NO with nitrogen-containing intermediate compounds to molecular nitrogen N_2, for example after the reaction $NO + NH_2 \rightarrow N_2 + H_2O$. Depending on the process, suitable reaction conditions (temperature, residence time, reducing agent) are necessary for this.

Procedure

1. Decide whether NO_x reduction is necessary
2. Determine the degree of denitrification necessary to meet emission requirements
3. Selection of the appropriate NO_x reduction process

Whether NO_x reduction is necessary depends not only on the emission limit values regarding NO_x concentration and NO_x mass flow, but also on the nitrogen content of the fuel or the resulting NO_x emissions. The NO_x emissions of the intended fuel assortment should be determined for comparable plants or estimated on the basis of empirical values (e.g. Table 4.9 or Table 13.11). The calculation of the NO_x mass flow from the NO_x concentration and the flue gas volume flow as well as the treatment of single and multiple boiler plants are described in [136]. With the NO_x concentration and the rated thermal input, i.e. the nominal boiler output divided by the boiler efficiency, it can be estimated from Figure 13.28 whether NO_x reduction is necessary.

If NO_x abatement is necessary, the degree of denitrification required to meet the emission requirements should be determined and the appropriate NO_x abatement process selected from Table 13.12.

Further information can be found in chapter 5.8.2

Table 13.11 Typical NO_x emissions of different fuels for plants without NO_x abatement processes.

Fuel	NO_x emission [mg/m³] at 11 % O_2	NO_x emission [mg/m³] at 13 % O_2
low nitrogen content, for example debarked spruce	100 - 150	80 - 120
Medium nitrogen content, for example forest wood with bark	150 - 250	120 - 200
Increased nitrogen content, for example bark, waste wood, wood from landscape management	250 - 400	200 - 320
High nitrogen content, for example UF chipboard	400 - 1,000	320 - 800

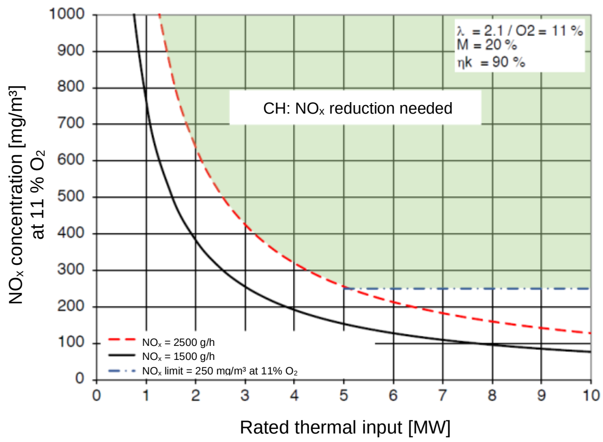


Figure 13.28 NO_x concentration in dependence of rated thermal input as a criterion for NO_x reduction measures.

Table 13.12 Denitrification efficiency and boundary conditions of various NO_x abatement processes (for a description of the processes, see chapter 5.8.2).

NO_x reduction technology		Denitrification level	N content	Boundary conditions
Primary measures "Low Nox" (without reducing agents)				
Air staging		low: high:	30 - 50 %50 - 70 %	internal reaction zone, primary air ratio 0.7 - 0.8, reaction from approx. 1,100 - 1,200 °C, conditionally suitable for fuels rich in ash
Fuel staging		low: high:	40 - 50 %60 - 75 %	Two fuel feeds, internal reaction zone, primary air number 0.8 - 0.9, reaction starting at about 800 °C
Secondary measures "Denox" (with reducing agent)				
SNCR process			50 - 75 %	internal reaction zone, temperature window about 850 - 950 °C, molar ratio important, undesired by-products possible
SCR process	low dust		90 - 95 %	Temperature window 200 - 250 °C, dust separation before catalytic converter

The activity of the catalysts in the SCR process is continuously reduced by the input of alkali metals via the exhaust gases. The effectiveness of the catalysts steadily decreases as they are poisoned by the alkali metals. For this reason, the SCR process can be operated in "low dust" mode with upstream dust separation.

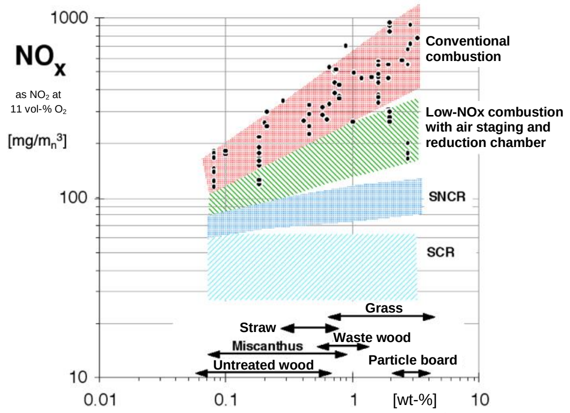


Figure 13.29 Comparison of NO_X emissions depending on the different nitrogen contents in the fuel with different reduction measures [120].

Furnace manufacturers can only guarantee compliance with specified NO_X emission limits if they obtain precise information on the nitrogen content in the specified fuel (fuel analyses). The nitrogen contents of individual fuel assortments in chapter 4 (Table 4.9, Table 4.10 and Table 4.11) allow an estimation of the fuel nitrogen content.

13.9.3 Selection of additional components

Additional components such as heat storage tank or economiser are determined on the basis of the detailed requirements for the biomass combustion system (see chapter 5.9 and chapter 7.5).

13.10 Central heating plant design

13.10.1 Central heating plant

13.10.1.1 Boiler room design, space requirements

If possible, the boiler room should be placed directly next to or below the silo so that complicated and cost-intensive conveying equipment is not necessary. Plants with a nominal output of more than 200 to 400 kW require a boiler room height of more than 3 m (2-storey with a platform is also possible). In addition, sufficient space must be provided for system maintenance and cleaning work in the combustion chamber and on the boiler.

The additional components such as coarse dust and fine dust precipitation, as well as the hydraulic integration of the boilers, heat storage tank, water heater, distribution system, expansion, control cabinet, flue gas cleaning, ash container, etc. must also be taken into account when planning the boiler room.

The space requirement should be shown in a layout drawing of the silo and boiler room at a scale of 1 : 50.

13.10.1.2 Hydraulic integration of the boiler system

For the hydraulic integration of the boiler system, the standard hydraulic schemes according to QM for Biomass DH Plants are to be adopted (see [62] or [71]).

In order to guarantee heat supply safety, as listed in the Q-Guidelines as Q-requirement D.4.8 [15], monovalent single-boiler systems must be equipped with connection pipes for emergency heating, for example a mobile heating system.

13.10.1.3 Boiler room ventilation

The supply of combustion air to the boiler room must be guaranteed in all cases. The combustion air must always be taken directly from the open air through a supply air opening and must not contain dust or harmful or flammable gases or vapours. In the case of larger systems, an exhaust air opening must be provided in addition to the supply air opening. If possible, the two openings should be arranged opposite or diagonally to each other so that cross-ventilation of the heating room is achieved. This prevents a build-up of heat in summer.

It makes sense to draw in the combustion air at the ceiling of the boiler room. This reuses the waste heat and allows the upper part of the boiler room to be kept cooler.

Biomass combustion plants and the fuel supply systems involved generate more noise than oil and gas fired plants. The supply and exhaust air openings of the boiler room must comply with the noise protection regulations mentioned in chapter 13.10.5. They are therefore often sound-insulated by means of sound-insulating weather grilles or, even better, designed according to the "snorkel principle" with an integrated duct silencer.

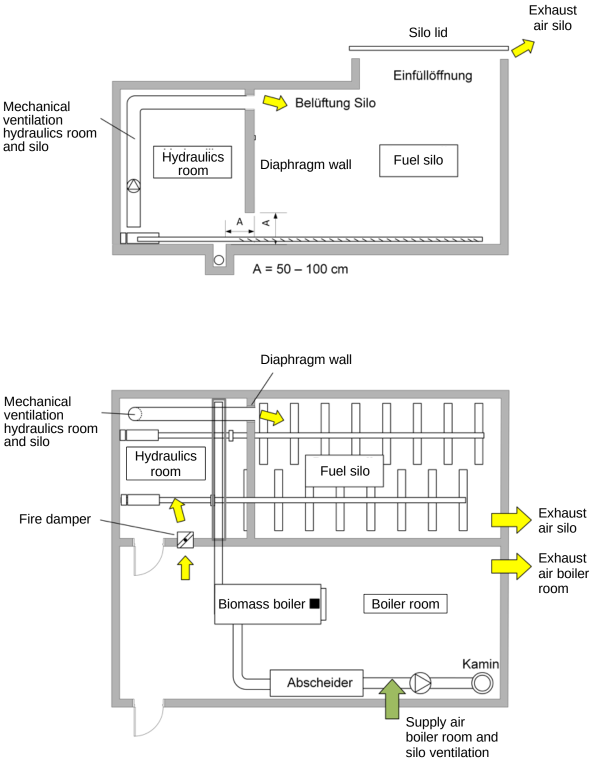


Figure 13.30 Combined boiler room and silo ventilation.

13.10.1.4 Dimensioning of ventilation system

For the ventilation of the boiler room and the combustion air supply, the same requirements apply as for conventional systems. The boiler room and silo ventilation are often combined.

The most important tasks of the aeration device are:

- Ensuring the combustion air supply (for calculation of the combustion air quantity, see chapter 20.8).
- Dissipation of the excess heat accumulating in the boiler room. The waste heat output can amount to about 2 to 3 % of the operating biomass boiler output due to radiation losses of the biomass boiler, particle separator and the hydraulic integration with the storage tank. The dissipation of the waste heat in the heating plant must be clarified so that the temperatures below the ceiling of the heating plant do not rise above 30 °C (not above 35 °C in the short term).
- Maintaining an air condition in the boiler room that allows a person to stay there without impairing their health.
- Prevention of negative pressure in the boiler room (< 10 Pa), which can interfere with the operation of the system and make it difficult to open the entrance doors.
- A sufficiently large cross-sectional opening must be designed and provided in accordance with the applicable regulations and the formulas contained therein (see chapter 19). For example, in Switzerland the cross-sectional area of the supply air opening can be determined with the following formula:

$$A_{\text{supply air}}\left[\text{cm}^2\right] = 6\left[\frac{\text{cm}^2}{\text{kW}}\right] \times \dot{Q}_K\,[\text{kW}]$$

Assumptions:

$\dot{Q}$ Boiler output in kW, ηK = 85 %, λ = 2, M = 40 %, supply air = 1 m/s

The cross-sectional opening $A_{\text{supply air}}$ must be enlarged if other air flows enter the heating chamber in addition to the combustion air, for example if,

- the silo ventilation draws its supply air from the boiler room (see chapter 14.2.4).
- the necessary air volume flow for dissipating the excess heat in the heating system is also drawn through the same cross-section. It should be noted that in very warm weather the combustion system may not be operated at nominal output and thus a smaller combustion air flow may be included in the calculation.

In principle, all relevant national and regional regulations, standards and guidelines must be observed when dimensioning the ventilation equipment.

13.10.2 Heating container and heating plants as prefabricated element

Heating containers and heating plants as prefabricated elements are sensible interim and provisional solutions for the start-up phase of a heating network. However, they are also suitable as a definitive solution with the following features:

- Construction: containers or prefabricated elements, set up on ground foundations
- Fuel storage: integrated in container or prefabricated element with small boiler output, heating container/prefabricated element with large boiler output supplied via two push floor exchange containers with a silo volume of 36 m³ each or further prefabricated elements which are interconnected.
- Maximum boiler output industrial boilers: up to approx. 500 kW with container height of 3 metres, up to approx. 1,000 kW with container height of 4 metres.
- Maximum boiler output series units: 250 kW to 450 kW. Several containers can be combined, there are usually one to two boilers installed per container (pellets, quality wood chips).
- For fuel requirements, see chapter 13.4

Figure 13.31 Heating container (source: Jenni Energietechnik and Schmid energy solutions).

Figure 13.32 Central heating plant as prefabricated element with integrated or additional fuel storage tanks (source: Holzenergie Schweiz).

13.10.3 Auxiliary energy demand

The annual auxiliary energy demand in the heating system is approximately 1.0 to 1.5 % of the heat produced, provided that care is taken to use the auxiliary energy efficiently. For the electric drives, this includes:

- Correctly dimensioned motors
- Optimal efficiency (especially of the exhaust gas fan)
- Speed-controlled motors

For systems with electric separators, economisers, flue gas condensation systems and other systems, the auxiliary energy demand can also be higher.

13.10.4 Chimney, fireplace

13.10.4.1 Dimensioning chimney height

The dimensioning of the chimney height must be carried out in accordance with the country-specific regulations and fulfil the local fire and noise protection regulations (see chapter 19).

The following influencing factors determine the chimney height:

- Building dimensions (height, width)
- Rated thermal input
- Immission level as a function of the highest obstacle area in the area of influence

13.10.4.2 Dimensioning the chimney cross-section

The dimensioning of the chimney cross-section must be carried out according to the country-specific regulations (see chapter 19). It is the task of the planner to ensure correct dimensioning by the chimney supplier and to check the offered chimney for conformity with the valid regulations by consulting the chimney supplier. The following specifications for the chimney supplier are relevant for dimensioning:

- Flue gas temperature and pressure at the chimney inlet
- Chimney height and required flue gas temperature at the outlet
- Flue gas humidity.

13.10.4.3 Chimney construction

When burning moist wood chips, the dew point of the flue gas is around 60 °C. In principle, well-insulated, stainless-steel chimneys are best suited for these boundary conditions. With very dry wood pellets, the dew point is somewhat lower at 40 °C to 45 °C with an excess air of 1.5 to 2.0.

Particular caution is required in the case of refurbishment when using existing chimneys. Often, the only solution is to install a new stainless chimney flue with loose insulation. Care must be taken to ensure that the bulk insulation is professionally backfilled, which is why a chimney supplier with experience in biomass systems is recommended.

In new installations, the biomass boiler should be able to operate with the lowest possible flue gas temperatures (< 150 °C), which requires a well-insulated chimney. Possible chimney types are:

- Ceramic chimneys
- Smooth-walled, rigid chrome-nickel steel tubes with a wall thickness of 1.0 to 1.5 mm
- Chimneys assembled from individual pieces

The chimney construction must meet the country-specific requirements regarding soot fire resistance and statics.

13.10.4.4 Nozzles for emission measurements

For emission measurement in installations subject to acceptance and measurement, a standard connection piece must be installed in the vertical chimney section (e.g. CH: "EMPA-Normstutzen", see Figure 13.33). A calming zone in accordance with the country-specific regulations must be allowed for before and after the connection piece. The exact position must be clarified with the responsible chimney sweep and with the accepting authority before installation.

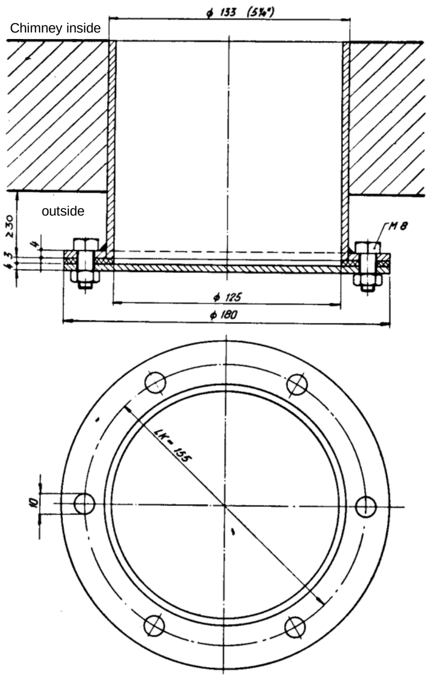


Figure 13.33 Installation dimensions of an EMPA-Normstutzen (standard spigots) [69].

13.10.5 Noise protection

When planning an automatic biomass heating system, the effects of sound propagation (airborne and structure-borne sound) during operation of the system must always be clarified. Airborne sound does not remain where it is generated, but is transmitted through the air and can also penetrate parts of the building. Structure-borne sound is triggered by vibrations or oscillations, transmitted through solid bodies and re-emitted as airborne sound. The energies that are introduced into a building component are significantly greater than with airborne sound. The propagation of structure-borne sound can be significantly reduced with vibration damping elements.

With regard to noise protection, the applicable standards, regulations and guidelines must be complied with. In Switzerland, for example, sensitivity levels are defined in the Noise Abatement Ordinance (LSV) as part of land use planning, analogous to zoning (definition of types of use and building heights). Depending on the type of use, the assignment of the sensitivity level by the municipality determines how much noise a facility may generate or how much noise the residents have to endure.

The Noise Abatement Ordinance lists the limit values of the maximum sound pressure levels for the individual areas. The noise rating level is the sum of the measured level and the level correction. The level correction is determined as a function of sound content and impulse content. For example, the level correction value can result in a significant additional increase in the noise rating level for conveyors (scraper chain conveyors, screw conveyors) that are operated in cycles and emit a strong cracking noise when starting up.

Noise rating level = Measured level + Level correction

The permissible noise rating level depends on the quiet level during the day and at night. Thus, noise emissions from a wood heating system are much less problematic if there is a high quiet level due to other noise emission sources such as traffic, commerce and industry.

The manual on sound insulation in building services [137] lists in detail further sound insulation measures in the area of heating installations.

With regard to the responsibility to comply with country-specific noise regulations (see chapter 19), the following indications can be made:

- When composing the planning team, it must be checked who will be responsible for the soundproofing planning. Sound engineering planning is an interdisciplinary task and must be carried out by a sound insulation specialist.
- The organisation in charge of the overall responsibility of the project (architect, general planner, general contractor, planning consortium) should carefully choose the sound insulation specialist (e.g. acoustical engineer).
- The building services engineer or system planner of the biomass heating system is obliged to draw the attention of the sound insulation specialist to the noise sources of the biomass heating system. Furthermore, technical data that the sound insulation specialist requires must be made available.

The following plant components of a biomass heating system are critical noise emission sources and have given rise to complaints in the past (see Figure 13.34).

Exhaust gas fan

The flue gas fan is the biggest source of noise in biomass DH plants. Problems arise mainly in plants where a high delivery pressure is necessary, due to high sound pressure levels at the chimney top and in the rooms adjacent to the chimney. The following measures can reduce noise emissions:

- Exhaust silencer
- Separation of flue gas duct and chimney regarding vibration transmission
- Fan with high conveying efficiency, which has no imbalance and can be operated at the lowest possible speed
- Mounting exhaust fan on vibration damping elements
- Chimney arrangement so that the chimney top is not directly next to a bedroom window, for example
- Preventing transmission of structure-borne sound from the chimney to the building structure
- Planning chimney far from rooms with high noise reduction requirements

Silo discharge system

The following measures can reduce noise emissions from push floors, discharge screws and hydraulic units:

- Separate the silo structure from the structure of adjacent living or working spaces to prevent structure-borne sound transmission.
- Mount the hydraulic unit on a vibration damper and cover it with a sound insulation bonnet.

Conveying system: Scraper chain conveyor, screw conveyors
The following measures can reduce the noise emissions of the conveyor system:

- Separate the heating room structure from the structure of adjacent living or working spaces to prevent structure-borne sound transmission.
- Separate the conveyor system during installation to prevent structure-borne sound transmission using vibration dampers or structure-borne sound insulating mats.

Heating room
Airborne sound transmission from the boiler room can be reduced by the following measures:

- Closed building with sufficiently high sound insulation
- Openings to the outside equipped with silencers, e.g. combustion air supply duct fitted with silencing baffles.
- Sound absorption panels on boiler room ceiling
- Combustion air fans with intake silencers

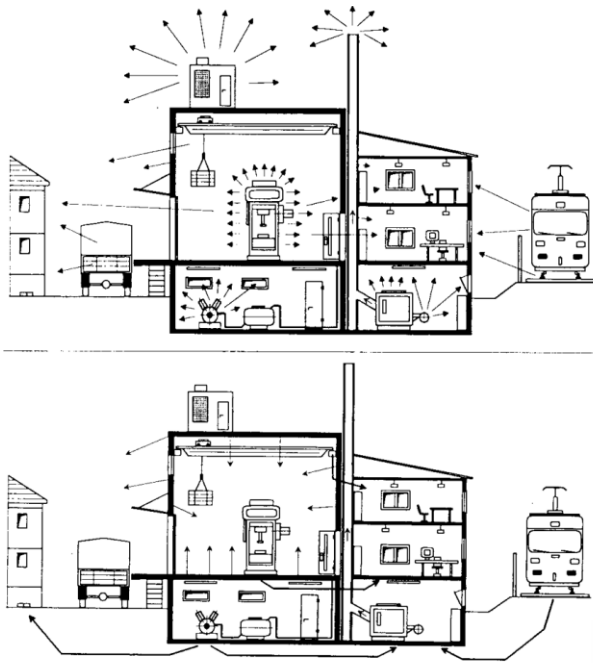


Figure 13.34 Air- and structure-borne sound [69].

14 Design of fuel storage, fuel conveying and ash removal

14.1 General notes

The following requirements must be observed when planning the fuel storage:

- Easily accessible by road
- Possibility to turn the delivery vehicle in front of the unloading point without time-consuming manoeuvres (observe the required turning radius).
- Uncomplicated fuel logistics in storage hall: “first in, first out”.
- Use of the topography of the terrain for easy fuel dumping (e.g. unloading point on a slope at the highest point).

In the project planning phase of the fuel storage facility, the possible variants of the arrangement should be clarified with the future fuel supplier in order to enable the delivery of the fuel with little time expenditure.

In Table 14.1 the fuel storage types are classified according to the fuel assortment and the supply strategy.

The requirements for structural design and operation in accordance with the applicable country-specific recommendations and regulations must be observed (see chapter 19), in particular:

- Fire and explosion prevention
- Safety regulations, so that accidents to persons can be prevented and persons with appropriate protective equipment can operate the silo without danger.
- Procedure in case of malfunctions and their elimination
- Emergency discharge system.

14.2 Selection and dimensioning of fuel storage

14.2.1 Fuel storage types

The appropriate choice and dimensioning of the fuel storage depends on the fuel assortment, the annual fuel demand and the supply strategy, which can be based on a direct, an indirect or a mixed supply chain. If necessary, special local conditions (for example, limited fuel availability during the Christmas holidays, accessibility of the forest in winter, restricted delivery times, etc.) must also be taken into account.

In the case of wood from elevated regions where year-round logging is not possible, the wood is temporarily stored at lower altitudes or directly at the wood-fired heating plant as **round timber in stacks** and chipped there as needed or temporarily stored as wood chips in warehouses. This enables the construction of small and thus cost-effective silos at the fuel customers' or at the wood-fired heating plant.

Fuel storage types:

- **Silo** (bunker): An automatic fuel discharge system conveys the stored fuel in the silo into the transport system of the biomass boiler plant.
- **Storage warehouse**: The weather-protected intermediate storage of fuel takes place in a warehouse. The warehouse at the biomass heating plant usually has a day silo.
- **Outdoor storage**: Temporary outdoor storage of wood chips on stockpiles and round timber in stacks

14.2.2 Dimensioning

There is great potential for savings in the correct dimensioning of fuel storage. Detailed optimisation is therefore a matter of urgency.

To save costs a fuel silo with a discharge system should always be designed as small as possible. However, the size cannot be assessed separately from the fuel logistics, but is part of the supply concept.

The costs can usually be kept within reasonable limits if the fuel silo holds five to seven daily demands of the firing plant at nominal power operation plus additional silo volume in the case of a **direct supply chain.**

Additional silo volume
The fuel silo is usually not completely empty when it is delivered (required time margin between order and delivery). Therefore, an additional silo volume should be taken into account in addition to the specified daily requirements. The additional silo volume should be the same size as the transport volume of the largest delivery vehicle to ensure that the silo can be filled with the specified daily requirements with a fully loaded delivery vehicle.

For monovalent firing systems, this corresponds to a supply period of six to eight days, as the heat capacity demand does not usually correspond to the boiler's nominal output for 24 hours. In an average winter, this leads to around 20 fuel silo feedings. In the case of an **indirect supply chain** with transport logistics available at short notice from the intermediate storage facility (e.g. warehouse), the size of the fuel silo can be reduced to 2 to 4 daily requirements. Often, heating plants have large storage capacities (warehouse, open-air storage with piles, etc.) so that intermediate storage can take place directly at the heating plant. In this case, the fuel silo can also be significantly smaller (e.g. one day's demand).

The number of vehicle movements for feeding the fuel store depends on the annual fuel demand and the transport capacity of the vehicle.

- **Directly** from the forest: A truck can transport 40 to 50 (60) LCM of wood chips directly from the forest, a truck-trailer combination 70 to 80 LCM. In principle, the delivered wood chips of a truck should be able to be unloaded immediately and, in the case of a truck-trailer combination, the additional 40 LCM after 10 minutes of transfer time.
- From **intermediate storage**: A truck with a push-off or sliding floor semi-trailer can deliver 80 to 90 LCM.

In addition to the storage volume, attention must also be paid to cost-effective solutions in the design of the storage facility, the necessary auxiliary equipment for filling and distributing the fuel and the ventilation equipment. In addition, the corresponding safety devices and regulations must be observed.

Table 14.1 Choice of fuel storage type depending on fuel assortment and supply strategy.

Fuel type	**Fuel storage type**	**Supply chain**	**Dimensioning** daily demand of the biomass boiler system for nominal output operation	**Daily demand** of the biomass boiler system at nominal output operation
Pellets	Closed pellet silo, storage room absolutely dry Above-ground round silo	indirect	Approximately 20 daily demands, see Figure 35 according to [67]	
Quality wood chips	Underground silo, above-ground silo	indirect	5 - 7 daily demands plus additional silo volume[1)]	
Wood chips up to P45S-M55+	Underfloor silo	direct	5 - 7 daily demands plus additional silo volume[1)]	< 50 LCM/d
Wood chips up to P45S-M55+	Above-ground round silo	direct	5 - 7 daily demands plus additional silo volume[1)]	> 50 LCM/d
Wood chips up to P45S-M55+	Warehouse with day silo	mixed	Minimum 7 daily demands	> 50 LCM/d
LH, DH, RZ, Ruz[2)] and waste wood up to P63-M55+	Warehouse with day silo Above-ground round silo	mixed	Minimum 7 daily demands	
RHH[2)]	Round or square silos	direct	Reconcile demand and need	

[1)]The fuel silo is usually not completely empty when delivered (required time margin between order and delivery). Accordingly, an additional silo volume should be taken into account in addition to the specified daily requirements. The additional silo volume should be the same size as the transport volume of the largest delivery vehicle to ensure that the silo can be filled with the specified daily requirements with a fully loaded delivery vehicle.
LCM = Loose cubic metres of wood chips
[2)]Fuel types see Table 4.10

14.2.3 Fuel silo design

Underfloor silos

Underfloor silos (see Figure 14.1) can be filled directly from the transport vehicle via one or more filling openings without any auxiliary device. The ideal and most cost-effective dimension is a tall silo with a square base and a silo lid which, if possible, cannot be driven over. In order to achieve a filling level > 70 % with a silo filling opening, the ratio of height to width must be at least 1. The silo shape is ideally to be extended with further silos lined up next to each other. In order to achieve a filling level > 70 % with other silo dimensions, the fuel can be introduced either via several silo openings or with filling screws or silo distributors.

The silo opening should have a minimum clear dimension of 3.5 m in length and 2 m in width. This reduces the amount of work required for unloading:

- Shorter unloading time due to less manoeuvring of the truck and better flow behaviour of the wood chips
- No subsequent cleaning of the unloading area
- Less damage to the silo lid.

The advantages of underfloor silos are their high filling level (> 70 %). In addition, no expensive placement and distribution devices are necessary. The disadvantages of underfloor silos include the fact that they are sometimes not feasible in case of groundwater problems and usually have higher construction costs (excavation and concrete work).

Figure 14.1 Feeding the underfloor silo (source Holzenergie Schweiz).

The silo size and geometry are determined by the requirement for low costs and the width of a push rod unit of 2 m maximum. For wider silos, several push rods must be provided, which in turn affects the costs. Other factors that affect the geometry and size are the requirement for the highest possible degree of filling (> 70 %) and the angle of repose of wood chips. This is usually 45°. Thus, in the case of underfloor silos with filling openings at ground level, a high silo should be aimed for, whereby the height should not exceed 1.5 times the width in order to prevent bridging, especially with moist wood chips.

To determine the height of the **outlet opening from the silo to the cross conveyor channel** (Figure 14.2), the flow behaviour and the angle of repose of the fuel must be taken into account (see Figure 14.2).

For wood chips with good flow behaviour (angle of repose around 45°), the height of the outlet opening can be fixed. It should be selected in such a way that it corresponds at most to the distance between the silo-side corner of the outlet opening and the beginning of the cross-conveyor channel, but at least 50 cm. This ensures that no wood chips flow uncontrolled into the cross conveyor channel and overfill the cross conveyor system.

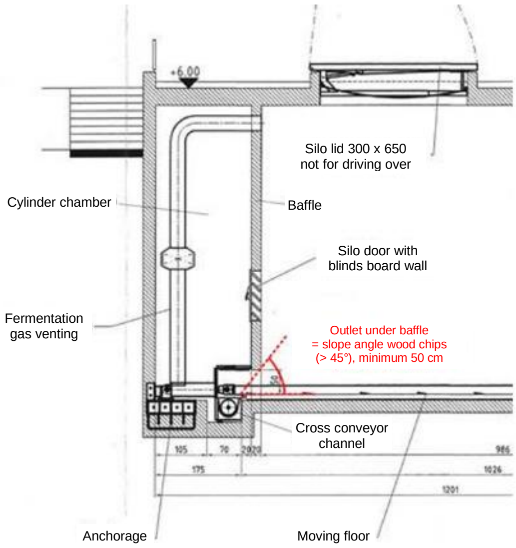


Figure 14.2 Passage opening from the silo to the cross conveyor channel (source: Holzenergie Schweiz).

In the case of fuels whose flow behaviour and angle of repose are not known (shredded waste wood, shredded wood from landscape maintenance, bark), the height of the passage opening must be designed variably; for example, with wooden planks that can be removed or inserted as required. In practical operation, the necessary height is then determined. It must be ensured that the fuel does not flow uncontrolled into the cross-conveyor channel and no compression takes place. Compression of the fuel at the baffle or at the wooden planks above the passage opening can lead to the fuel not being able to be discharged.

Uncomplicated discharge of fuels with unfavourable flow behaviour from the silo can also be achieved by installing a metering roller above the outlet opening (see Figure 6.21).

In addition to containers with a capacity of 30 - 40 m³, individual wood chips suppliers also have **pump containers** with a capacity of up to 30 m³. With these pump containers, it is possible to feed quality wood chips despite an unfavourable silo arrangement. A solution with silo lids and an expensive unloading trough with filling screws can thus be avoided. When pumping the wood chips, however, it must be ensured that the transport air produced can flow out of the silo. If possible, the corresponding opening should be provided at the filling opening. Pumping results in additional costs. The filling time takes about 30 minutes for 30 LCM.

If a silo has to be filled with tipping vehicles despite difficult placement conditions, an unloading trough outside the building with a screw conveyor system is necessary (see Figure 6.11).

Mobile chips container with discharge as silo replacement

In the case of subsequent installation of a wood heating system, the construction of an underground silo is in most cases very cost-intensive or not always possible due to the structural conditions. Here, a supply by mobile 30 m³ containers with built-in push floor discharge is conceivable. One or more containers are docked to the (common) conveyor system on a suitable forecourt or inside the building. The connection is formed by a permanently installed cross conveyor that moves the discharged wood chips to the furnace charging system. The drive unit for the container moving floor is placed in the boiler room.

Round silos

In the case of biomass DH plants with a biomass boiler output > 5 MW, the fuel can be stored in a warehouse with a day silo or in above-ground round silos with a milling screw discharge. To avoid bridging, the maximum filling height of the round silo must be limited depending on the flowability of the fuel.

The following maximum filling heights Hmax. apply as guide values:

- Moist wood chips, low fine content, maximum length particles 200 mm: H_{max} = 1.5 x D (diameter round silo)
- Dry, shredded waste wood, low fines content, maximum length particles 200 mm: H_{max} = 1.0 x D (diameter round silo)

If moist fuel remains in the round silo for a longer period of time, it dries out and tends to form strong bridges. This reduces the flowability and the automatic discharge of the fuel is no longer possible.

14.2.4 Silo ventilation

Silos for dry fuel (shavings) are not ventilated. This prevents the fuel from absorbing moisture from the air. In closed silos with moist fuel, the increased humidity must be removed by means of mechanical ventilation. In addition, fermentation gases, including CO_2, are produced during the storage of moist wood chips due to decomposition processes. Since CO_2 is heavier than air, it spreads along the floor of the fuel store, hydraulic room and boiler room and collects at the lowest points. To ensure that there is never a risk of asphyxiation for maintenance personnel, the affected areas must be protected with suitable ventilation equipment. The corresponding country-specific safety devices and regulations in chapter 19 must be observed.

The moisture release of the wood chips causes a high relative humidity in the fuel storage. This condenses on the cold walls, ceiling and especially on uninsulated silo lids and causes the fuel to re-humidify. The extraneous water on the fuel surface can cause severe mould growth. To prevent this, the accumulating moisture must be removed by the ventilation system (controlled by a timer), which ventilates the silo crosswise. The walls, ceiling and lid of the fuel store can thus be kept dry.

Silo ventilation with outside air

Outside air flows through a light shaft into the hydraulic room. There, the air is mechanically conveyed into the chips silo near the floor by a ventilation system and led outdoors as exhaust air via the silo lid or light shaft. In the case of intermittent ventilation, the ventilation system must be designed for a 3 to 5 times hourly air exchange of the hydraulic room, whereby the ventilation must be in operation for at least 10 minutes per hour.

Intermittent ventilation can be dispensed with if the ventilation is designed for a 20-fold air change per hour and a 15-minute waiting period is observed between switching on the ventilation and entering the room (e.g. with a door interlocked by timer).

If there are direct openings between the hydraulic room and the silo, for example because the cross-conveyor channel in the hydraulic room is not closed, a short air flow can occur between the silo and the hydraulic room. To ensure that the fermentation gases and air humidity are nevertheless carried away, an additional extraction unit must be installed in the silo above the fuel. In order for outside air to flow in, its delivery volume must be slightly larger than that of the extraction in the hydraulic room.

In particular, it should be noted that at filling heights of more than five metres, the fermentation gases that form above the bulk material must be discharged in a controlled manner.

If the outside air is cold and the fuel is damp, ice may form due to moisture condensation in the hydraulic room and in the ventilation duct network.

Combined boiler room and silo ventilation

It makes sense to combine the ventilation systems of the boiler room and silo because the warm air from the boiler room reduces freezing issues in the hydraulic room and supports the drying process of the wood chips. In the case of intermittent ventilation, the ventilation system must be designed for a 3 to 5 times hourly air exchange of the hydraulic room, whereby the ventilation must be in operation for at least 10 minutes per hour.

Intermittent ventilation can be dispensed with if the ventilation is designed for a 20-fold air change per hour and a 15-minute waiting period is observed between switching on the ventilation and entering the room (e.g. with a door interlocked by timer).

Outside air flows into the boiler room through a weather protection louver. Part of the air is fed into the furnace by the combustion air blowers, the rest flows through the fire damper into the hydraulic room. There, the air is mechanically conveyed into the chips silo by a ventilation system and led outside as moist exhaust air.

If there are direct openings between the hydraulic room and the silo, e.g. because the cross-conveying channel in the hydraulic room is not closed, a short-circuit air flow can occur between the silo and the hydraulic room. To ensure that the fermentation gases and humidity are nevertheless carried away, an additional pipe fan in front of the fire damper must be used to convey slightly more warm boiler room air into the cylinder room than the fan in the cylinder room extracts.

If the boiler room is significantly lower than the hydraulic room and the silo, the door between the boiler room and the hydraulic room must be absolutely air tight. Otherwise, there is a risk of fermentation gases accumulating in the boiler room, especially in low-load operation and in summer when the system is at a standstill but there are still wood chips in the silo.

If the floor level of the silo is lower than that of the boiler room, cold outside air from the boiler room can flow into the hydraulic room and hinder the desired drying process. This can be prevented by using an additional ventilation pipe with a pipe fan to guide warm air from the boiler room ceiling directly into the hydraulic room via the fire damper.

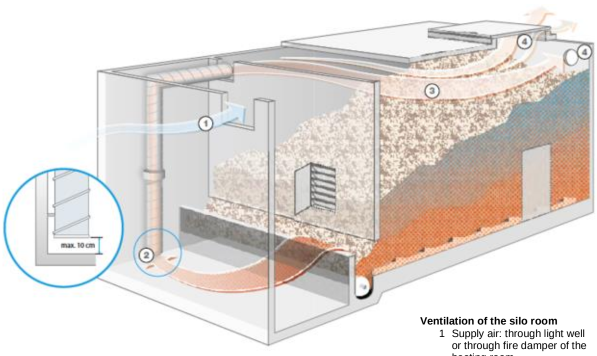


Figure 14.3 Silo ventilation (source: Suva [138]).

Discharging the silo exhaust air

When planning the silo exhaust air opening, it must be remembered that fermentation gases have an unpleasant odour. In case of possible odour nuisance, it is recommended to lead the silo exhaust air over the roof with a separate exhaust air system.

14.2.5 Warehouse design

For smaller and medium-sized plants, a silo is usually used for fuel storage; for a plant size > 2 MW, a warehouse is much more cost-effective (Figure 14.4). For plants < 2 MW with a direct supply chain, the construction of an accessible storage warehouse with an easily accessible push floor, and with a day silo can also be an economic solution if an expensive underfloor silo can be dispensed with. For very large biomass DH plants, an alternative to the storage warehouse is an above-ground round silo.

Figure 14.4 Warehouse (source: Holzenergie Schweiz).

The management of a warehouse is carried out with the following logistics:

- Management of the warehouse and feeding of the day silo and moving floor with wheel loader or telescopic loader
- Fully automatic crane system, which has an unloading trough and day silo
- Loading and unloading system with scraper chain conveyor. Pre-silo with scraper or push floor for loading the scraper chain conveyor, discharge of the fuel to the furnace charging system with push floor.
- Feeding from discharge trough with screw conveyor system, discharge with push floor
- Storage and discharge with special system such as Toploader.

Warehouses should be cross-ventilated, so that the moisture escaping above the fuel is removed. In the case of the crane system and the loading and unloading system with scraper chain conveyor, an emergency feed into the day silo must also be provided so that the wood heating system can continue to operate in the event of a failure of the hall management system. With the crane system, the fuel can, for example, be tipped directly onto the push floor of the day silo, which conveys the fuel to the charging system. In the loading and unloading system, the fuel can, for example, fall through an opening in the conveyor channel of the scraper chain conveyor onto the charging system.

14.2.6 External warehouse

Outdoor storage of wood chips on stockpiles or of logs in piles at the heating plant or at a central location should be sunny and accessible all year round (Figure 14.5 and Figure 14.6).

The disadvantage for wood chips in outdoor storage is the increased energy losses due to loss of substance.

In the case of wood chips on stockpiles, which are managed with a wheel bearing, contamination by sand and stones must be avoided. A tarred site with drainage or a site on compact, dry subsoil should be provided

Figure 14.5 Outdoor storage of wood chips on stockpile (source: Holzenergie Schweiz).

Figure 14.6 Outdoor storage of round timber in piles (source: Holzenergie Schweiz).

When storing moist fuels such as wood chips from forest residues, industrial residues, wood from landscape management, residual wood from thinning, as well as shredded or un-shredded bark, the following general conditions must be observed:

- Good aeration of the fuel on the stockpile is achieved by a low proportion of fines including needles, leaves and twigs and by coarse lumpiness of the fuel.
- A high proportion of fines and a small lumpiness prevent the fuel from drying evenly and promote the formation of mould at the top of the pile. The rising of moisture is prevented in layers with a high proportion of fines, and the moisture released condenses out again in these layers (especially at the top of the pile).
- The degradation of dry matter in the fuel (high degradation values up to 4 % per month with high water content) can be reduced by short handling times and optimal drying of the fuel with coarse lumpiness (well ventilated). The note also refers to the storage of fuel in silos or warehouses.
- Especially in the case of fuels with open-pored cells such as coniferous wood, the drying of the fuel over a longer storage period can be optimised by covering the piles with fleeces, which significantly reduce the external wetting of the fuel by precipitation. Coniferous wood piles are partly covered with choppable foils to avoid extraneous moisture.
- The drying rate of the fuel, which can be up to 10 % water content reduction during the first month, is much higher in summer and the transitional period than in the cold winter period.

14.2.7 Spontaneous combustion and loss of substance

When storing large quantities of wood chips, there is a risk of spontaneous combustion. There is always an increased risk if several of the following conditions are fulfilled at the same time:

- Particularly long storage period (e.g. more than 3 months)
- Storage in warm weather (summer months)
- The fuel is moist and possibly still green when it is stored.
- The fuel contains larger portions of needles or leaves.
- Some of the fuel is very finely chopped.
- The fuel contains high proportions of fresh bark or fine branches (e.g. nutrient-rich crown material).
- Shredding was done with shredders, or chippers with blunt knives
- Different qualities (e.g. coarse/fine, moist/dry, top wood/stem wood) are stored one after the other in the same warehouse.
- The fuel is inhomogeneous and is deposited in different layers during storage (heap formation). Boundary layers form between the individual fuels with different quality or origin.
- The fuel is piled relatively high (> 4 m).
- The fuel is compacted during storage by vehicles driving over it.
- Depending on the type of storage management and especially in the case of longer storage phases, the material stored first is not removed first. This means that the storage period of the fuel is not uniform.

In addition to the risk of spontaneous combustion, such storage conditions also lead to considerable energy losses due to biological degradation - some of which, however, are not externally noticeable. In the case of moist, fine wood chips, these losses are 2 to 3 percent per month. Therefore, long-term storage of low quality wood chips is not advisable.

A combination of the following measures should therefore be taken to prevent spontaneous combustion fires:

- Separating different wood chips qualities in their own piles
- Avoiding high water content in the stored material by allowing the wood to dry before chipping
- Avoiding blunt cutting tools for shredding
- The coarsest possible wood chips structure
- Avoiding larger portions of needles or leaves as these are easily microbially attackable substances
- Short storage period (especially when outside temperatures are warm during storage).
- Aeration (warm air inlet, moisture outlet)
- Dumping height < 4 m (if possible, formed as a pointed cone or pile)
- Small storage cross-section for outdoor storage (pile width < 6 m)
- Avoid long-term storage (also because of fuel losses)
- If necessary, active drying or ventilation cooling
- Use of temperature probes for monitoring (suitable are, for example, probes that are also used for monitoring hay stacks).
- Observe minimum distance to buildings or other structures and maximum storage quantity.

Preventive fire protection

When storing fuel, increased attention must be paid to fire prevention, and the applicable fire prevention regulations must always be complied with. The responsible fire brigade is familiar with the local conditions and jointly prepared operational plans should be available.

If stored fuel piles are opened or removed for firefighting, oxygen access can lead to an open fire.

14.2.8 Wood chips silo design

The silo size is determined based on the balance of the monthly wood chips demand and the monthly residual wood production. Here, a chips silo has the function of a fuel depot and at the same time acts as a buffer to absorb the inflow of material. The planner must clarify how much residual wood will be produced in a certain period of time and what proportion of it can be utilised as fuel. Surplus residual wood can be supplied to third parties. Suitable shapes are round or square silos.

The requirements for structural design and operation in accordance with the applicable recommendations and regulations (see chapter 19) must be observed in particular:

- Fire and explosion prevention
- Health and safety regulations so that people with appropriate protective equipment can carry out silo management safely
- Procedure for troubleshooting
- Emergency discharge system

14.2.9 Pellet storage design

The following requirements for the structural design and operation of a pellet store are described in detail in the storage room brochure “Recommendations for the storage of wood pellets” [67]:

- Professional delivery and storage of pellets
- Impact protection mat
- Properties such as dry storage space (no moisture ingress), dust-tight walls and wall penetrations, static requirements, explosion prevention, etc.
- Storage volume or capacity depending on nominal output of pellet boiler
- Discharge system depending on nominal output of pellet boilers
- Ventilation of storage room for health and safety (to prevent high CO concentrations)
- Pellet stores over 50 m³ must be equipped with an external door.
- Storage room cleaning

Furthermore, safety regulations are listed which must be observed when entering the pellet store so that accidents caused by toxic CO concentrations can be prevented.

The pellet storage room must comply with the locally applicable regulations and guidelines regarding fire and accident prevention (see chapter 19).

14.3 Selection and dimensioning of fuel discharge

14.3.1 General remarks

The appropriate choice and dimension of fuel conveyance depends on the fuel assortment and its flowability. This is determined by the particle size (lumpiness), the water content, the fines content and the processing technique. Chopped fuel results in cut surfaces, while shredded fuel results in broken surfaces. The choice of discharge and fuel transport system depending on the fuel assortment and the type of fuel storage can be seen in Table 14.2.

Pellets or dry quality wood chips with a low proportion of fines have a high flowability.

14.3.2 Fuel conveying

The dimensioning of the discharge and conveying equipment for the required operational safety with the given fuel assortment should be carefully planned

The conveying principle depends on the fuel. The size and dimension of the conveying equipment is usually determined by the firing system supplier based on the boiler output and the silo size. However, the planner has a decisive influence on the arrangement of the silo and boiler.

In addition to the requirement that the fuel store and boiler should be as close to each other as possible, in multi-boiler systems each firing unit should have its own conveying system. Accessibility to the boiler, fly ash separator, fine dust filter and chimney must not be impaired by the conveying equipment.

14.3.3 Discharge

Silo discharge

For moist forest chips, chips from the sawmill industry and bark, a silo with push floor discharge is recommended. The moving floor is insensitive to oversized fuel particles and foreign matter such as stones. The dimensioning of the push floor (especially push rods and hydraulic cylinders) must be designed for the maximum possible or permissible dumping height and must be specified and checked by the planner.

For chips silos in round and square shapes, centre screws are suitable for conveying the fuel to the centre, although the low-cost conical screw is also used for small silo diameters. For rectangular silo designs, a pendulum screw or a push floor is used for silo discharge.

Discharge from pellet storage

Discharge from the pellet storage is often carried out with a central screw discharge in conjunction with an inclined floor (for small storage capacity) or by means of spring core discharge, articulated arm space discharge (for large storage capacity). The storage room must be able to be filled and emptied as completely and easily as possible. Dead spaces must be minimised. Pneumatic extraction systems are used for systems < 50 kW.

Table 14.2 Choice of fuel storage type depending on fuel assortment, fuel discharge and conveyor system.

Fuel range	Fuel storage type	Dispensing system	Fuel conveyor system	Furnace feeding system
Pellets	Closed pellet storage Absolutely dry Above-ground round silo	Medium screw discharge Spring core discharge Articulated arm discharge Centre discharge Moving floor discharge	Screw conveyor	Stoker screw
Quality wood chips	Underground silo, above-ground silo	Spring core discharge Articulated arm discharge Centre discharge Sliding floor discharge	Screw conveyor	Stoker screw
Wood chips up toP45S-M55+	Underground silo Above-ground round silo Storage warehouse with day silo	Moving floor discharge Milling screw discharge	Screw conveyor Scraping chain conveyor Transverse push floor Hydraulic push conveyor	Stoker and double stoker screw Pusher Direct pusher
LH, DH, RZ, Ruz and waste wood up to P63-M55+	Storage warehouse with day silo Above-ground round silo	Moving floor discharge Milling screw discharge	Scraping chain conveyor Transverse push floor Hydraulic push conveyor	Pusher Direct pusher
RHH	Round or square silos	Conical screw discharge	Screw conveyor	Stoker screw

14.3.4 Fuel conveyor systems

Pneumatic conveying
The conveying of dust, chips, dry wood chips and pellets is possible both pneumatically and mechanically. In the case of pneumatic equipment, blowers take over the conveying; with mechanical equipment, screw conveyors are used. If the structural situation permits, for example with short transport connections, mechanical conveyor systems are preferable to pneumatic ones. The advantages of mechanical conveying are that they

- are less susceptible to failure,
- require less drive energy and
- are more cost-effective.

Screw conveyor

The area of application of the screw conveyor is limited to the following maximum fuel dimensions:

- The maximum length of fuel pieces corresponds to the diameter of the screw.
- The maximum thickness results from the clearance between the screw diameter and the nominal diameter of the feed channel or nominal diameter of the screw guide tube.

Flexible pieces in the fuel can become stuck or wound up on the screw core (for example, fresh long bark pieces or long reduction chips). This can cause problems during screw conveying. Fuels with poor flow behaviour, such as coarsely shredded landscape maintenance wood, can cause conveying problems at the transfer points due to bridging.

Scraper chain conveyor or push system
Fuels with large lumpiness (very long or thick pieces) as well as fuels with poor flow behaviour are to be conveyed by means of a scraper chain conveyor or pusher system.

14.3.5 Furnace feed

Screw conveyor

See above in chapter 14.3.4.

Double screw conveyors with a large nominal diameter also allow the conveyance of long pieces in the fuelwith a smaller diameter of the individual screw conveyors.

Hydraulic pusher, direct pusher systems or pusher transmitter systems
Pushers allow very long fuel dimensions with an end piece length of up to 100 cm to be conveyed into the combustion chamber.

An additional cutting edge on the direct pusher system or pusher transmitter system can cut off fuel parts with excess length. Two cutting edges separated from each other by a relief zone are advantageous in order to significantly reduce the electrical energy requirement for the hydraulic unit of the pusher system. Bark from the perforated rotor with bark sections up to 80 cm can be conveyed into the furnace without pre-shredding. Waste wood with a high proportion of foreign material (stones, metals, etc.) causes high wear on the pusher device.

The wear of the pusher device when charging the furnace with waste wood can be significantly reduced by pre-separating the foreign material content.

Note on the risk of backfiring

In order to prevent backfiring into the pusher system, the biomass boiler must be operated at a minimum continuous load, which allows continuous fuel insertion.

The following guide values for a necessary minimum continuous load apply:

- wet fuel > M40: 20% of the nominal boiler output
- dry fuel < M40: 30% of the nominal boiler output.

Low load operation below the required minimum continuous load is excluded.

Pushers are mainly used in firing systems for sawmill residues with bark or wood from landscape maintenance. For dry shavings and dust, pushers must be equipped with an additional fire prevention slide valve in the chute that closes automatically in the event of a blackout because of the risk of backfiring.

14.4 Selection and dimensioning of ash removal

The ash logistics for the heating plant must be defined in detail as early as the planning phase, with the aim of low-maintenance, simple, compliant and dust-free ash removal.

The following ash fractions are produced during the combustion process (Figure 9.1):

- Coarse ash (grate ash, boiler ash, bed ash)
- Cyclone fly ash (cyclone ash, fly ash, boiler fly ash)
- Fine fly ash (filter ash).

Ash storage in the heating plant
The intermediate storage of the ash produced for ash removal can be done, for example, by means of ash containers or ash bunkers:

- Ash containers in sizes of 240 l, 400 l, 600 l, 800 l, 1,000 l are arranged, for example, as an “ash container station”.
- A dry ash bunker integrated into the heating plant structure (no intermediate storage of large slag parts possible, ash removal with a transport vehicle with built-in ash extraction system).

Other options for ash storage are:

- Skips or special “Roll on-Roll off” containers in the heating plant or outdoors
- Big Bags (FIBC - Flexible Intermediate Bulk Container)

Ash removal conveyor systems

The coarse ash is transported to the ash container or bunker by mechanical ash discharge systems with screw conveyors with a maximum gradient of 45° without the ash flowing back in the screw channel, push rod conveyors, scraper chain conveyors, trough chain conveyors, bucket conveyors or wet ash removal with scraper chain conveyors.

The conveying of the cyclone fly ash and the fine fly ash to the ash bin or ash bunker can be done with a screw conveyor with a maximum gradient of 45° or with a pneumatic ash suction system, whereby it should be noted that mechanical ash removal conveying systems have the following advantages over pneumatic ones:

- Less susceptibility to faults (foreign parts, slag parts, ember particles)
- Lower auxiliary energy requirement
- Lower noise emissions
- No wear of pipe bends.

In the case of ash rich in slag or ash with a high foreign content of stones, sand, etc., screw conveyors are subject to high wear. For long transport distances, push rod, scraper chain, trough chain or bucket conveyors should be used.

The transport route of the ash discharge system to the ash container, ash bunker or from the heating plant to the skip or the “roll on/roll off” containers must be dust-tight and robust with the shortest possible, simple arrangement (linear).

Easy access via maintenance openings simplifies detection of faults and maintenance work.

In the case of ash discharge systems that lead to a skip or a “roll on/roll off” container in the outdoor area, noise pollution must be reduced to the required level.

Pneumatic ash removal conveying systems can be used in the case of long distances or complicated arrangements of the transport route. It should be noted that pneumatic systems can only be used with slag-free ash and ash without foreign matter, for example with electrostatic precipitators or fabric filters.

Ash removal

Based on the specified disposal logistics (see chapter 9), a decision must be made as to whether the various ash fractions are to be temporarily stored separately. In this context, future recycling of certain ash fractions must also be taken into account by making provisions for subsequent separation.

For large plants > 2 MW biomass boiler output, the ash accumulation should automatically be conveyed into skips or “roll on/roll off” containers for trucks. The ash container should be loaded onto the transport vehicle in a simple manner. An uncomplicated changing device (e.g. skips that can be moved on rails) to the available replacement ash container enables easy ash removal (see Figure 14.7).

Figure 14.7 Ash trough changing device (source: AEE INTEC).

In the case of medium-sized biomass boiler systems < 2 MW total output, it should be possible to move the ash containers directly out of the heating plant into the open air so that expensive auxiliary equipment such as hydraulic ash container lifts, lifting platforms, lift devices or pneumatic conveying equipment can be avoided.

When designing the ash disposal system, it is important to take into account the easy loading of the ash container onto a transport vehicle and the generation of dust when emptying the ash container into a refuse collection vehicle. To avoid the formation of dust, a tear-proof, sealable bag can be placed in the empty container and sealed before emptying. Ember-free ash can be filled into disposable bags (FIBCs), transported and deposited.

For medium-sized plants, ash removal using a transport vehicle with a mounted ash extraction system is becoming more common (Figure 14.8). This enables simple ash handling in the heating plant. The pipe for ash transport from the heating plant to the outside (connection pipe of the transport vehicle) is usually designed as a fixed installation (observe euquipotential bonding).

Figure 14.8 Transport vehicle with mounted ash extraction system (source: Holzenergie Schweiz).

15 Execution and acceptance of the biomass boiler system

15.1 General requirements and definition of most important terms

The execution and acceptance of the heat distribution are described in the Handbook on Planning of District Heating Networks [19]. In the following, the execution and acceptance of the biomass boiler system will be discussed. The current regulations of the federal states must be observed; they can lead to deviations from the requirements and procedures listed below as examples, as can project-specific contractual agreements.

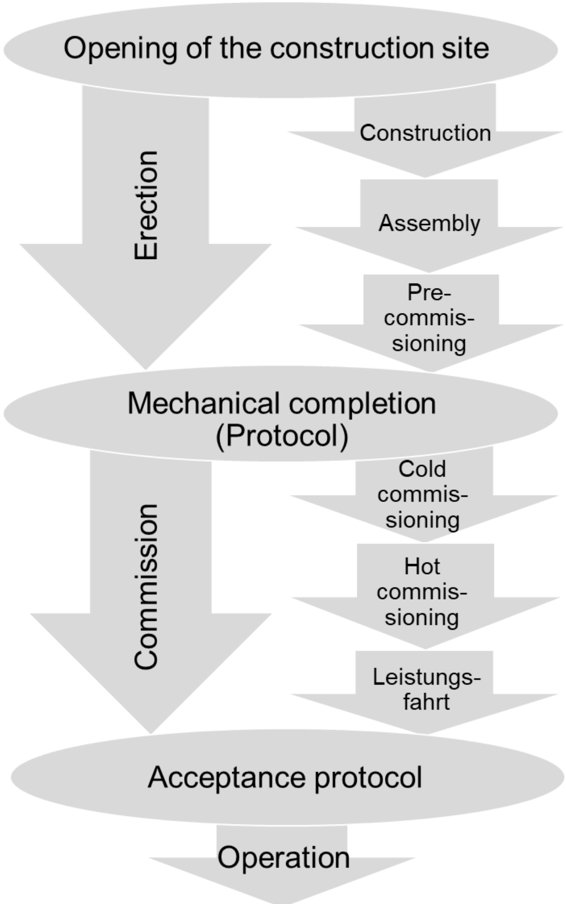


Figure 15.1 Erection, commissioning and operation of a plant (based on [139]).

Figure 15.1 shows the usual project phases: Erection, commissioning and operation. With the opening of the construction site, the **erection of the plant** begins, i.e. construction and assembly. Subsequently, safety and functional tests are carried out; these may be associated with the commissioning of infrastructure and ancillary facilities and are also referred to in their entirety as commissioning. The logging of the so-called mechanical completion marks the end of the commissioning preparations; now it is time for the actual **commissioning**. With the cold commissioning, the operational readiness is established to such an extent that the plant can be started up. During the subsequent hot commissioning, the plant runs under operating conditions for the first time. The aim of the subsequent trial operation is to adjust the system so that it achieves the agreed parameters and proves to be usable for continuous operation. The proof of performance with acceptance measurements is to be provided by the performance run, which is also referred to as an acceptance test. The performance test ends with the signing of the **acceptance report** by the contractual partners. The plant now enters commercial operation (continuous operation) [139].

With the commissioning, each company puts its plant section into operation in accordance with the service contract. The commissioning of the individual plant components is carried out in accordance with the generally applicable regulations. If several plant sections are to be commissioned together, the site supervision (site management), in consultation with the individual contractors, coordinates the timing of the individual commissioning with a schedule. The respective company is responsible for the commissioning of the individual plant components.

Each part of the installation is accepted individually in accordance with the service contract. The construction supervision is responsible for carrying out the acceptance. If the acceptance is successful, the part of the installation constructed by the company is handed over to the client.

The handover of the entire facility to the building owner has been completed,

- if all plant components have been accepted in accordance with the service contract and subsequent rectification of faults has been carried out, and
- when the construction supervision has handed over the fully completed documentation of the overall system to the building owner.

15.2 Construction supervision

Construction supervision, also called site management or technical site management, must be carried out by an experienced and competent person. This is the responsibility of the building owner and must therefore be organised by the building owner. Usually, construction supervision is handed over by the building owner to the planner. It serves in particular to control the timely and professional execution of the plant components by the individual suppliers as well as the higher-level construction coordination. It is recommended to make precise agreements on which quality assurance measures are to be carried out by the component suppliers and which by the construction supervisor.

The construction supervision is to hold construction meetings at maximum one-week intervals, in which all plant suppliers must participate. In these meetings, the current status of the project, the interfaces between the individual plant suppliers, the schedule and any other matters are to be discussed. Minutes of all meetings are to be written and sent to all participants.

The construction supervision should request essential data in due time from plant suppliers to be forwarded to other plant suppliers for their execution.

The tasks of construction supervision include ensuring that the installation work of the plant suppliers is carried out in accordance with the service contracts. This applies in particular to completeness, professional installation and execution, work safety and cleanliness. The quality of the installation, ongoing documentation and the quality assurance measures of the component suppliers must be regularly checked in random samples and documented (e.g. welding seams, tightness, wiring, direction of rotation, installation in accordance with plans and flow diagrams).

The construction supervision should regularly inform the client about the current project status.

15.3 Critical points during the construction phase

In the following, some critical points during the construction phase are dealt with as examples.

Installation of the silo inserts

Anchoring profiles and guide rails for the silo discharge must be installed at an early stage of construction. As a rule, the structural engineer draws up the formwork and reinforcement plans necessary for silo construction, integrating the structural elements of the discharge system. The planner coordinates the delivery of construction companies and equipment suppliers and checks the silo plans of the structural engineer.

The inserts of the silo discharge are installed by the plant supplier who coordinates the installation time with the construction company. Especially in this demanding execution phase, the planner should ensure the correct interaction between the construction company and the plant supplier on site.

Determining laying of pipes and cables

The exact positions of pipe penetrations for district heating, data, water, sewage, telephone, electricity and possibly oil and gas lines should be made known to the building contractor by the planner during the foundation work so that the pipes and cables are not positioned in unfavourable places later on. The prerequisite is that the planning of these lines in the boiler house has already taken place at this point.

Consideration of earthing straps for equipotential bonding and lightning conduction

The installation of earthing straps, their discharge into the ground and the connection possibilities for equipotential bonding of the machines and lightning conductors must also be carried out in coordination with the construction company as early as the foundation phase. It is often the case that at this point an electrical company has not yet been firmly contracted and the construction company must therefore carry out this work or commission an electrical company to do it. In principle, it is advisable that this work is already included in the tender for the construction activities.

Installation of large plant components

The installation of large system components must be planned along with the progress of the construction of the building. In the process, appropriate openings must be kept clear for installation of components. Unsuitable installation options for system components could lead to partial dismantling of doors, gates, roofs or walls (wall cuts) which could cause delays and unexpected costs for the building owner.

Attachment of mounting aids

Often, temporary assembly aids and lifting equipment are used by the suppliers for the assembly of heavy plant components, e.g. load hoists that are attached to the ceiling. Such equipment must be planned accordingly as it can have an impact on the statics of the building and must be taken into account in the dimensioning.

In this context, it should be considered whether assembly aids and lifting equipment may be permanently installed so that they are also available for later maintenance and servicing work.

15.4 Commissioning and start-up

15.4.1 Preparations for commissioning, cold commissioning

For commissioning, the following preparations must be made after the installation of the new system has been completed [139]:

- Basic cleaning,
- Safety and function tests, leak tests,
- Commissioning of ancillary facilities and infrastructure.

The functional check of the individual system components is usually carried out by the boiler manufacturer, including all electrical drives and the I&C technology. After documenting the mechanical completion, the next step is the cold commissioning, which makes the system ready for operation. A protocol indicates that the system is ready for operation.

In practice, a number of key aspects arise for biomass boiler systems during these preparatory phases:

- The first firing of the biomass boiler system requires dry fuel so that the lining of the combustion chamber can be completely dried out. The fuel requirements in terms of quantity and quality must be agreed with the system supplier.
- The fuel silo should initially be filled to a maximum of one third. If problems occur with the discharge system, it is not necessary to empty the entire silo content through the filling opening.

- To prevent bridging, allow sufficient time for the silo concrete to dry out before the first filling. A two-week drying phase is considered the minimum. Before filling, the function and design of the discharge system as well as the surface quality of the silo floor must be checked by the plant supplier. The supplier then gives the site management the go-ahead for the initial filling. Before filling, the silo interior must be cleaned.
- In order for the heat generator system to be put into operation, it must be ensured that there is sufficient heat extraction.
- It is the task of the site management, in consultation with the plant suppliers, to coordinate the presence of the individual companies.

Checklist preparation for commissioning

- Heating system and expansion vessel filled (heat output ready for operation)?
- Has the piping been done correctly?
- Boiler pump functioning?
- Combustion air and flue gas fans functional?
- Boiler return temperature protection functional?
- Sensor placement correct?
- Safety thermostat set correctly?
- Safety valve mounted?
- Thermal discharge safety device functional?
- Pipe connections, backfire prevention installed and ready for operation?
- Electrical connections incl. safety chain checked for proper functioning?
- Flue gas cleaning, chimney and chimney connection OK?
- Conveying systems (fuel, ash) checked for function?
- I&C, interfaces, communication, visualisation and, if applicable, data recording functional?

15.4.2 Hot commissioning of the plant

The prerequisite for the hot commissioning of the boiler system, which is also referred to as warm commissioning, is the completed function check and the commissioning of the system parts that are not included in the scope of delivery of the system supplier but are required for the operation of the boiler system. The hot commissioning of the system takes place when the biomass boiler system is fired up for the first time (start-up), whereby the simultaneous interaction of all system parts must take place using the automatic system control. First, the combustion chamber lining is dried out according to the manufacturer's specifications. Then the firing capacity is ramped up in stages. During this phase, the construction supervision, the specialised commissioning personnel and the skilled personnel for all relevant plant components (boiler manufacturer, system builder, plumber, electrician, control engineer) as well as the future operating personnel should be present or available at short notice. Sufficient time should be allowed for this phase. Depending on the size of the system, a whole day to several days should be planned. Hot commissioning is often referred to as trial operation [139].

In heating and power plant technology, trial operation can also be understood as a separate operating phase between hot commissioning and continuous operation [139]. In the case of wood-fired boiler systems, it can begin as soon as

- the unit can be operated in automatic mode and fulfils all safety tests (e.g. safety temperature limiter, thermal discharge safety device);
- the boiler system has been adjusted for trial operation and, if necessary, operation with different fuel mixtures has been tested;
- the initial briefing of the operating personnel with the operating manual has taken place.

During the trial operation, which can last from a few to several days depending on the size and complexity of the system, among other things,

- the system is optimally regulated,
- significant deficiencies are to be remedied,
- uninterrupted, trouble-free operation of the system under the supervision and responsibility of the system supplier must be demonstrated.

Also, during the trial operation, the operating data should already be recorded and evaluated so that irregularities in the system operation can be detected and resolved in good time before acceptance.

Emission and performance values are to be documented as a measurement report and handed over to the building owner.

If faults occur which force the system to be shut down and which last longer than agreed in the service contract, the trial operation must start again from the beginning after the fault has been rectified. The trial operation must also start again if the total duration of all individual faults exceeds a period agreed in the service contract.

The plant supplier is responsible for the commissioning of the biomass boiler plant and for the trial operation, as the plant has not yet been handed over to the building owner. A prerequisite for a smooth start of heating operation is the appointment of the responsible operating personnel, who are instructed accordingly. During the commissioning of the plant, the operating personnel have the opportunity to become familiar with the biomass boiler plant and it is important that they are supported by the plant supplier and the site management. This includes preliminary instruction of the operating personnel by the plant supplier. The preliminary instruction should be based on the operating manual.

Scope of an operations manual

Operation of the biomass boiler system:

- Checks before commissioning and start-up

- Switch positions and effects
- Operating modes

What to do in case of malfunctions:

- Fault and alarm concept
- What to do in case of malfunctions and fault message list
- Table for documenting fault messages

Maintenance plan:

- Cleaning and ash removal intervals
- Defining audit work by third parties

Safety:

- Safety equipment
- Safety regulations
- Avoiding accidents with fermentation gases
- Avoiding accidents on conveyor equipment

Documentation:

- Plant layout
- Electrical plans
- Complete list of operating equipment in plain text

In most cases, the operating manual is not yet available in its final version during the trial operation (revision scheme missing, maintenance plan still in draft form, etc.). However, it is sufficient to consult this draft. The correct handling of the switching functions, the observance of the safety regulations and instructions in case of malfunctions must be clear. During commissioning of the system, the site management must ensure that the operating personnel is fully instructed by the system supplier for the subsequent trial operation. The initial instruction of the operating personnel must be recorded in a protocol to be signed by the site management, the plant supplier and the operating personnel.

15.5 Acceptance

The trial operation has been successfully completed and the company would now like to hand over the system to the client. This handover by the company or acceptance by the client makes it possible to check the compliance with the specifications and the technical regulations.

One basis for the handover is the performance test, also called acceptance test. The purpose of the performance test is to provide legally binding proof of the plant's performance, which must be provided during a defined operating period as part of commissioning. The programme for this is contractually agreed [139].

The performance test begins when the system supplier has stabilised and optimised the operation of the system and the control system to such an extent that it can basically be released for trouble-free continuous operation. The system supplier is responsible for the performance test of the biomass boiler system, as the system has not yet been handed over to the owner. If the verification is successful, acceptance negotiations often follow, which end with the signing of the acceptance protocol. The plant is then in the intended commercial operation (continuous operation) [139].

Country-specific regulations

With regard to the acceptance and its documentation, the current country-specific laws, standards and regulations as well as the project-specific contractual agreements must be observed. In this respect, reference should also be made to the relevant standards for contracts for work and services, in which the topics of acceptance and handover are regulated for specific trades. There may be deviations from the exemplary requirements and procedures mentioned below, including special deadlines.

Responsibility, participating parties, procedure

Cold and hot commissioning of the biomass boiler system are the responsibility of the system supplier and must be completed at the time of acceptance. However, the joint acceptance is conducted by the construction supervision. The following must take part in the acceptance:

- the construction supervision,
- the equipment supplier and
- the building owner.

During acceptance, the scope of delivery and performance of the plant supplier is checked on the basis of the service contract.

At the time of acceptance, the plant supplier must

- submit the fully updated system documentation, including operating instructions, revised electrical diagrams, revised implementation plans, test records and declaration of conformity (see Q-Guidelines, E.5) and
- instruct the operating personnel of the biomass boiler system in detail on how to operate and maintain the system.

Instruction of the plant operating personnel and written operating documents

Instruction of the operating personnel is particularly important for biomass boiler systems. High efficiency and low pollutant emissions can only be achieved by systems that are operated and supervised carefully and professionally. If, for example, a different fuel is used than during the adjustment, the operating personnel must know that the system setting is now no longer optimal and should be readjusted.

A good operating manual, which also contains instructions on what to do in the event of malfunctions and how to set the control setpoints, is essential for optimal system maintenance.

The final operating documents should be handed in no later than at the time of acceptance. Any changes made to the operating set-up during trial operation should be documented and updated. Often, revision and operating documents are only submitted after acceptance. However, responsibility is transferred to the building owner with the successful final acceptance. This can lead to legal problems if the owner can prove that he was insufficiently prepared for the task, which may happen in the absence of clear operating instructions.

With automatic biomass boiler systems, the safety chain is more extensive than with conventional heating systems. Special attention must be paid in the operating manual to preventing accidents, for example in the silo room or on discharge equipment.

Acceptance protocol

The joint inspection and acceptance are accompanied by the drawing up of a protocol signed by all parties, which serves as evidence for all parties involved. The protocol records all items of the service contract and their fulfilment.

In the following, only those points are listed that require special attention for an automatic biomass heating system:

- Scope of delivery checks (type, performance check, dimensions, completeness)
- Execution control (fastenings, insulation, material quality, dimensional accuracy)
- Safety controls (safety devices, backfire prevention, accident prevention)
- Verification of control functions (delivery limit)
- Emission and performance verification
- Commissioning and trial operation test report

The joint inspection often reveals small deficiencies and work that has not been fully completed. It can lead to three different decisions:

1. The installation can be accepted
2. The installation can be accepted with reservations (minor defects).
3. The installation cannot be accepted (major defects).

Acceptance may be refused if major defects are found. The client or the construction supervisor must grant the plant supplier an acceptable period of time for their rectification. Subsequently, a second acceptance is necessary. Items that are listed in the first protocol as being in conformity with the contract are no longer checked in the second acceptance.

The distinction between minor and major defects is determined by practice. In principle, a defect is considered to be significant if there are reasons for the client to have it rectified as quickly as possible. This includes defects that prevent the proper operation or commissioning of a system, that can lead to damage or that endanger the life or health of persons, the property of the client or third parties. Aesthetic defects are not significant. In general, the effect of a fault on the overall installation must be taken into account when assessing it.

If some emission and performance guarantee values cannot be verified during the joint inspection, these must be explicitly recorded as performance reservations in the inspection protocol.

Handover of the plant to the client

With the successful acceptance, the plant constructed by the plant supplier is handed over to the client. When handing over the plant to the client, the client must assume the following obligations:

- Handover of supervision: From the time of handover, it is the responsibility of the client to take all measures to protect the life and health of persons, their belongings and the property of third parties. These obligations must be fulfilled by the plant supplier until handover.
- Transfer of risks: The plant supplier no longer bears any risk for accidents resulting in damage or loss of the plant
- Warranty and limitation periods begin.
- The plant supplier must submit the final report within a defined period of time.

The risk is not passed on to the client until acceptance has taken place without defects. From the time of acceptance, the warranty period for the entire performance begins. Only for self-contained parts of the performance does the transfer of risk begin with the partial acceptance.

Tasks of the planner during handover to the client

The following tasks are to be completed by the planner when handing over the entire facility to the client:

- The system documentation in accordance with Q-Guidelines D.5 is handed over in full to the building owner.
- The concept for operational optimisation according to Q-Guidelines D.6 is submitted to the building owner.

Part 4 - Operation and management

16 Operational optimisation after commissioning

16.1 Reasons and objectives

After the successfully completed commissioning and acceptance (see chapter 15), the system, both newly built and a system extension, goes into regular operation and becomes the responsibility of the owner. Experience shows that in most cases optimal plant operation cannot yet be achieved with complex biomass DH plants and heating grids, even if plants have been planned and built correctly and commissioning with trial operation has been carried out professionally.

Reasons for this include:

- The planning uncertainty due to the fluctuation range in the heat demand calculation
- Commissioning and trial operation cannot represent all load conditions and operating conditions occurring during an entire year of operation
- Lack of operational experience regarding the behaviour and control dynamics of the plant
- Changing fuel assortments and quality fluctuations (e.g. water content)

In addition, it often takes several years until the final expansion level of the heating network is reached, which was the basis for the planning and dimensioning of the heat generation. If the degree of expansion at the time of operational optimisation differs significantly from the final expansion, this should be done analogously and as far as possible according to the procedure described here. Due to the dynamic development of a heating network over many years, it is all the more important to establish ongoing system monitoring and continuous optimisation and to periodically repeat the detailed system monitoring in accordance with the expansion status.

If there are relatively constant operating conditions throughout the year with regard to load trend, fuel quality and other factors, the optimisation of operation can be shortened and carried out during commissioning and trial operation. However, it should be ensured that the subsequent requirements of operational optimisation can be covered. This could be the case, for example, with a biomass heating plant for process heat supply and a subordinate weather-dependent load share.

In the course of commissioning and trial operation, a basic system and control setting is made that enables stable and automatic operation. However, the control system in particular must be further optimised on the basis of initial operating experience. The objective of this (initial) optimisation of operation is to achieve operation in accordance with the planning as per the functional description with maximum efficiency, low emissions and stable operating parameters such as the flow temperatures. This also includes the gentlest possible mode of operation in order to achieve the longest possible service life (period of operation between cleanings) and to avoid malfunctions, for example, due to slag formation, exceeding or falling below permissible operating limits, etc. The comprehensive operational optimisation leads to low operating costs, a low environmental impact and a long plant service life.

Operational optimisation requires a systematic assessment and review of the current plant operation based on complete and reliable measurement data, as well as a comparison of the operating data and key figures with the specifications of the functional description in order to answer the following questions:

- Does the system function as intended in all operating states?
- Do the control parameters still need to be adjusted?
- Where are there still deficiencies or open questions?
- When and how can existing deficiencies be remedied?
- Are guarantee values, which can only be assessed in long-term operation, adhered to (power consumption, period of operation between cleanings, etc.)?

Operational optimisation with QM for Biomass DH Plants

In addition to professional and conscientious planning, ongoing operational optimisation is an important cornerstone for successful long-term plant operation. As this was often neglected in the past, operational optimisation is mandatory within the framework of QM for Biomass DH Plants (see chapter 2).

The requirements, responsibilities and procedures explained in chapters 16.2 to 16.4 essentially correspond to the specifications in the Q-Guidelines [15]. QM for Biomass DH Plants offers the following documents and tools:

- Functional descriptions for standard hydraulic schemes [62] and [71]
- Measuring point lists
- Description of the data recording
- Predefined key figures
- Operational optimisation concept - see supplementary document 424 in the Q-Guidelines [15]
- FAQ 8: How should the assessment and presentation of data in the operational optimisation be done?

The operational optimisation presented here is to be regarded as a minimum requirement and can also be carried out in much greater detail and/or extended to other plant components as required.

With careful operational management, data collection, monitoring and optimisation measures derived from this should be continuously documented. This creates a data and knowledge base that is of great value for later plant expansion, refurbishment and modernisation (see chapter 18).

16.2 Requirements and responsibilities

Depending on the size of the system, the basic operational optimisation is carried out in the first one to two years after acceptance of the system. In the case of district heating systems, at least one full year of operation or one full heating period should be used for this operational optimisation.

In the course of planning, a comprehensive functional description must be created. This is, among other things, the basis for the detailed planning and execution, in particular the hydraulic connection and control, but also a fundamentally necessary prerequisite for successful operational optimisation. The following documents are required for operational optimisation:

- Complete and final hydraulic diagram
- Detailed description of the functioning of the system for all relevant operating states including control description
- Complete measuring point list containing the measuring position and range, the temporal resolution and the measuring accuracy for each measuring point
- Description of the automatic data recording with documentation of the basic principle, the data or file structure as well as the location and duration of the data storage.
- List of agreed and guaranteed key figures to provide evidence of optimal operation
- Documentation and data sheets of the main system components

In addition, clear responsibilities for the preparation and implementation of the optimisation work must be defined and necessarily included in the assignment of the main planner and, if applicable, other responsible agents (e.g. manufacturing or control engineering companies). The allocation of the main responsibility for the required activities is recommended as follows, but can also be chosen differently depending on the situation:

- Planning and specification of data recording by the planner
- Monitoring of the automatic data recording by the operating personnel
- Implementation of supplementary manual records by the operating personnel
- Reading and providing the measured data by the operating personnel of the plant as well as control engineering companies or manufacturers
- Evaluation, calculation of key figures and assessment of the data by the planner.

Optimisation activities should be carried out in close coordination with plant operating personnel and manufacturers.

The responsibilities and requirements regarding data collection and implementation of operational optimisation should be summarised in an operational optimisation concept (see additional document 424 in the Q-Guidelines [15].

In order for successful operational optimisation to take place together with the manufacturers, corresponding financial guarantees (liability rebates) for the warranty period must be provided for in the service contracts. Otherwise, it cannot be guaranteed that all manufacturers will participate in the operational optimisation in a targeted manner.

16.3 Data processing and assessment

Comprehensive measurement equipment of the heating plant and heating network and suitable control technology for the transmission, storage and visualisation of the measured operating data are an important aid for ongoing operational management and an essential basis for carrying out operational optimisation.

In the course of monitoring, the operating data is processed and evaluated. For this purpose, the main **annual values** for the operating year under consideration and the key figures derived from them are determined according to Table 16.1. This provides a quick overview of the plant operation and enables the comparison of the determined key figures with the planning values.

In addition, detailed **operating data** with a high temporal resolution (e.g. 5-min values) are required, which must be provided with the help of appropriate measurement plant equipment and data acquisition (chapter 5.10). These are to be evaluated for selected **operating states** and time periods. For this purpose, the following operating states are defined in accordance with QM for Biomass DH Plants:

- **Low load** near the heating limit in the transitional period or in summer
- **Main load** as the load range in which most heat production takes place. For example, the daily average outside temperature is in the range 0 - 10°C. In multi-boiler systems, cascade operation counts as the main load but also as the high load.
- **High load** in very cold weather, for example when the daily average outdoor temperature is below 0°C. Cascade operation in multi-boiler systems and peak load operation with bivalent boilers also count as high load.
- **Extraordinary load and operating conditions**

The selection of the operating states must be adjusted accordingly depending on the system configuration or the standard circuit ([62] or [71]) and other influencing factors, for example if there is no summer operation.

In order for this detailed data to be interpreted and assessed, a graphical representation of the data is essential and must meet the following requirements:

- Display of a representative weekly history for each of the defined operating states
- Representation of the daily course of selected days
- It must be possible to present the most important data together in a single slide.

- The diagrams must be easy to read and have axis labels and legends so that numerical values can be easily read.
- Creation and presentation, for example of an Excel file, support the analysis and interpretation of the data.

The detailed requirements regarding the measuring points to be evaluated and the evaluation criteria are specified in Table 16.2 and Table 16.3 summarised. These also contain recommendations on how the individual parameters can be grouped into meaningful daily and weekly progress diagrams. If necessary, the presentation of the diagrams can be adapted to the respective questions to be assessed.

Some control systems or plant visualisations offer comprehensive options for the user-specific creation and export of time frame diagrams, which can then be used directly for assessment and operational optimisation.

Further details and examples can be found in FAQ 8 of QM Holzheizwerke.

Table 16.1 Required annual values and key figures derived from them.

	Parameter	Unit	Assessment
For all biomass boilers	Annual heat production	MWh/a	Number of full load operating hours
	Nominal boiler output	kW	Guide value Standard hydraulic scheme
	Total operating hours	h/a	Number of start-ups per year
	30 – 50 %	h/a	
	50 - 75 %	h/a	
	75 – 100 %	h/a	
	Stand-by	h/a	
	Ignition/start-up	h/a / n	
	Electricity demand biomass boiler	kWh/a	Specific electricity demand
Flue gas condensation	Annual heat production	MWh/a	Number of full load operating hours
	Nominal heat output	kW	Share of condensation in the annual heat production of biomass boilers
	Total operating hours	h/a	
	Electricity demand flue gas condensation	MWh/a	Specific electricity demand
	Water consumption	l/a	Specific water consumption
Dust precipitation (electrostatic precipitator/fabric filter)	Total operating hours	h/a	Availability
	Operating hours filter active	h/a	
	Operating hours bypass	h/a	
	Availability according to FAQ 38	h/a	
	Operating hours firing ON	h/a	
	Related operating hours precipitation ON	h/a	
For all bivalent boilers and other heat sources	Annual heat production	MWh/a	Number of full load operating hours
	Nominal heat output	kW	Share in annual production
	Total operating hours	h/a	
	Electricity demand bivalent boiler/other	MWh/a	Specific electricity demand
Heating network	Annual heat demand from the control centre	MWh/a	Heat distribution losses
	Annual heat demand consumers	MWh/a	ΔT annual mean
	Water quantity	m³/a	Losses storage/central
	Electricity demand network pumps	MWh/a	Specific electricity demand
Fuel use and auxiliary energy	Wood chips, bark, shavings, etc.	kg/a (m³/a)	Annual efficiency of the plant
	Pellet	m³/a	Annual efficiency pellet boiler
	Oil or gas		Annual efficiency bivalent boiler
	Electricity demand heat pump		Annual COP heat pump
	Total system electricity demand		Specific electricity demand of the entire plant

Table 16.2 Diagrams, measuring points and assessment criteria - weekly course.

Diagram	Parameter	Unit	Assessment
Weekly trends	Output biomass boiler 1	kW	Relevance Selection Daily
	Output biomass boiler 2	kW	Number of start-ups per day/week
	Output bivalent boiler	kW	Switching on/off bivalent boiler
	Network heat capacity Actual	kW	Interaction with other heat sources
	Storage tank charging state	%	
	Outside temperature	°C	

Table 16.3 Diagrams, measuring points and assessment criteria - diurnal cycle

Diagram	Parameter	Unit	Assessment
Overview	Outside temperature	°C	Operating status
	Storage tank charging state Actual	%	Storage tank state of charge control
	Storage tank charging state Target	%	Switching on/off bivalent boiler
	Output biomass boiler 1	kW	Interaction with other heat sources
	Output biomass boiler 2	kW	
	Output bivalent boiler	kW	
	Heat output of other heat sources	kW	
For every biomass boiler	Boiler outlet temperature	°C	ΔT at nominal power output
	Boiler inlet temperature	°C	
	Output biomass boiler 1	kW	Minimum power
	Output biomass boiler 2	kW, %	Heat output covers demand without oscillation; boiler power at lowest possible level
	Residual oxygen content / Lambda	% / -	Firing efficiency
	Exhaust gas temperature	°C	Boiler outlet temperature control
			Number of start-ups per day
			Compliance with light load condition
			Minimum daily heat production
			Summer operation and change of biomass boilers in autumn/spring
For all other heat sources (except bivalent boilers)	Heat output Actual	kW	
	Heat output Set value	kW	
	Inlet temperature	°C	
	Exit temperature	°C	
	Other specific parameters (depending on the type of heat source)		Specific key figures depending on the type of heat source
			Number of start-ups per day
Additional diagram	Network flow temperature Actual	°C	Temperature difference of the heating network
	Network return temperature Actual	°C	Size of the peak loads of the heating network
	Network heat capacity Actual	kW	Bivalent boiler only in operation when required
	Enable signal bivalent or other heat generators	kW, %	Biomass boiler output remains at a maximum when operating the bivalent boiler
	Main flow before/after storage tank	°C	Planned sequence of use of other heat sources
	Main return before/after storage tank	°C	Nominal heat output
			Minimum heat output
			ΔT at nominal heat output
			Boiler outlet temperature control
			Heat output covers demand without oscillation
			Boiler power at the lowest possible level
			Boiler outlet temperature control
Storage tank	All storage tank temperature sensors	°C	Temperature stratification charge/discharge
	Storage tank charging state	%	Usable temperature difference in the storage tank T

Required additional parameters:
- Daily mean value [°C] for the respective selected day
- Daily heat production [kWh/d] for each heat generator
- Minimum load condition [kW or % of nominal load] for each biomass boiler or also other heat generators

16.4 Implementation

Once all the operating data has been prepared, the actual analysis and assessment can be carried out on this basis and the actual plant operation can be compared with the functionality of the plant defined according to the planning (target operation). This is the task of the main planner. In the course of this final inspection, they must document whether the system is functioning as intended. As a basis for this, all previously mentioned documents, operating data, key figures and diagrams as well as the assessment criteria from Table 16.1 to Table 16.3 must be used. Furthermore, it is recommended to include in the assessment all additional information, such as recurring emission measurements, operating logs/incident records, operating experience of the operating personnel and a plant tour.

When carrying out operational optimisation, the following questions, among others, must be answered:

- Is the existing measurement data complete and plausible or could there be measurement errors?
- Are the planned values the same as actual values of the heat demand of the entire system and of individual connected customers in the course of a customer analysis (basis is the Excel tool for demand assessment and appropriate system selection)? In case of major deviations, a detailed analysis should show whether there is a systematic error or other reasons.
- Does the biomass boiler provide the contractually agreed nominal output (constant and without oscillation)?
- Does the biomass boiler operate at the contractually agreed minimum output without interrupting the combustion air supply?
- Does the plant efficiency (annual efficiency of heat generation and heating network) correspond to the planned target values?
- Does the output control in part-load operation work in such a way that the biomass boiler(s) is/are always operated at the lowest possible level so that the biomass boiler(s) is/are able to follow the course of the output demand gradually and without oscillation?
- Are oil or gas boilers, if present, only activated when absolutely necessary? Are these deactivated again as soon as the required output can be covered by the biomass boiler? Do the switch-over points (bivalence points) correspond to the planned assumption (Excel tool for demand assessment and appropriate system selection)?
- Is summer operation possible with the (small) biomass boiler and when should the switchover from the small to the large biomass boiler or vice versa take place in autumn/spring?
- Do all heat storage charging controls function according to the specifications in the functional description and is the operation of the biomass boilers uniform?
- Is the temperature stratification in the storage tank maintained during charging and discharging and is the intended usable temperature difference achieved?
- Are frequent start-ups and shutdowns avoided?
- Do operating conditions occur that lead to odour nuisance and high emissions?
- Is the system operated with the specified residual oxygen values and flue gas temperatures?
- Can all specified fuels be used without problems?
- Is the ash burnout complete and are there any problems with slagging?
- Do the measured temperatures correspond to the planning values and is the behaviour over time stable?
- Does the main flow temperature of the heating network follow the planned control strategy (e.g. outside temperature-dependent)?
- Does the main return temperature correspond to the expected values? Where is there potential for optimisation (for this purpose, a customer analysis can be carried out in accordance with the Handbook on Planning of District Heating Networks [19]).
- Does the availability of the electrostatic precipitator, if any, comply with the specifications or warranty values? (see FAQ 38)
- Does the specific power consumption correspond to the planned values or the manufacturer's specifications?
- Is the guaranteed period of operation between manual boiler cleanings achieved?
- Are the service intervals shorter than agreed?
- Is there an increasing number of malfunctions in individual plant components?
- Does increased wear occur in system components (e.g. from fireclay in the furnace, grate elements)?

If this assessment reveals deficiencies in the functioning and operation of the plant components, corresponding optimisation measures are to be defined. As a rule, these concern in particular the gradual adjustment of the control parameters with simultaneous observation of the effects.

When adjusting control parameters, consider to only adjust one parameter at a time and allow enough time to observe the effects. Depending on the parameter adjustment, the biomass combustion system reacts very slowly and hours or days should be allowed for this process. All adjustments must be documented in detail in an operating log. The documentation must be done in such a way that all parties involved in the project can later see and understand any changes.

If necessary, control system experts and manufacturers should be consulted. Gross defects should be communicated immediately in writing to the manufacturers in the course of the warranty. If safety-relevant deficiencies of any kind are detected in the course of operational optimisation, competent persons (including planners) have a duty to inform the persons responsible for the systems and should immediately communicate the deficiencies in writing.

The responsible operating personnel should be involved in the assessment and optimisation as much as possible. The aim of operational optimisation is also to establish plant monitoring during operation and continuous operational optimisation.

17 Operation and maintenance

17.1 Business organisation

A biomass heating plant with a heating network is a company like any other. Accordingly, the same requirements apply with regard to professional administrative and commercial management.

The Executive Board is responsible for the following tasks in the administrative and commercial area:

- Clarification of the most important regulations, guidelines and laws to the operating personnel
- Informing the operating staff about the provisions in the heat supply contracts and the fuel supply contract that are important for them.
- Conclusion of legally compliant contracts (fuel supply contract, heat supply contracts, etc.)
- Recording and implementing optimisation potential in the following areas:
  - Fuel and electricity purchasing (electricity pooling)
  - Insurances
  - Personnel deployment/personnel leasing
  - Fuel logistics with the aim of reducing fuel handling and vehicle use (possibly renting resources such as wheel loaders or using them in synergy, e.g. with the municipality).
- Cooperation with operator associations and/or other heating plants (e.g. purchasing pools, joint spare parts stocking)
- Professional customer service (communication with customers, information, service, hotline, etc.).)

For successful technical operation, the following notes on operational organisation must be observed.

Orderly operation requires an operational organisation with a list of persons involved and their responsibilities and powers. A complete, up-to-date system documentation according to the Q-guideline QM for Biomass DH Plants "E.5 Q-requirements system documentation" [15] forms the basis with which operating personnel can operate and maintain the biomass heating plant with heating network with the current system data at any time.

All applicable laws and directives as well as, in particular, the requirements according to the operating plant permit must be included in the ongoing plant operation. This applies to the following areas, among others:

- Fire prevention
- Occupational safety/protective equipment
- Explosion prevention
- Recurring inspections

Emergency plans for the following scenarios are to be developed:

- Emergency heat supply (external backup boiler connection)/guaranteeing the heat supply in the event of total generation failure
- Obtaining a mobile emergency heat supply system as quickly as possible
- Procedure in the event of a blackout and examination of the need for an emergency power supply.
- Procedure in case of limited accessibility to the central heating plant (e.g. winter, mountainous region) with regard to fuel supply, operating resources and personnel.
- Which essential spare parts must be available on site to avoid longer interruptions of operation?

17.2 Technical operation

The most important prerequisites for the proper operation of a biomass heating plant are:

- The use of biomass assortments that are suitable for the biomass boiler system and for which it has been regulated. The fuel quality must correspond to the fuel definition according to the service contract with the plant supplier.
- Regular monitoring of operating data such as flue gas temperature, excess air, flue gas fan speed, operating times, etc.
- Regular inspection of the plant so that, for example, leaking hydraulic hoses can be detected at an early stage or oversized fuel particles can be removed from the fuel.
- Regular system maintenance according to the manufacturer's instructions
- Detailed job specifications for the operating personnel with job description, responsibilities and authorisation for the individual task areas

The **procedure in the event of malfunctions** is described in the manufacturer's operating manual. The operating staff must be specially prepared for major malfunctions (blackout, failure of a biomass boiler, interruption of the fuel supply, ...) in order to be able to react quickly in an emergency. With an understanding of malfunctions and knowledge of how to remedy them, many complications can be prevented in advance.

17.3 Maintenance

17.3.1 General

Maintenance includes servicing, inspection (monitoring), repair (upkeep) and improvement of the plant technology.

The objectives of maintenance are easy, economical, trouble-free, optimal and environmentally friendly operation, a high annual utilisation rate and the preservation of the value of the system and its components.

Keeping an operations journal makes it possible to track the chronological course of the most important maintenance steps at any time. This is the basis for the coordination and planning of the necessary maintenance measures. Condition-based and predictive maintenance also includes, among other things, wall thickness and wear measurements at critical points (e.g. boiler tubes, fireclay, grate/grate elements, delivery units, pumps, fans) as well as the inspection of leakage warning and safety devices, pressure maintenance (make-up quantities) and regular checks of the heat transfer medium quality. This can increase the service life of the system and reduce repair and maintenance costs in the long term.

The economic viability of operating a biomass heating plant with a heating network is strongly influenced by the costs of maintenance and must already be taken into account in the planning stage (see also chapter 3).

The share of maintenance is often related to the investment costs. In Figure 17.1 the maintenance costs amount to 4 % of the investment costs of heat generation. Further information can be found in chapter 10.3.

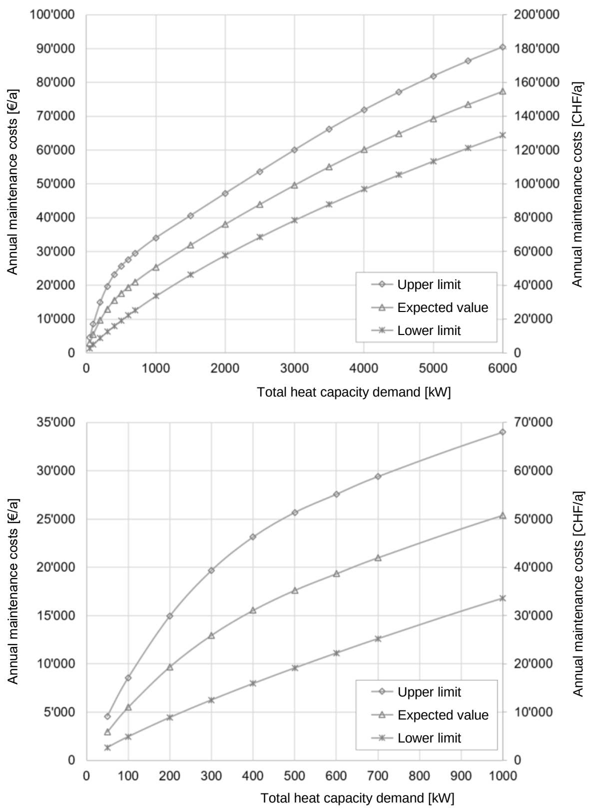


Figure 17.1 Annual expenditure for maintenance depending on the total heat capacity demand of the system (empirical value = 4 % of the investment costs on the basis of [123]; above ... total range, below ... detail section for small power range).

The economic viability of operating a biomass heating plant with a heating network is strongly influenced by maintenance costs and must already be taken into account in the planning stage (see also chapter 3).

17.3.2 Servicing and inspection

Servicing and inspection include operational monitoring such as checking the availability of the particle separator, rectification of faults, servicing such as cleaning or lubrication, regular functional checks of the system components and periodic servicing by the manufacturers of the individual system components. The service contract for the biomass boiler system or the particle separator as well as the periodic cleaning of the boiler and the chimney system by chimney sweeps serve this purpose. In addition to the regular inspection, all legally required periodic inspections must be carried out and documented (e.g. backfire protection, lifting equipment, automatic gates, vehicles, fire protection and extinguishing equipment, emergency lighting, etc.). If this is not permissible in the form of in-house inspections, appropriately certified bodies must be commissioned with this.

Maintenance and inspection amount to 2% of the investment costs of heat generation as a guideline and thus account for half of the total maintenance costs according to Figure 17.1. Further information can be found in chapter 10.3.

Low maintenance operation

To ensure that a biomass boiler system can be operated with low maintenance in addition to trouble-free operation, the effort required for boiler cleaning must be minimised.

This requires automatic boiler tube cleaning and automatic discharge of ash from the combustion chamber.

Boiler cleaning

The ash and foreign material left over from the combustion process are deposited in the following places, which must be cleaned periodically by the operating personnel or by the chimney sweep:

- Heat exchanger passes of the boiler or the downstream heat exchanger (fly ash) and their baffle chambers
- Burnout zone
- Combustion chamber (grate ash), around the burnout retort in the case of underfeed firing, at the end of the grate in the case of the grate firing systems
- Under the grate (grate ash) or under the burnout retort

The boiler supplier's operating documents describe boiler cleaning and specify how often cleaning is necessary. The cleaning interval depends on the fuel, the combustion behaviour of the fuel on the grate (stable fuel bed without breakthroughs or hotspots), the operating mode and status of the system.

A good indicator of the contamination state of the system is the flue gas temperature, which should therefore be checked regularly. Dirty heat exchanger surfaces worsen the heat transfer to the heating water. The result is an increased flue gas temperature and thus higher flue gas losses. Boiler cleaning is necessary when the flue gas temperature rises by 20 K - 30 K. As a rule, the interval is between two and three weeks.

With automatic pneumatic or mechanical boiler tube cleaning, the interval between two manual boiler cleanings can be increased to a full load operating hour number of 2,500 - 3,000 h/a or to a half-yearly interval (see also chapter 5.5).

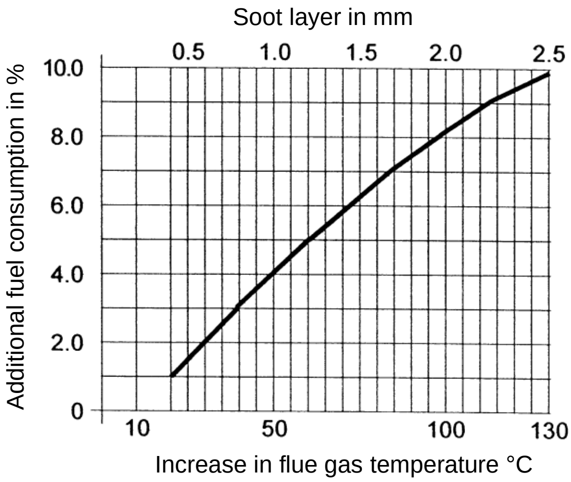


Figure 17.2 Relationship between soot layer on the heat exchangers, additional fuel consumption and increase in flue gas temperature in the boiler.

The additional cleaning can be significantly reduced with the following automatic system components:

- Under grate ash removal for the grate throughfall in grate firing systems
- Refractory ash removal for underfeed and grate firing systems

Maintenance contract (service contract)

In the maintenance contract (service contract), the periodic maintenance of the plant components by the plant supplier is agreed.

Periodic maintenance should ensure trouble-free operation that does not lead to damage to the system components. The technical functionality is to be ensured by the replacement of worn parts.

Scope of the maintenance contract for an automatic biomass boiler system

Within a time interval of two years, the following maintenance work must be carried out on an automatic biomass boiler system (see also chapter 5):

- **Revision**: During plant revision, the system components are checked for wear and tear and functional efficiency of the conveying system, the combustion chamber, the furnace grate, the boiler and the safety devices when the system is not in operation, for example in summer.
- **Emission maintenance**: During emission maintenance, the functionality of the system in operation is checked with regard to combustion quality and efficiency, control, safety devices such as backfire prevention or safety thermostat. It may be necessary to specify new settings for the combustion control.

Additional remote maintenance by the boiler manufacturer is an important support for the operating personnel in troubleshooting and optimising operation and includes the following activities:

- Remote diagnosis
- Control
- Remote access and advice by phone
- Remote control

A maintenance contract guarantees the continuity of this service. In this way, malfunctions can be reduced to a minimum or immediately remedied remotely. Operational safety is increased. Further information can be found in chapter 5.10 and in chapter 16.

Contractual partner

Depending on the size and complexity of the system as well as the number of main contractors, more than one maintenance contract for the biomass heating system is necessary. Possible contractors are:

- Manufacturer of the biomass boiler with control
- Manufacturer of the silo aggregates (filling and emptying of the silo, the warehouse)
- Exhaust treatment manufacturer
- Manufacturer of the hydraulic integration
- Manufacturer of the control or building management system
- Product-independent, specialised companies.

A maintenance contract may have to be concluded with all the companies listed above. The services included in the respective maintenance contracts shall be coordinated with each other.

Content of the contract

A service contract should contain the following points:

- Purpose
- Clear description of services and deliverables (guarantees also possible!)
- Description of exclusions and exceptions
- Listing of hourly rates and allowances as well as expenses
- Costs
- Validity and duration
- Cancellation
- Refurbishment
- Contact address and organisation for requesting services in case of emergency
- Duties of the operator
- Rights of the entrepreneur

17.3.3 Repair and improvement

Periodic replacement of system components such as combustion chamber lining, grate elements or pumps with the same state of the art technology are referred to as maintenance. If, on the other hand, system components are replaced by technologies of a newer state of the art, this corresponds to an improvement.

Repair and improvement amount to 2% of the investment costs of heat generation as a guideline and thus account for half of the total maintenance costs according to Figure 17.1. Further information can be found in chapter 10.3.

17.4 Occupational safety

The occupational safety of the operating personnel is essentially determined by observing and complying with the country-specific requirements for the safety equipment of the corresponding plant components with regard to the prevention of fire accidents and explosions (see also chapter 19).

In addition, great attention must be paid to occupational hygiene, as this has a major influence on the health of the operating personnel. The operating personnel of a biomass heating plant is exposed to the following health-relevant immissions and influences:

- Ash dust during boiler cleaning, ash handling, maintenance work on the flue gas system and ash removal system
- Wood dust in the fuel storage area during fuel delivery, fuel handling, maintenance work on the fuel transport system.
- Mould in the fuel storage area during fuel delivery, fuel handling, maintenance work on the fuel transport system.
- Noise
- Fermentation gases in the fuel storage area and in adjacent rooms
- Carbon monoxide in the pellet storage
- System parts with high temperatures or high temperature radiation.

Ash dust, wood dust and mould spores have fine dust particles that are respirable and can thus impair lung function. Wood dust and mould spores can cause allergies, which can weaken the health of the person concerned. The operating personnel must take the following precautions:

- Wearing a protective mask when exposed to immissions of ash dust, wood dust and mould spores
- Using protective equipment if the noise level is high
- Ventilating thoroughly before entering fuel storage areas and rooms with possible high concentrations of fermentation gas to prevent possible asphyxiation
- Complying with the safety regulations from the storage room brochure “Lagerung von Holzpellets” [67]; Regulations must be observed when entering pellet storage facilities so that accidents caused by toxic CO concentrations can be prevented.
- Wearing appropriate protective clothing with a protective shield when handling plant components or when working in the immediate vicinity of plant components that exhibit high temperatures to prevent burns.
- Switching off or interrupting the power supply during troubleshooting or maintenance work on system parts with electric drives.

17.5 Insurance

In order to ensure the long-term economic operation of a biomass heating plant, appropriate insurance policies must always be taken out. This is particularly important because often contractual heat supply obligations are specified in customer contracts. Unexpected faults and interruptions in heat supply can occur at any heating plant. The following insurance is possible:

- Building (during construction phase)
- Fire
- Fire, interruption of operation
- Machine breakage
- Machine breakage, interruption of operation
- Public liability
- Natural hazards

It is advisable to carry out a precise risk assessment in cooperation with experts.

Additional insurance points are:

- Co-insurance of ancillary costs in the event of damage
- Co-insurance of expert costs in the event of a claim
- Legal protection
- Pipelines

It is recommended to check whether a framework insurance agreement for biomass DH plants with a heating network can be concluded with the following scope (if not already included in other insurances):

- Building insurance (usually compulsory)
- Contents insurance
- Business interruption insurance
- Additional cost business interruption insurance
- Liability insurance
- Special criminal law protection insurance

The agreements in the insurance contracts must be strictly adhered to. In addition to all legal requirements (especially recurring inspections and documentation - chapter 17.3.2), any additional requirements imposed by insurance companies must be observed in order to guarantee insurance cover.

18 Optimisation and refurbishment of existing plants

18.1 Explanations

New plants that are planned and realised within the framework of QM for Biomass DH Plants carry out the **operational optimisation** described in chapter 16 during the first years of operation. In this process, it is checked whether the plant reaches the technical and economic target values of QM for Biomass DH Plants in the latest development stage of the heating network. If the plant is built according to these specifications and target values, the operating data required for this assessment are available.

This chapter is intended for existing plants that have been in operation for several years, regardless of whether QM for Biomass DH Plants has been involved. In order for existing plants to remain sustainable the most important plant components of heat generation and distribution must be periodically reviewed with regard to technology and economic efficiency, and optimisation potential must be identified and tapped. Densification or expansion of the heat supply, state of the art innovations, new legal regulations such as stricter emission limits or the banning or declining acceptance of fossil fuels, high wear and tear of system components, accumulation of operating problems or system failures or new ownership structures can trigger a more in-depth review (**status quo analysis**) of the system. This may show that certain components should be optimised (**optimisation of existing plants**), or that individual components or even the entire plant must be refurbished (**refurbishment of existing plants**).

The following chapters describe procedures, tools and measures and are intended to show the planner how to support the plant operation staff in optimising and/or refurbishing the plant. The starting point is always a status quo analysis in accordance with chapter 18.2.2, which is to be expanded in the case of a plant refurbishment in accordance with chapter 18.3.2

18.2 Optimisation of existing plants

18.2.1 Procedure

The following steps are necessary to optimise existing systems:

- Status quo analysis of the existing technology and the current economic situation
- Assessment of the results of the status quo analysis, if possible, by means of benchmark comparison
- Identification of optimisation measures with cost/benefit analysis, in-depth clarifications in sub-areas if required.
- Implementation of optimisation measures and monitoring success.

The optimisation should be carried out by experts. In order to obtain target-oriented and reliable results, cooperation with the operating staff is necessary. They must provide the necessary information. If safety-relevant deficiencies of any kind are detected, there is a duty to inform the person responsible for the system, so that the corresponding deficiencies must be communicated immediately in writing.

18.2.2 Status quo analysis of technology and economy

The basis of every analysis is an up-to-date and comprehensive database and an estimate of future development. Thus, the most comprehensive data and information listed below must be obtained for the status quo analysis.

General condition of the plant
Relevant for plant assessment are a description of the general condition of the plant, the status of the plant technology and equipment, the general description of the current situation and possible problems, if these are not covered in detail in the following points, and current or future expansion plans. A plant tour provides an overview of the current state.

Heat generation

- Description of heat generators
- Year of construction and general condition, nominal outputs, additional components (fine dust separator, economiser, etc.), emission measurements, records of malfunctions and repairs
- Basic and annual data required for the Excel tool for demand assessment and appropriate system selection (see chapter 11)
- Operating data required within the scope of operational optimisation (see chapter 16)
- Hydraulic diagram, standard circuit WE, function/control description
- Examination of use of space, potential for expansion in the heating plant and on site
- Checking safety aspects in the heating system including fuel storage (country-specific regulations in chapter 19)

Fuel and ash

- Logistics of fuel supply and ash disposal
- Fuel requirement of an operating year (quantity, type, quality)
- Fuel quality according to fuel supply contract
- Fuel analysis and classification of fuel quality according to QM for Biomass DH Plants (chapter 4).
- Storage capacities gross, net of silo, warehouse, outdoor storage area
- Records of operational malfunctions in the area of the silo and fuel transport up to the firing system as well as the ash conveying system

Heat distribution

- Network plan with indication of pipe dimensions and temperature levels
- Basic and annual data required for the Excel tool for demand assessment and appropriate system selection (see chapter 11)
- Operating data required within the scope of operational optimisation (see chapter 16)
- General condition of the heating network, leakage monitoring, heat transfer stations and water quality
- Records of the required replenishment volumes
- Hydraulic diagram of a typical heat transfer station

Operation and maintenance (maintenance, inspection, repair and improvement)

- Annual servicing required according to chapter 17.3.2
- Average required annual maintenance and improvement according to chapter 17.3.3

Contractual and legal framework

- Responsible body, legal form of the plant operator
- Fuel supply contract
- Heat supply contract with technical connection regulations and tariff model
- Servitudes (e.g. right of way)
- Contracts for services provided to third parties (system operation/support, heat billing, etc.)
- Legal regulations (emission limits, health and safety regulations and others according to chapter 19)
- Organisation of plant operation

Economic efficiency

- All basic data for a profitability calculation (see tool Profitability calculation (chapter 10)
- Effective energy, operating and maintenance costs as well as income from connection fees and heat sales
- Estimation of the development of the next five to ten years

Survey of the operating behaviour of heat generation and heat distribution

The recording of the operating behaviour should be oriented towards the optimisation of operation according to chapter 16 and FAQ 8. The recording of the operating behaviour depends to a large extent on the measurement equipment with which the heating plant and the heating network are equipped and in which form the operating data can be visualised. In the best case, this can be done by monitoring the operational control system (see chapter 16.3). If only few or no operating data are recorded, then the assessment of the operating behaviour must be based on:

- Observations of the operating staff
- Targeted observations on selected days in winter, in the transitional period and in summer.
- Temporary, targeted measurements on selected days in winter, in the transitional period and in summer, for example by means of long-term measurements in accordance with QS Support Holzfeuerungen [140].

18.2.3 Assessment of status quo analysis

In the following, different possibilities are described how the results of the status quo analysis can be related to the characteristic values of QM for Biomass DH Plants.

Excel tool for demand assessment and appropriate system selection

The Excel tool for demand assessment and appropriate system selection [109] calculates the most important key figures of the plant, compares them with the characteristic values of QM for Biomass DH Plants and thus enables rough statements to be made on the following aspects:

- Number of full load operating hours of the biomass boilers: What power reserves are available in heat generation?
- How high is the share of biomass in the annual heat production?
- Is the volume of the heat storage tank sufficient?
- Is the operation of the (smallest) biomass boiler permissible in summer?
- Is the connection density of the heating network sufficient?
- How high are the heat distribution losses?
- How high is the supply autonomy of the fuel store?
- How reliable is the heat supply in the event of a failure of the largest biomass boiler?

Operational optimisation according to milestone MS5

If the collection of operational data and behaviour can be carried out according to chapter 16, the most important key figures of the plant can also be created with the help of the Excel tool for demand assessment and appropriate system selection. Further statements on the operating behaviour are also possible, such as for example:

- Does the operating behaviour of the system correspond to the functional description? Where does it deviate?
- Is increased system wear or a shortened service life of components such as combustion chamber lining, arch bricks, grate elements, ash screw, etc. to be expected?
- Do high load peaks and load reductions occur in the heating network?
- Does the electrostatic precipitator achieve the expected annual availability?
- Is the power consumption of the system within the expected range?

Helpful hints on how to carry out operational optimisation can be found in FAQ 8 [141].

Costs for maintenance and servicing (see chapter 17)

If information on the average annual costs for maintenance and repair is available, these values can be compared with the corresponding diagrams and thus allow statements such as:

- Are the average annual servicing costs within the expected range?
- Is there potential to reduce these costs?
- Are the average annual costs for repair (maintenance) within the expected range?
- Can these be reduced through operational optimisation?

Excel tool "Erneuerung Holzenergieanlagen" (refurbishment of biomass district heating plants)

In the consulting tool "Erneuerung Holzenergieanlagen" [16] the most important technical system data on heat generation and heat distribution as well as on economic efficiency are entered. The tool calculates the most important technical and economic data and compares them with the target values of QM for Biomass DH Plants. The results are also displayed graphically, so that it can be quickly recognised whether the characteristic values of the system are within the expected range or whether they exceed or fall below an upper or lower limit. The results and possible optimisation or refurbishment measures are discussed with the plant operator.

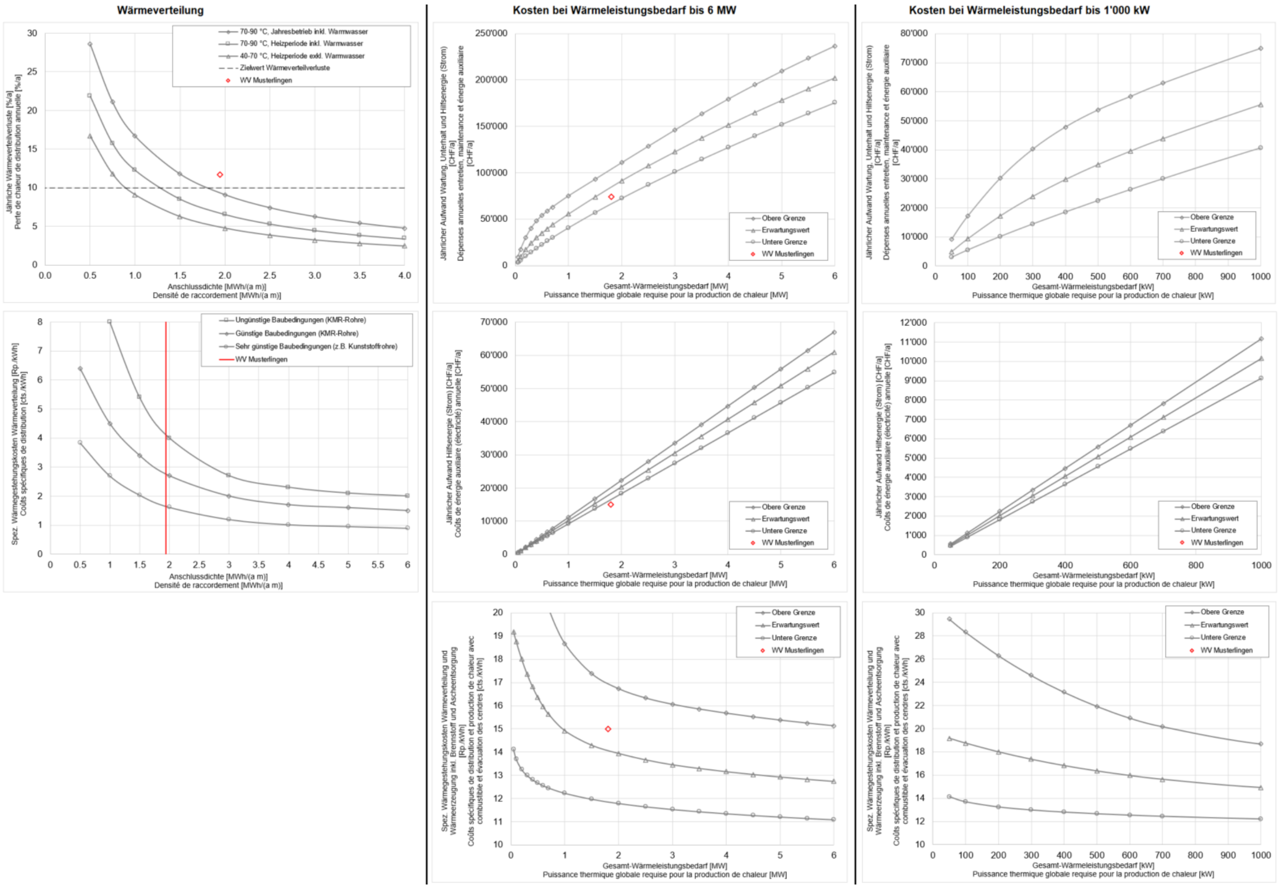


Figure 18.1 Exemplatory graphs from the consultation tool "Erneuerung Holzenergieanlagen" [16].

Heating plant consultations by Q-managers in Austria

In Austria, consultations for (older) biomass DH plants are offered by the federal government or within the framework of the support programmes of the provinces. These consultations are carried out by independent experts (Q-managers of klima**aktiv** QM Heizwerke). In addition to the examination of plant data and relevant documents, the expert also conducts a one-day inspection of the plant. Finally, a written report with recommendations for optimisation measures is submitted.

Benchmark comparison from operating data in the QM Heizwerke database

In Austria, the QM process is supported by the klima**aktiv** QM Heizwerke database, in which all relevant technical and economic plant data are recorded and documented (see chapter 2.3.6). This also includes the mandatory annual disclosure of the most important operating data. Based on this, important key figures are automatically calculated and prepared for comparison with target values and comparative values of other heating plants (benchmarks) as information for operating staff, planners and Q-managers. Figure 18.2 shows an example of benchmarks of a heating plant for the specific electricity consumption of the entire plant.

The aim of this service of the programme management of klima**aktiv** QM Heizwerke is to give the operating staff in particular an overview of the status quo of the plant (and its development during the previous years) and to motivate them to deal with the operating data of their plant (see also [142]). With the help of the benchmarks, it is possible to identify optimisation potential within the respective site-specific framework conditions - if necessary with the support of experts.

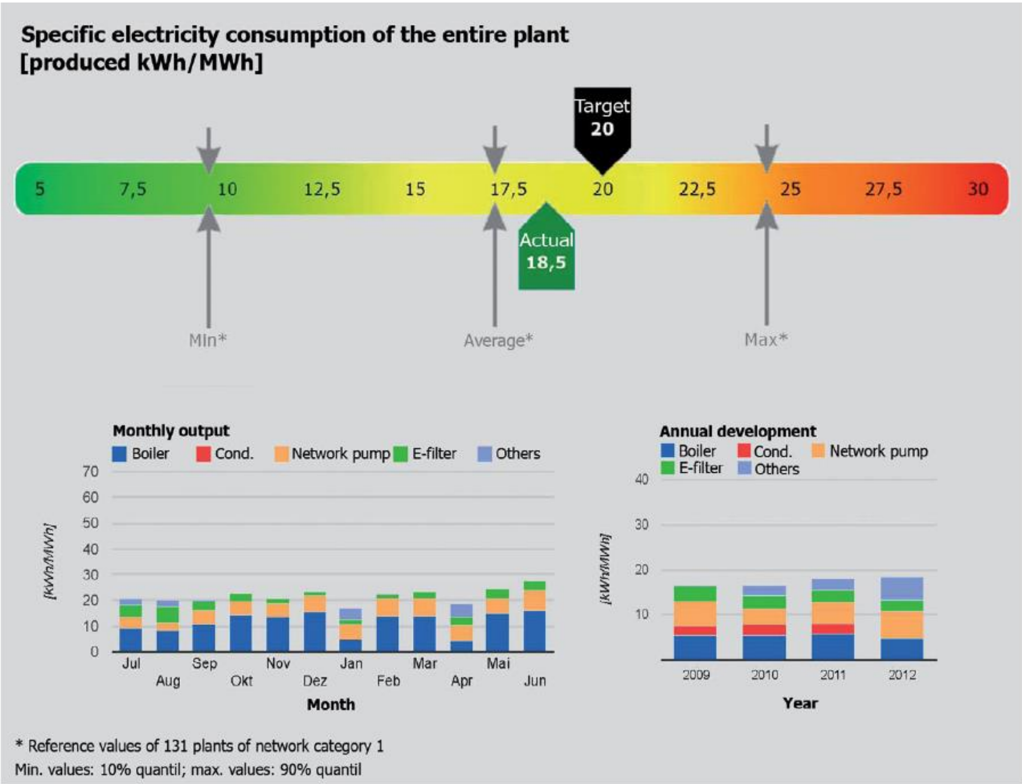


Figure 18.2 Example of an evaluation of klima**aktiv** QM Heizwerke benchmarks (source: AEE INTEC).

Quality analysis of biomass heating plants

For biomass DH plants in Germany, C.A.R.M.E.N. e.V. offers operators a so-called operational analysis ("Betriebsanalyse") [143]. The procedure is based on the heating plant consultations carried out in Austria. The scope of the analysis can be individually coordinated with the needs of the operating personnel.

Excel tool Economic Profitability Calculation

The Economic Profitability Calculation tool [144] shows the current economic aspects of a plant and the possible further development in depth. Although it does not make any optimisation recommendations, it can very easily show how cost-reducing or yield-increasing measures/investments will affect the economic efficiency of the plant.

In-depth clarifications

The assessment of the documents and the results of the status quo analysis may conclude that more in-depth clarifications are necessary, such as:

- Visit/inspection of the plant and a typical transfer station
- Additional, selected measurements for in-depth assessment of the operating behaviour

- In-depth heat network analysis using analysis tools such as THENA [106], Sophena [102], Excess consumption [145], etc.:
  - Identification of defective heat transfer stations
  - Determination of potentials in existing district heating network branches for the connection of additional customers

18.2.4 Measures for the optimisation of existing plants

18.2.4.1 Cost-cutting measures

In many cases, the optimisation of an existing plant is triggered by a lack of economic efficiency. The focus is then initially on measures that reduce costs. Cost-covering measures include:

Ensure compliant fuel quality

The use of low-priced fuel assortments of low quality that do not meet the specification of the firing system can lead to operational malfunctions, increased maintenance and wear as well as inadmissible emissions and thus worsen the economic efficiency of the system. Measures:

- Analysis of fuel quality
- Use of a fuel quality that is suitable for the transport system and the firing type
- Frequent testing of water content, periodic testing of fines, overlengths and foreign content
- Consistently rejecting non-compliant fuels.

Reduce fuel consumption

- Increase the annual efficiency of the biomass boilers:
  - Enable long operating times with suitable power control in combination with sufficiently dimensioned heat storage tanks (if required, retrofit heat storage tank with storage charging management).
  - Reduce residual oxygen content in the flue gas in all output ranges by the firing system supplier (optimisation of combustion control, air staging, flue gas recirculation), annual follow-up check, check oxygen measurement (O_2 probe, lambda probe) regularly, check for leaks and false air entry.
  - Monitor flue gas temperature continuously and reduce it by means of suitable, automated boiler cleaning measures or, if necessary, by shortening boiler cleaning intervals.
  - Check retrofitting of efficiency-increasing measures (e.g. economiser, exhaust gas condensation).
  - Check whether the biomass boiler operation meets the requirements for operation in summer with dry fuel. If not:
    - Run system in summer with an existing fossil boiler that is operated with gaseous or liquid biofuels in the future, if possible.
    - Check retrofitting of a smaller biomass boiler for summer operation
    - Examine alternative, decentralised domestic hot water supply for summer operation and do not operate the heating network in summer.
- Reduce losses of the heating network:
  - Control the flow temperature of the heating network according to weather conditions and reduce it to the minimum necessary temperature level.
  - Reduce the return temperature of the heating network:
    - Locate defective heat transfer stations based on an analysis of the heat consumers for excess consumption (see Handbook on Planning of District Heating Networks [19] chapter 10).
    - Check the primary-side equipment at the heat transfer stations
    - Hydraulic retrofitting on the secondary side
  - Enforce technical connection regulations of the heat transfer stations with regard to maximum permissible return temperatures or introduce them if necessary. If the connection density of the heating network is too low, examine an alternative, decentralised domestic hot water supply for summer operation and do not operate the heating network in summer.
  - Use district heating pipes with the highest insulation standards when expanding the heating network or replacing pipelines.

Reduction of costs for maintenance and repair

- Optimise the manual cleaning intervals by observing the exhaust gas temperature. Use auxiliary devices
- Automate manual cleaning work through suitable retrofitting where possible
- Check retrofitting of an automatic ignition of the biomass boiler
- Reduce disruptions in the fuel transport system through compliant fuel qualities. Optimally position and appropriately adjust sensors in the fuel transport system
- Regular inspection/revision of the system components (service contract for early detection and repair of damage)
- Ensure high water quality (heat transfer medium) to prevent damage (corrosion, deposits on heat meters and fittings, overheating in the boiler area).
- Ensure low-wear and low-maintenance operation of the system:
  - by setting the control parameters appropriately so that the biomass boiler can be operated at all times with a stable fuel bed without the formation of hotspots (volcanoes) or cinders
  - by retrofitting a heat storage tank with suitable heat storage charging management to achieve long, continuous boiler operating times with few start/stop phases.

Reduce costs for electricity consumption

- Aim for a high temperature difference between the flow and return temperatures of the district heating network, if possible, through measures that reduce the return temperature of the district heating network (on the primary side).

- Aim at a maximum temperature difference between the flow and return of the biomass boiler of 15 K at nominal output
- Apply suitable differential pressure control of the capillary pumps
- Apply suitable dimensioning of the respective capillary pump for winter and summer operation.
- Use energy-efficient drives and aggregates (fans, pumps, conveyor technology, compressors, etc.)
- Use speed control for fans (instead of butterfly valves)
- Avoid unnecessary pressure losses in the hydraulic piping and in the flue gas ducts
- Avoid false air entry in firing systems, dust precipitation systems and in flue gas ducts
- Avoid compressed air leakage

18.2.4.2 Measures to increase earnings

A lack of economic efficiency also requires yield-increasing measures. These include:

Review tariff model

- Check heat supply contracts (tariff model and tariff design) and adjust if necessary:
  - Reduce weather dependency of annual yields
  - Make tariff adjustments via appropriate indexation

Ensure accuracy of heat meters

- Maintain high water quality:
  - Ensure that the water treatment equipment (magnetic flow filter, degassing, etc.) is functioning properly. If necessary, retrofit the equipment accordingly
  - Check water quality periodically
- Check the correct position of the heat meters and have the heat meters recalibrated in accordance with the legal requirements.

Tap capacity reserves in heat generation and distribution - network densification

- Check capacity reserves in the heating network or in branches using suitable network analysis tools (e.g. THENA [106] or others).
- Network densification through acquisition of suitable customers in the perimeter of the existing heat network

Expansion of heat generation and distribution - network expansion

- With the help of suitable network analysis tools, the remaining reserves in the heating network can be shown and potential customers can be better identified. Expansion of the heating network should only be considered if the technical parameters of QM for Biomass DH Plants and a contractually guaranteed heat supply of 60 % of the new heat potential to be tapped are achieved.
- Ensure that the biomass boiler or boilers reach their rated capacity
- Expansion of heat generation capacity:
  - Check fuel supply capacities
  - Check space potential in the boiler room for an additional biomass boiler or for the replacement of an existing biomass boiler with a larger biomass boiler.
  - Only carry out when the expected annual number of full load operating hours of the existing biomass boilers are reached

18.2.4.3 Further measures

Other measures should also be considered and include the following:

Operational safety and security of heat supply

- Analysis and elimination of safety hazards for persons and machines
- For heating plants without fossil-fuel boilers, provide connections for the use of a mobile, external heating system.
- Set up of operational organisation in such a way that operation is guaranteed in the event of absences due to holidays or illness.

High share of renewables in annual heat production

- Fossil fuel boiler in operation only when absolutely necessary during peak load demand and switched off as early as possible.

Reduction of emissions

- The measures listed help to reduce undesirable emissions in regular operation as well as in the transient operating phases of the biomass boilers.
- Examine retrofitting of dust precipitation even without stricter legal requirements in order to proactively increase the acceptance of biomass combustion systems.

Commercial/administrative measures

- Regular review of expenditure and cost structure and possible cost savings
- Financial reorganisation if necessary
- Optimisation of electricity tariffs by comparing tariffs and joint electricity purchasing/pooling (e.g. via operator associations). Preference should be given to certified green electricity.
- Cooperation of several plants in spare parts storage, joint ash disposal and fuel purchasing
- Optimisation of insurance rates and other expenses
- Use of software tools to simplify heat billing and operational management

18.3 Refurbishment of existing plants

18.3.1 Introduction

The analysis and assessment of existing plants described in chapter 18.2 aim to optimise the existing plant components of heat generation and heat distribution and thereby improve the technical and economic situation of the overall system. However, the assessment may also conclude that individual plant components or even the entire plant should be refurbished. In most cases, this concerns the area of heat generation.

The following reasons can lead to the retrofitting of individual components, a partial or even complete refurbishment of the heat generation system, even without a prior analysis of the system:

- Ongoing economic difficulties
- Expiry of the expected service life of components or biomass boilers
- Changes in legal regulations, for example with regard to emission limits, heat storage obligation, obligation to provide evidence about the availability of dust separation, restriction of the use of fossil fuels
- Neighbourhood complaints as a result of noise or odour nuisance in the nearer environment of the central heating plant
- Imminent expiry of deadlines for the implementation of official orders, for example retrofitting of dust precipitation and/or heat storage tanks

If an existing plant is to be partially or completely refurbished, the optimisation potential shown in chapter 18.2 should always be investigated and, if possible, tapped.

18.3.2 Procedure for refurbishment

Even if initially only the refurbishment of a single component is considered, a holistic analysis of the plant by an expert is necessary. The following steps must be taken for the refurbishment of existing plants:

- Status quo analysis of the existing technology and the current economic situation
- Assessment of the results of the status quo analysis
- Identification of refurbishment measures with cost/benefit analysis (if necessary, carry out in-depth clarifications in sub-areas) and recommendation of a refurbishment strategy.
- Implementing the refurbishment strategy and monitoring its success

If a comprehensive refurbishment of an existing plant is being considered, the procedure is basically the same as for the realisation of a new installation. The entire planning process described in Part 3 of the Planning Handbook must then be followed. It is generally recommended to have QM for Biomass DH Plants accompany the refurbishment of a plant.

Status quo analysis with evaluation of results

In a first step, the consultation tool “Erneuerung Holzenergieanlagen” listed in chapter 18.2.3 can be used to identify initial priorities for possible refurbishment measures. In a second step, the detailed status quo analysis of technology and economy described in chapter 18.2.2 should be carried out. The assessment of the results should also take the following aspects into account:

- **Demand assessment and appropriate system selection** (see chapter 11): In addition to the annual heat demand and heat capacity demand of the current system, the medium and long-term development of the potential heat supply area must be taken into account, i.e. future thermal building renovations as well as the future development of housing, commerce and industry in the heat supply area. A balance must be struck between the most realistic possible assessment of future development and unnecessary, excessive reserves.
- **Heat distribution** (see chapter 12): In addition to densification in the existing heat network, expansion must also be examined. This requires in-depth clarifications of the performance potential in the existing heating network using analysis tools such as THENA [106], Sophena [102] or others. If other heating networks are in operation in the vicinity of the existing heating network, a possible connection with these networks should also be examined. In case of high rates of leakage, pipe bursts or uncertainties regarding the condition of the heating network and the expected lifetime, it is recommended to carry out an in-depth analysis of the heating network with the help of experts and specialised companies.
- **Heat generation** (see chapter 13): The analysis should include all existing systems and components of the heating system, i.e. heat generators, storage tanks, hydraulics, pumps, fuel and ash logistics, I&C systems, process visualisation. More in-depth clarifications should show,
    - what condition the existing systems and components are in and whether they can continue to be used in the medium or long term.
    - whether measures to increase efficiency/heat recovery can be realised.
    - whether the existing storage capacities are sufficient or whether additional storage capacities bring an advantage.
    - whether measures to reduce maintenance and repair costs can be implemented.
    - whether measures to reduce noise emissions from the biomass heating plant can be implemented.
    - whether measures can be implemented to avoid odour nuisance (raising the chimney, optimised combustion process).
    - whether alternative heat sources can be integrated.
    - whether the control and data acquisition systems can be modernised.
    - whether a step by step procedure is possible and how the heat supply can be ensured during the refurbishment of the plant.

- **Fuel** (see chapter 4): It must be clarified how the biomass potential available in the future will develop and whether the available fuel quality is suitable for existing and/or new components.
- **Building of the heating system**: It must be clarified how components that are no longer used can be removed from the heating system and how new components can be introduced. If necessary, appropriate structural measures should be taken.
- **Economic efficiency** (see chapter 10): As part of the analysis of the heat supply contracts, it should also be examined whether the system operator can adjust the heat tariffs.
- **Legal aspects**: It must be clarified whether the legal framework conditions (e.g. emission limits, authorisation and permit procedures) have changed and how this affects potential refurbishment measures.

Show refurbishment strategy in a feasibility study
A feasibility study should evaluate different refurbishment strategies by means of a cost-benefit analysis and include the following points:

- Overall assessment of the existing plant
  - Potential of the existing plant
  - Expansion potential heating network
  - Customer analysis
  - Political, social development
- Identify refurbishment measures (see chapter 11.2)
- Show refurbishment measures for heat generation:
  - Retrofit or refurbish particle precipitation
  - Retrofit storage tank, retrofit or improve storage charging management
  - Modify or replace fuel delivery system
  - Replace single or multiple biomass boilers
  - Retrofit staged flue gas recirculation (primary/secondary)
  - Retrofit heat recovery
  - Optimise hydraulics in the heating plant
  - Improve logistics for ash removal and ash conveying system including intermediate ash storage
  - Integrate new heat carriers/heat sources
  - Check possibility of power generation
- Present refurbishment measures for heat distribution:
  - Professional acquisition and customer care
  - Definition of expansion stages
  - Return temperature reduction for heat recovery retrofit
  - Long-term renovation and modernisation concept for the heating network. This includes, among other things, systematic renovation of pipe sections, coordination with other construction activities (e.g. road renovation) in the supply area, replacement of heat exchangers, regulators, control valves or the entire house transfer station).
- Examine suitable step by step procedure of individual refurbishment measures
- Show how the operation of the plant will be ensured during the conversion phase
- Offer new services (fibre optic internet connection, cable laying in existing cable pipe heating network, additional cooling network, expansion of services for customers (secondary side optimisation or heat exchanger cleaning, e-car sharing, etc.).)
- Make a recommendation for a joint refurbishment and renovation strategy

Implementation of the refurbishment strategy
The decided refurbishment and renovation measures are to be implemented, and a performance review is to be carried out (e.g. through monitoring with QM for Biomass DH Plants).

18.3.3 Refurbishment not possible

The feasibility study may conclude that a refurbishment cannot be carried out or can only be carried out under very difficult conditions due to technical or administrative framework conditions. Reasons for this are, for example, a lack of space in the heating plant or on the property, expiring lease contracts, missing or unobtainable building or operating permits, significant changes in technical or legal framework conditions. In addition, it is possible that the economic viability of a refurbishment or the necessary financing cannot be secured. In such situations, other avenues must be explored to ensure future operation of the facility.

New construction of the heat generation plant
If the refurbishment of the existing heat generation plant is not possible, a decommissioning and completely new construction should be considered, either at the same or at another location in the area of the existing district heating network. This offers the possibility of a new planning process without technical and economic restrictions. In particular, this creates the possibility to densify and expand the existing heat network. The design of the new heat generation plant offers the opportunity to realise a system with lower operating and fuel costs because:

- more cost-effective fuel assortments can be used
- fuel and ash logistics can be redefined
- new heat carriers/heat sources can be included
- a heating technology and system dimensioning can be selected that achieves a high annual efficiency, enables low costs for maintenance and repair and has a large expansion potential in the long term.

Merging with other plants
It should also be considered whether existing problems could be solved by merging the existing heating network with another heating network in the vicinity instead of by refurbishment/new construction. If the capacity of the other heating plant is not sufficient for merging the two heating networks or the expansion potential is already exhausted, it can also be examined whether a new central heating plant for both heating networks can be built at a new location.

If there are several other heating networks in the immediate and wider vicinity of the existing heat generation plant, it should be examined whether a merger of all district heating networks would be conceivable and advantageous. Individual heating plants could be used together or a new central heating plant could be built at a suitable location.

Contracting

In the case of difficulties in carrying out a plant refurbishment, the involvement of a contractor can be an option. Practical experience has shown that specialised contractors can bring new concepts, business models and long-term development perspectives to a project and thus advance the revitalisation of old plants.

Some specialised contractors often already operate several biomass DH plants and district heating networks and have experience in assessing and revitalising existing plants. For example, synergies can be used and costs saved through centralised management, professional marketing, existing operating staff or existing fuel supply chains.

Appendix

19 Regulations

When constructing and operating a biomass heating plant, a wide range of requirements must be observed. It is the responsibility of the planner to know and apply local laws, ordinances, standards and guidelines as well as other regulations that must be observed. The following is a selection of relevant regulations for Switzerland, Germany and Austria. In addition to national regulations, international regulations may be relevant, for example International Organization for Standardization (ISO), European Committee for Standardization (CEN). The selection is based on the following topics, among others:

Fuel requirements

The fuel requirements of the listed regulations define, among other things, which fuels are permitted for which type of firing system.

Pollutant emissions

The emission of air pollutants such as dust and carbon monoxide, sometimes also nitrogen oxides and sulphur dioxide, is limited. Usually, the limits depend on the rated thermal input of a biomass heating plant and the fuel used.

Ash

The transport of wood ash, its possible utilisation as fertiliser and/or the disposal of the (filter) ashes are regulated by law. In the event of future recycling of ash, separate collection of ash fractions is necessary.

Health and safety

Accident prevention is always important. For example, it must be prevented that a person entering a wood fuel storage facility falls, gets buried or is injured by the conveyor system. The storage of moist fuel produces fermentation gases that can collect on the floor of the silo, hydraulic room and boiler room; hazardous areas must be equipped with suitable ventilation devices so that there is never a risk of asphyxiation for personnel. In some cases, the responsible authorities also prescribe CO warning devices for personal protection. A notice should be attached to wood chips storages indicating possible mould growth and pointing out the associated health hazard. When storing wood pellets in an enclosed space, a notice is necessary to indicate the risk of carbon monoxide formation. The handling of ash can also be associated with hazards and staff must be protected by taking appropriate measures (e.g. dust protection).

Hydraulic safety devices

The prevention of an impermissible rise in temperature or pressure in the hydraulic system of the heat generation, in particular in the boiler, must be ensured by the installation of safety devices.

Fire prevention

The development and spread of fire in the boiler room and fuel storage area must be prevented by providing suitable equipment and structural measures. Emergency exits must be available.

Noise protection

The effects of sound propagation (airborne sound and structure-borne sound) during the operation of a biomass heating plant must always be clarified and the regional noise protection regulations must be complied with. The main sources of noise are the exhaust fan, chimney top, silo discharge, conveying and transport technology and, if applicable, the preparation of the woodchip fuels on site. Noise emissions are to be reduced by suitable measures.

Lightning protection system

The biomass heating plant, machinery and district heating network must be protected against lightning by means of lightning and surge protection devices.

Explosion prevention

In hazardous areas with high explosion risk, constructive as well as operational preventive measures must be provided.

Regulations, ordinances, standards and guidelines in Switzerland

When implementing a heating system in Switzerland, numerous legal provisions, ordinances, guidelines and standards must be observed. The following is a selection of the regulations that are important for heating technology and for the utilisation of energy from biomass. No liability for any errors or omissions. Legal regulations must always be applied in the latest version.

Table 19.1 Regulations, ordinances, standards and guidelines in Switzerland (selection).

Topic	Short title	Title	Description
Demand assessment	SIA-Norm 380/1 SIA-Norm 384/1 /2 /3 SIA-Norm 385/1	Grundlagen für energetische Berechnungen von Gebäuden Heizungsanlagen in Gebäuden Anlagen für Trinkwarmwasser in Gebäuden – Grundlagen und Anforde-rungen	Basics for energy calculations of buildings Heating systems in buildings Installations for domestic hot water in buildings - Basic principles and requirements
Contractual arrangements	SIA 108 SIA 112 SIA 118	Ordnung für Leistungen und Honorare der Ingenieureinnen und Ingenieure der Bereichen Gebäudetechnik, Maschinenbau und Elektrotechnik Modell Bauplanung Allgemeine Bedingungen für Bauarbeiten	Regulations for Services and Fees of Engineers in the Fields of Building Technology, Mechanical and Electrical Engineering Building design General conditions for construction work
Fuel requirements	LRV EN ISO 17225	Luftreinhalte-Verordnung Feste Biobrennstoffe (ersetzt EN 14961)	Air Pollution Control Ordinance Solid biofuels (replaces EN 14961)
Emission requirements	LRV Cercl`Air	Luftreinhalte-Verordnung	Air Pollution Control Ordinance
	Empfehlung Nr. 31p	Vollzugsblätter Emissionsüberwachung Holzfeuerungen über 70 kW_{FWL}	Enforcement sheets, emission monitoring, biomass firing systems over 70 kW input capacity
Ash	VVEA	Verordnung über die Vermeidung und die Entsorgung von Abfällen	Ordinance on the Avoidance and Disposal of Waste
	VeVA	Verordnung über den Verkehr mit Abfällen	Ordinance on the Movement of Waste
Safety	Suva	Schweizerische Unfallversicherungsanstalt Grünschnitzelsilos (Best. Nr. 66050.D) Checkliste Grünschnitzelsilos (Best. Nr. 67006.D) Checkliste Holzspänesilos (Best. Nr. 67007.D) Merkblatt Explosionsschutz (www.suva.ch/2153.d) SUVA 88813 – Die acht lebenswichtigen Regeln der Instandhaltung	Swiss Accident Insurance Fund Green chips silos (order no. 66050.D) Checklist green chips silos Checklist wood shavings silos Leaflet on explosion prevention The eight vital rules of maintenance
	SWIKI	Schweizerischer Verein von Gebäudetechnik-Ingenieuren Richtlinie 91-1 Be- und Entlüftung von Heizräumen Richtlinie HE301-01 Sicherheitstechnische Einrichtung für Heizungsanlagen (ersetzt Richtlinie 91-1 mit Ergänzungen Nr.1 und 2) BT 102-01 Wasserbeschaffenheit für Gebäudetechnik-Anlagen Richtlinie HE200-01 Lagerung von Holzpellets beim Endkunden	Swiss association of Building Services Engineers Guideline ventilation of boiler rooms Guideline safety equipment for heating systems (replaces guideline 91-1 with supplements No.1 and 2) Water quality for building services installations Guideline storage of wood pellets at the end customer's premises
	SN EN 12779	Sicherheit von Holzbearbeitungsmaschinen - Ortsfeste Absauganlagen für Holzstaub und Späne - Sicherheitstechnische Anforderungen	Safety of woodworking machines - Stationary suction systems for wood dust and chips - Safety requirements

	DGUV-Information 209-083	Silos für das Lagern von Holzstaub und -spänen – Bauliche Gestaltung, Betrieb	Silos for the storage of wood dust and chips - Structural design, operation
	DGUV-Information 209-045	Absauganlagen und Silos für Holzstaub und -späne; Brand- und Explosionsschutz	Extraction systems and silos for wood dust and chips; Fire and explosion prevention
	BGI Informationen 739-2		
	DGV	Druckgeräteverordnung DGV (SR 930.114)	Pressure Equipment Ordinance
	proPellets.ch	Empfehlungen zur Lagerung von Holzpellets 2018	Recommendations for storing wood pellets
Fire prevention	VKF	Vereinigung Kantonaler Feuerversicherungen	Association of Cantonal Fire Insurers
		Brandschutzrichtlinie 24-15 Wärmetechnische Anlagen	Fire Protection Guideline Thermal Systems
		104-15 Spänefeuerungen	Shavings furnaces
		105-15 Schnitzelfeuerungen	Wood chips furnaces
		106-15 Pelletsfeuerungen	Pellet furnaces
		Abgasanlagen ff	Exhaust gas equipment
	Lokale feuerpolizeiliche Vorschriften		Local fire regulations
Noise reduction	LSV	Lärmschutz-Verordnung	Noise Abatement Ordinance
	SIA 181	Schallschutz im Hochbau	Sound insulation in building construction
Chimney cross-section and chimney height	LRV	Luftreinhalte-Verordnung	Air Pollution Control Ordinance
	SIA 384/4	Kamine für den Hausbrand	Chimneys for domestic use
	BAFU	Bundesamt für Umwelt	Federal Office for the Environment
		UV-1318-D Mindesthöhe von Kaminen über Dach	UV-1318-D Minimum height of chimneys above the roof

Regulations, ordinances, standards and guidelines in Germany

When implementing a heating system in Germany, numerous legal provisions, regulations, directives and standards must be observed. In addition to German law, European legal regulations and standards are becoming increasingly important. The following is a selection of the regulations that are important for heating technology and for the utilisation of energy from biomass. No liability for any errors or omissions. Legal regulations must always be applied in the latest version.

Table 19.2 Regulations, ordinances, standards and guidelines in Germany (selection).

Topic	Short title	Title	Description
Demand assessment	GEG	Gebäudeenergiegesetz	Building Energy Act
	DIN EN 12831-1	Heizungsanlagen in Gebäuden	Heating systems in buildings
	DIN V 18599	Energetische Bewertung von Gebäuden	Energy assessment of buildings
	DIN EN ISO 52016-1	Energetische Bewertung von Gebäuden	Energy assessment of buildings
	VDI 2067	Wirtschaftlichkeit gebäudetechnischer Anlagen	Efficiency of technical building systems
Contractual arrangements	BGB	Bürgerliches Gesetzbuch	Civil Code
	VgV	Vergabeverordnung	Procurement Ordinance
	VOB	Vergabe- und Vertragsordnung für Bauleistungen	German Construction Contract Procedures
	AVBFernwärmeV	Verordnung über allgemeine Bedingungen für die Versorgung mit Fern-wärme	Ordinance on general conditions for the supply of district heating
	HeizKV	Verordnung über verbrauchsabhängige Abrechnung der Heiz- und Warmwasserkosten	Heating Ordinance on consumption-based billing of heating and hot water costs
	HOAI	Honorarordnung für Architekten und Ingenieure	Scale of fees for architects and engineers
Fuel requirements	BImSchG	Bundes-Immissionsschutzgesetz	Federal Immission Control Act
	TA Luft	Technische Anleitung zur Reinhaltung der Luft	Instructions on Air Quality Control
	1. BImSchV	Verordnung über kleine und mittlere Feuerungsanlagen	Ordinance on small and medium-sized combustion plants
	4. BImSchV	Verordnung über genehmigungsbedürftige Anlagen	Ordinance on Installations Requiring a Permit
	13. BImSchV	Verordnung über Grossfeuerungs-, Gasturbinen- und Verbrennungsmotoranlagen	Ordinance on Large Combustion Plants, Gas Turbines and Internal Combustion Engines
	44. BImSchV	Verordnung über mittelgrosse Feuerungs-, Gasturbinen- und Verbrennungsmotoranlagen	Ordinance on medium-sized combustion, gas turbine and internal combustion engine plants
	DIN EN ISO 17225	Biogene Festbrennstoffe (ersetzt DIN EN 14961)	Biogenic solid fuels (replaces DIN EN 14961)
Emission and immission requirements	BImSchG	see above	see above
	TA Luft		
	1. BImSchV		
	4. BImSchV		
	13. BImSchV		
	44. BImSchV		
	VDI 2066	Messen von Partikeln	Measurement of particles
	VDI 3462-4	Emissionsminderung	Emissions reduction
	VDI 3253	Emissionen aus stationären Quellen: Methoden zum qualitativen Nachweis des kontinuierlichen effektiven Betriebs von Staubabscheidern bei Feuerungsanlagen für feste Brennstoffe mit einer Feuerungswärmeleistung zwischen 1 MW und weniger als 5 MW	Emissions from stationary sources: Methods for the qualitative demonstration of the continuous effective operation of dust collectors in combustion plants for solid fuels with a rated thermal input between 1 MW and less than 5 MW
	AwSV	Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen	Ordinance on Installations for Handling Substances Hazardous to Water
	BBodSchV	Bundes-Bodenschutz- und Altlastenverordnung	Federal Soil Protection and Contaminated Sites Ordinance

	KrWG	Kreislaufwirtschaftsgesetz	German Closed Substance Cycle Waste Management Act
	DüG	Düngegesetz	Fertiliser Act
	AVV	Abfallverzeichnis-Verordnung	Waste Catalogue Ordinance
	BioAbfV	Bioabfallverordnung	Biowaste Ordinance
	DepV	Deponieverordnung	Landfill Ordinance
	DüMV	Düngemittelverordnung	Fertiliser Ordinance
	DüV	Düngeverordnung	Fertilising Ordinance
	NachwV	Nachweis-Verordnung	Verification Ordinance
Safety	UVV	Unfallverhütungsvorschriften	Accident prevention regulations
	DGUV	DGUV Vorschriften- und Regelwerk	German Statutory Accident Insurance Rules and Regulations
	MRL	Maschinen-Richtlinie	Machinery Directive
	DGRL	Druckgeräte-Richtlinie	Pressure Equipment Directive
	Niederspannungs-RL	Niederspannungsrichtlinie	Low-Voltage Directive
	EMV-RL	Elektromagnetische Verträglichkeit-Richtlinie	Electromagnetic Compatibility Directive
	REACH	REACH-Verordnung	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation
	BetrSichV	Betriebssicherheitsverordnung	Ordinance on Industrial Safety and Health
	DIN EN ISO 12100	Sicherheit von Maschinen	Safety of machinery
	DIN EN 303-5	Heizkessel – Heizkessel für feste Brennstoffe, manuell und automatisch beschickte Feuerungen, Nennwärmeleistung bis 500 kW – Begriffe, Anforderungen, Prüfung und Kennzeichnung	Heating boilers - Boilers for solid fuels, manually and automatically fired, nominal heat input not exceeding 500 kW - Definitions, requirements, testing and marking
	DIN EN 12828	Heizungsanlagen in Gebäuden – Planung von Wasserheizungsanlagen	Heating systems in buildings - Design of water heating systems
	DIN EN 61000	Elektromagnetische Verträglichkeit (EMV)	Electromagnetic compatibility (EMC)
	DIN 4747	Fernwärmeanlagen	District heating systems
	VDI 2694	Bunker und Silos	Bunkers and silos
	VDI 2035	Verhütung von Schäden durch Korrosion und Steinbildung in Warm-wasserheizungsanlagen	Prevention of damage due to corrosion and scale formation in hot water heating systems
	VDI 3464	Lagerung von Holzpellets beim Verbraucher - Anforderungen an Lager sowie Herstellung und Anlieferung der Pellets unter Gesundheits- und Sichereitsaspekten	Storage of wood pellets at the consumer - Requirements for storage as well as production and delivery of the pellets under health and safety aspects
	AGFW-FW	AGFW-Regelwerk	AGFW Rulebook
	DEPV	Leitfaden zur Lagerung von Holzpellets	Guideline for the storage of wood pellets
Fire and explosion prevention	MBO	Musterbauordnung	Model Building Code
	FeuV	Feuerungsverordnung	Firing Ordinance
	VVB	Verordnung über die Verhütung von Bränden	Ordinance on the Prevention of Fires
	ATEX	ATEX-Herstellerrichtlinie, ATEX-Betriebsrichtlinie	ATEX (ATmosphères Explosives) manufacturer's directive, ATEX operating directive
	ISO 8421	Brandschutz, Begriffe	Fire prevention, terms
	DIN EN 1127	Explosionsfähige Atmosphären - Explosionsschutz	Explosive atmospheres - Explosion prevention
	DIN 4102	Brandverhalten von Baustoffen und Bauteilen	Fire behaviour of building materials and components
	VDI 2263	Staubbrände und Staubexplosionen	Dust fires and dust explosions
Noise protection	BImSchG	Bundes-Immissionsschutzgesetz	Federal Immission Control Act
	TA Lärm	Technische Anleitung zum Schutz gegen Lärm	Technical Instructions for Protection against Noise
	AGFW-FW	AGFW-Regelwerk	AGFW set of rules
Chimney	TA Luft	Technische Anleitung zur Reinhaltung der	Technical Instructions on Air Quality Control

		Luft	
	DIN EN 13084	Freistehende Schornsteine	Free-standing chimneys
	DIN EN 13384	Abgasanlagen – Wärme- und strömungstechnische Berechnungsverfahren	Exhaust systems - Thermal and fluidic calculation methods
	DIN 1298	Abgasanlagen - Verbindungsstücke für Feuerungsanlagen	Exhaust systems - Connecting pieces for combustion systems
	DIN 18160	Abgasanlagen	Exhaust systems
	VDI 3781-4	Ableitbedingungen für Abgase	Discharge conditions for exhaust gases
Lightning protection	DIN EN 61643	Überspannungsschutzgeräte für Niederspannung	Low-voltage surge protection devices

Regulations, ordinances, standards and guidelines in Austria

When implementing a heating system in Austria, numerous legal provisions, ordinances, guidelines and standards must be observed. The following is a selection of the most important regulations in Austria for heating technology and for the utilisation of energy from biomass. No liability for any errors or omissions.

Legal provisions must always be applied in the latest version. Austrian laws and ordinances can be retrieved free of charge at http://www.ris.bka.gv.at. Nationally applicable standards and guidelines are issued by the following bodies, among others:

- Austrian Standards Institute (Austrian Standards) - http://www.austrian-standards.at
- Austrian Association for Electrical Engineering (ÖVE) - http://www.ove.at
- Austrian Board of Trustees for Agricultural Engineering and Rural Development (ÖKL) - http://www.oekl.at
- Austrian Noise Abatement Working Group (ÖAL) - http://www.oal.at
- Prüfstelle für Brandschutztechnik - http://www.pruefstelle.at, Allgemeine Unfallversicherungsanstalt (AUVA) - http://www.auva.at.

Table 19.3 Regulations, ordinances, standards and guidelines in Austria (selection).

Topic	Short title	Title	Description
Plant operation	GewO	Gewerbeordnung	Trade regulations
	NSG	Naturschutzgesetze der Länder	Nature conservation laws
Demand assessment and conception	ÖNORM EN ISO 52016	Energetische Bewertung von Gebäuden	Energy assessment of buildings
	ÖNORM EN 12828	Heizungsanlagen in Gebäuden - Planung von Warmwasser-Heizungsanlagen	Heating systems in buildings -
	ÖNORM H 5151-1	Planung von zentralen Warmwasser-Heizungsanlagen mit oder ohne Warmwasserbereitung - Teil 1: Gebäude mit einem spezifischen Transmissionsleitwert über 0,5 W/(K.m²) - Ergänzungsnorm zu ÖNORM EN 12828	Design of domestic hot water heating systems
	ÖNORM EN 12831-1	Heizungsanlagen in Gebäuden - Verfahren zur Berechnung der Norm-Heizlast	Heating systems in buildings - Method for calculating the standard heating load
	ÖNORM H 7500-1	Heizungssysteme in Gebäuden - Verfahren zur Berechnung der Norm-Heizlast für Gebäude mit einem mittleren U -Wert >= 0,5 W/(m2 · K) - Nationale Ergänzung zu ÖNORM EN 12831-1	Heating systems in buildings - Procedure for calculation of standard heating load for buildings
	ÖNORM H 7500-3	Heizungssysteme in Gebäuden - Teil 3: Vereinfachtes Verfahren zur Berechnung der Norm-Gebäudeheizlast	Heating systems in buildings - Part 3: Simplified method for calculation of standard building heating load
	ÖNORM H 5142	Haustechnische Anlagen - Hydraulische Schaltungen für Warmwasser-Heizungsanlagen, Kühlsysteme und solarthermische Anlagen	Building services - hydraulic circuits for hot water heating systems, cooling systems and solar thermal systems
	ÖNORM B 2503	Kanalanlagen - Ergänzende Richtlinien	Sewer systems - Supplementary guidelines
	ÖNORM B 2506	Regenwasser-Sickeranlagen	Rainwater seepage systems
	ÖNORM H 5050	Gesamtenergieeffizienz von Gebäuden	Overall energy performance of buildings
	OIB-RL 6/2019	Energieeinsparung und Wärmeschutz	Guidelines on energy saving and thermal insulation for buildings of the Austrian Institute of Construction Engineering
	ÖNORM M 7140	Betriebswirtschaftliche Vergleichsrechnung für Energiesysteme nach dynamischen Rechenmethoden	Comparative economic calculation for energy systems according to dynamic calculation methods
	ÖKL-Merkblatt Nr. 67	Planung von Biomasseheizwerken und Nahwärmenetzen	Leaflet on planning of biomass heating plants and local heating networks

	VDI 2067	Wirtschaftlichkeit gebäudetechnischer Anlagen	Efficiency of technical building systems
Contractual arrangements	BVerG	Bundesvergabegesetz	Federal Procurement Act
	HeizKG	Heizkostenabrechnungsgesetz	Heating Cost Settlement Act
	ÖNORM A 2050	Vergabe von Aufträgen über Leistungen - Ausschreibung, Angebot und Zuschlag – Verfahrensnorm	Award of contracts for services - Invitation to tender, tender and contract award - Procedural standard
	ÖNORM A 2060	Allgemeine Vertragsbestimmungen für Leistungen – Vertragsnorm	General contractual provisions for services - Contract standard
Fuel requirements	ÖNORM EN ISO 17225	Biogene Festbrennstoffe	Biogenic solid fuels
	ÖNORM C4005	Holzhackgut und Schredderholz für die energetische Verwertung in Anlagen mit einer Nenn-Wärmeleistung über 500 kW - Anforderungen und Prüfbestimmungen - Nationale Ergänzung zu ÖNORM EN ISO 17225-1	Wood chips and shredder wood for energy recovery in plants with a rated thermal input exceeding 500 kW - Requirements and test specifications - National supplement to ÖNORM EN ISO 17225-1
	ÖNORM M 7132	Energiewirtschaftliche Nutzung von Holz und Rinde als Brennstoff – Begriffsbestimmungen und Merkmale	Energy recovery from wood and bark as fuel - Definitions and characteristics
	ÖNORM S2100	Abfallverzeichnis	List of waste
Emission and immission requirements	FAV	Feuerungsanlagenverordnung	Firing Installations Ordinance
	AWG	Abfallwirtschaftsgesetz u. Abfallwirtschaftskonzept (AWK)	Waste Management Act and Waste Management Concept (AWK)
	IG-L	Immissionsschutzgesetz - Luft	Air Pollution Act
	WRG	Wasserrechtsgesetz	Water Act
	AAEV	Allgemeine Abwasseremissionsverordnung	General Waste Water Emission Ordinance
	IEV	Indirekteinleiterverordnung	Indirect Discharger Ordinance
	RL 2000/76/EG	Richtlinie über die Verbrennung von Abfällen	EC Directive on the incineration of waste
Ash	AWG	Abfallwirtschaftsgesetz	Waste Management Law
	KPV	Kompostverordnung	Compost Ordinance
	AVV	Abfallverzeichnisverordnung	Waste Catalogue Ordinance
	AbfallbilanzV	Abfallbilanzverordnung	Waste Balance Sheet Ordinance
	ALSAG	Altlastensanierungsgesetz	Act on the Remediation of Contaminated Sites
	DMG	Düngemittelgesetz	Fertilisers Act
	ForstG	Forstgesetz	Forest Act
	WRG	Wasserrechtsgesetz	Water Act
		Ascherichtlinien der Länder	Ash guidelines of the countries
Noise protection	ÖNORM B 8115	Schallschutz und Raumakustik im Hochbau	Sound insulation and room acoustics in building construction
	ÖAL-Richtlinien	Richtlinien des Österreichischen Arbeitsring für Lärmbekämpfung	Guidelines of the Austrian Working Group for Noise Abatement
Safety	AschG	ArbeitnehmerInnenschutzgesetz	Employee Protection Act
	BauKG	Bauarbeitenkoordinationsgesetz	Construction Work Coordination Act
	ETG	Elektrotechnikgesetz	Electrical Engineering Act
	AAV	Allgemeine Arbeitnehmerschutzverordnung	General Employee Protection Ordinance
	AstV	Arbeitsstättenverordnung	Workplace Ordinance
	BauV	Bauarbeiterschutzverordnung	Construction Worker Protection Ordinance
	DDGVO	Duale Druckgeräteverordnung	Pressure Equipment Ordinance
	ETV	Elektrotechnikverordnung	Electrical Engineering Ordinance
	ESV	Elektroschutzverordnung	Electrical Safety Ordinance
	ÖNORM EN 303-5	Heizkessel – Heizkessel für feste Brennstoffe, manuell und automatisch beschickte Feuerungen, Nennwärmeleistung bis 500 kW – Begriffe, Anforderungen, Prüfung und	Boilers - Solid fuel boilers, manually and automatically fired, nominal heat input not exceeding 500 kW - Definitions, requirements, testing and marking

		Kennzeichnung	
	ÖNORM M 7510-4	Überprüfung von Heizungsanlagen – Einfache Überprüfung von Feuerungsanlagen für feste Brennstoffe	Inspection of heating systems - Simple inspection of firing systems for solid fuels
	ÖVE E 8120	Verlegung von Energie-, Steuer- und Messkabeln	Laying of power, control and measuring cables
	ÖVE/ÖNORM E 8200-627	Vieladrige und vielpaarige Kabel für die Verlegung in Luft und in Erde	Multicore and multipair cables for installation in air and in earth
	ÖVE EN 50110	Betrieb von elektrischen Anlagen	Operation of electrical installations
	DIN EN 61000	Elektromagnetische Verträglichkeit (EMV)	Electromagnetic compatibility (EMC)
	AUVA-Merkblätter	Sicherheitsinformationen der Allgemeinen Unfallversicherungsanstalt	Safety information of the General Accident Insurance Institution
	ÖNORM EN ISO 20023	Biogene Festbrennstoffe - Sicherheit von Pellets aus biogenen Fest-brennstoffen - Sicherer Umgang und Lagerung von Holzpellets in häuslichen- und anderen kleinen Feuerstätten	Biogenic solid fuels - Safety of pellets from biogenic solid fuels - Safe handling and storage of wood pellets in domestic and other small combustion plants
	ÖNORM H5195-1	Wärmeträger für haustechnische Anlagen - Teil 1: Verhütung von Schäden durch Korrosion und Steinbildung in geschlossenen Warmwasser-Heizungsanlagen	Heat transfer media for domestic installations - Part 1: Prevention of damage by corrosion and scale formation in closed hot water heating systems
Fire prevention	ÖNORM EN 1366	Feuerwiderstandsprüfung für Installationen	Fire resistance test for installations
	ÖNORM B 3800	Brandverhalten von Baustoffen und Bauteilen	Fire behaviour of building materials and components
	ÖNORM F 1000	Feuerwehrtechnik und Brandschutzwesen	Firefighting and fire prevention technology
	ÖNORM H 5170	Heizungsanlagen – Anforderungen an die Bau- und Sicherheitstechnik sowie an den Brand- und Umweltschutz	Heating installations - Requirements for construction and safety engineering and to fire and environmental protection
	TRVB H118	Automatische Holzfeuerungen	Automatic biomass furnaces
	TRVB	Technische Richtlinien vorbeugender Brandschutz	Technical Guidelines for Preventive Fire Protection
Lightning protection	ÖVE E 40/1987	Schutz von Erdern und erdverlegten Metallteilen gegen Korrosion	Protection of earth electrodes and buried metal parts against corro-sion
	ÖVE/ÖNORM E 8049	Blitzschutz baulicher Anlagen	Lightning protection of structures
Explosion prevention	ExSV 2015	Explosionsschutzverordnung	Explosion Protection Ordinance
	ElExV 1993	Elektro-Ex-Verordnung	Explosion protection for electrical equipment
Chimney	ÖNORM M 9440	Ausbreitung von luftverunreinigenden Stoffen in der Atmosphäre – Berechnung von Immissionskonzentrationen	Dispersion of air pollutants in the atmosphere - Calculation of ambient air concentrations
	DIN EN 13384	Abgasanlagen – Wärme- und strömungstechnische Berechnungsverfahren	Exhaust systems - Thermal and fluidic calculation methods

20 Important calculations and conversions

20.1 Excess air ratio Lambda

The excess air ratio (λ) describes the ratio between supplied and stoichiometric (= theoretical minimum required) combustion air volume:

$$\lambda = \frac{\text{supplied combustion air volume}}{\text{stoichiometric combustion air volume}} \quad [-]$$

The excess air ratio influences the combustion quality and the combustion temperature. It can be calculated from the exhaust gas composition [60]. In the simplified procedure, the following formulas can be derived to calculate lambda:

$$\lambda = \frac{21}{21 - O_2 + 0.4\ CO} \quad [-]$$

or

$$\lambda = \frac{20.4}{CO_2 + CO} \quad [-]$$

and

$$O_2 = 21 - CO_2 - 0.6\ CO \quad [-]$$

with:				
	CO_2	=	carbon dioxide concentration in dry exhaust gas	[vol-%]
	CO	=	carbon monoxide concentration in dry exhaust gas	[vol-%]
	O_2	=	Oxygen concentration in dry exhaust gas	[vol-%]
	20.4	=	$CO_{2\ max}$ (= maximum possible CO_2-content in exhaust gas)	[vol-%]
	21	=	Oxygen concentration of air	[vol-%]

Example:

Measured variables:	CO_2	=	9.0 vol-%
	CO	=	250 ppm = 0.025 vol-%

Calculation:

$$\lambda = \frac{21}{21 - 9 - 0.6 * 0.025} = 1.75 \quad [-]$$

Assessment: On the one hand, the excess air ratio lambda (λ) should be as low as possible (high combustion efficiency), on the other hand, it must not be too low, because with an insufficient quantity of combustion air, the combustion quality deteriorates drastically and the combustion temperature rises into a critical range (danger of slagging).

The excess air coefficient is typically λ ≈ 1.6 - 2.2 for biomass furnaces.

Note: The so-called 'lambda sensors' measure the oxygen content or the excess air ratio in the moist exhaust gas. The conversion to dry exhaust gas can be found in Chapter 20.5.

20.2 Conversion from ppm to mg/m³

Emission measuring instruments for CO, HC and NO_x usually indicate the measured values in **vol-%** or in **ppm**. The unit ppm (ppm = **p**arts **p**er **m**illion = 1 : 1,000,000 = one millionth) corresponds, like vol-%, to the *volume fraction* of a gas and is thus independent of gas temperature and pressure. The conversion from vol-% to ppm can be made according to Table 20.1.

Table 20.1 Conversion from vol-% to ppm

vol.-%	ppm
100	1,000,000
10	100,000
1	10,000
0.1	1,000
0.01	100
0.001	10
0.0001	1

The emission limit values are usually not given in volume units, but in mg/m^3. The conversion from **ppm** to **mg/m^3** is done by multiplication with the **density** of the respective gas component. As the values are to be given at standard conditions (temperature = 0 °C, pressure = 1013 mbar), the conversion is made with the standard density (molar mass / standard volume), i.e. the density at standard conditions.

emission value [mg/m^3] = standard density in kg/m^3 * emission value in ppm

CO [mg/m^3] = **1.25** kg/m * CO [ppm]

NO_x [mg/m^3] = **2.05** kg/m * NO_x [ppm] (NO_x given as NO_2 ≈ 2.05 kg/m^3)

HC* [mg/m^3] = **0.54** kg/m * HC [ppm] (for CH_4 as calibration gas ≈ 0.54 kg/m^3)

HC* [mg/m^3] = **1.62** kg/m * HC [ppm] (for C_3H_8 as calibration gas ≈ 1.62 kg/m^3)

* Gaseous organic substances, to be indicated as total carbon (C)

Example: Conversion of CO concentration (without conversion to reference oxygen content)

Measured value: CO = 200 ppm

Calculation: **CO** [mg/m^3] = 1.25 kg/m^3 * CO [ppm] = 1.25 kg/m^3 * 200 ppm = **250 mg/m^3**

20.3 Oxygen reference value

For the comparison of emissions from different furnaces or different tests on the same unit, a reference value is required. Without conversion of the emission values to a reference value, no comparison with other data is possible. The oxygen content O_2 in the dry flue gas is defined as the reference value. The reference oxygen content is country-specific and depends on the size of the plant. In the Ordinance on Air Pollution Control (Luftreinhalte-Verordnung LRV), a reference oxygen content of 13% applies up to a rated thermal input of 1 MW, and 11% applies above this. In the European standard EN 303-5 for biomass systems, a reference oxygen content of 10 % applies up to a rated thermal output of 500 kW. In the 44. BimSchV, a reference oxygen content of 6 % applies to medium-sized biomass systems with a rated thermal input of over 1 MW.

Table 20.2 Conversion of vol-% $O_{2\ reference}$ to $\lambda_{reference}$

Vol-% $O_{2,ref}$	λ_{ref}
13	2.625
11	2.100
10	1.910
6	1.400

Emission measurement values must be converted to the defined reference quantity, i.e. to standard conditions and to the reference oxygen content. This prevents lower emission values from being determined by diluting the exhaust gases with false air (e.g. at the chimney inlet upstream sampling for emission measurement). Through the conversion, the measured values are converted to a specified dilution according to the corresponding reference oxygen content. The conversion is carried out according to the following scheme:

$$\text{Emission value}\left[\frac{mg}{m^3}\right] \text{ at reference } O_2 \text{ content} = \text{emission value}[ppm] * \text{standard density}\left[\frac{kg}{m^3}\right] * \frac{21 - O_{2,ref}\ [\%]}{21 - O_{2\ measured}\ [\%]}$$

This is equivalent to a conversion from the measured λ to the λ according to the reference O_2 content. The calculation of λ can be done by measuring O_2 or CO_2. To calculate λ_{ref}, the corresponding oxygen content $O_{2,ref}$ is used.

$$\text{Emission value}\left[\frac{mg}{m^3}\right] \text{ at reference } O_2 \text{ content} = \text{emission value } [ppm] * \text{standard density}\left[\frac{kg}{m^3}\right] * \frac{\lambda_{measured}}{\lambda_{ref}}$$

Example: Calculation of CO concentration with reference oxygen content

Measured variables:	CO	=	200 ppm	
	O_2	=	9.0 vol-%	(λ = 1.75)
Reference value:	$O_{2,ref}$	=	13 vol-%	(λ_{ref} = 2.625)

Calculation:

$$\text{CO emission value} = 200\ ppm * 1.25\frac{kg}{m^3} * \frac{21\% - 13\%}{21\% - 9\%} = 167\ \frac{mg}{m^3} \text{ at } 13\%\ O_2$$

or

$$\text{CO emission value} = 200\ ppm * 1.25\frac{kg}{m^3} * \frac{1.75}{2.625} = 167\ \frac{mg}{m^3} \text{ at } 13\%\ O_2$$

Conversion to a different reference oxygen content

Depending on the legal requirements and performance classes, different emission limit values with different reference oxygen contents apply. Table 20.3 can be used to convert emission values, given in mg/m³ in relation to a specific reference oxygen content, to another common reference oxygen content.

Table 20.3 Conversion of an emission value to a different reference oxygen content.

Reference oxygen content in vol-%	0	1	2	3	4	5	**6**	7	8	9	**10**	**11**	12	**13**	14	15	16
0																	
1																	
2																	
3																	
4																	
5																	
6	140.0	133.3	126.7	120.0	113.3	106.7	**100**	93.3	86.7	80.0	**73.3**	**66.7**	60.0	**53.3**	46.7	40.0	33.3
7																	
8																	
9																	
10	190.9	181.8	172.7	163.6	154.5	145.5	**136.4**	127.3	118.2	109.1	**100**	**90.9**	81.8	**72.7**	63.6	54.5	45.5
11	210.0	200.0	190.0	180.0	170.0	160.0	**150.0**	140.0	130.0	120.0	**110.0**	**100**	90.0	**80.0**	70.0	60.0	50.0
12																	
13	262.5	250.0	237.5	225.0	212.5	200.0	**187.5**	175.0	162.5	150.0	**137.5**	**125.0**	112.5	**100**	87.5	75.0	62.5
14																	
15																	
16																	

Reading example: 100 mg/m³ at reference oxygen content 10 vol-% equal 90.9 mg/m³ at 11 vol-% O_2 and 136.4 mg/m³ at 6 vol-% O_2

Example: Conversion of the CO emission value given at a reference oxygen content of 11 % by volume to a reference oxygen content of 6 % by volume.

Initial value: CO emission value = 180 mg/m³ based on 11 vol.% O_2

According to Table 20.3

CO emission value = 100 mg/m³ related to 11 vol.% O_2 corresponds to

CO emission value = 150 mg/m³ related to 6 vol.% O_2

The CO emission value converted to 6 vol.% O_2 is therefore:

$$\text{Emission value new} = \text{emission value initial} * \frac{\text{emission value Table 20.1 new}}{\text{emission value Table 20.1 inititial}}$$

$$= 180\,\frac{mg}{m^3} * \frac{150\,\frac{mg}{m^3}}{100\,\frac{mg}{m^3}} = 270\,\frac{mg}{m^3} \text{ at 6 vol-\%} O_2$$

20.4 Conversion from mg/m³ to mg/MJ

For the comparison of emission loads of different fuels, e.g. oil and wood, emissions are related to the *amount of energy produced* [mg/MJ_{useful} or mg/kWh_{useful}]. The quotient of emission and energy amount is also called emission factor. It should be noted that the amount of energy supplied [mg/MJ_{end}] is also used as a reference parameter. The two parameters are linked via the efficiency or the annual efficiency.

The specification of emissions in mg/MJ is common in many countries, so that a conversion from mg/m^3 to mg/MJ is necessary for the international comparison of measured values.

When converting from mg/m^3 to mg/MJ, it should be noted that the amount of energy supplied in the case of biomass combustion depends on the calorific value and thus also on the fuel water content. This means that a correct conversion is only possible if the calorific value and the fuel water content are known. The conversion to the supplied fuel energy or useful heat can then be carried out as follows:

$$\text{emission value}\left[\frac{mg}{MJ_{End}}\right] = \text{emission value}\left[\frac{mg}{m^3}\right] \text{at } O_{2,ref} \ * \ \frac{\lambda_{ref} \ * \ V_{air\,min}}{18.3 - 2.442 \ * \ \frac{M}{100 - M}}$$

$$\text{emission value}\left[\frac{mg}{MJ_{useful}}\right] = \frac{\text{emission value}\left[\frac{mg}{MJ_{End}}\right] * 100\%}{\eta_a}$$

with:	λ_{ref}	=	excess air ratio at $O_{2,ref}$	[-]
	$V_{air\ min}$	=	stoichiometric combustion air volume = 4.58	[m^3/kg]
	M	=	fuel water content	[wt-%]
	η_a	=	annual efficiency	[%]

Example: Conversion of CO concentration from mg/m³ at reference oxygen content to mg/MJ

Initial value: CO = 100 mg/m^3 at 11 vol%.

M = 25 wt-%

λ_{ref} = 2.1

η_a = 85 %

$$\text{CO emission value}\left[\frac{mg}{MJ_{end}}\right] = 100 \ * \ \frac{2.1 \ * \ 4.58}{18.3 - 2.442 \ * \ \frac{25}{100 - 25}} = 55 \ \frac{mg}{MJ_{end}}$$

$$\text{CO emission value}\left[\frac{mg}{MJ_{useful}}\right] = \frac{55 \ \frac{mg}{MJ_{end}} \ * \ 100\%}{85\%} = 65 \ \frac{mg}{MJ_{useful}}$$

20.5 Conversion from moist to dry exhaust gas

In some emission measuring instruments, e.g. hydrocarbon measuring instruments based on flame ionization detection (FID) or NO_x measuring instruments based on chemiluminescence detection (CLD), the measurement is carried out in the hot, moist exhaust gas. The reason for this is that during the usual cooling of the exhaust gas upstream of the emission measuring instrument in a gas cooler to approx. 5°C, some of the substances to be measured pass into the liquid condensate and therefore falsify the measured value in the measuring instrument. Since the emission limit values apply to dry exhaust gas at standard conditions (0 °C, 1013 mbar), a conversion to dry exhaust gas must be carried out when measuring in wet exhaust gas, as the water vapour otherwise leads to a dilution of the emissions. For velocity measurements in hot, wet exhaust gas, temperature and pressure compensation must be performed in addition to the humidity correction.

The conversion factor f can be calculated with knowledge of the excess air ratio λ (in the dry flue gas) and the fuel water content M according to the following equation [54]:

$$\text{conversion factor f} = \frac{\text{volume flow wet exhaust gas}}{\text{volume flow dry exhaust gas}}$$

$$\text{conversion factor f} = 1 + \frac{0.287}{\lambda} * \left(\frac{M}{100 - M} + 0.512\right)$$

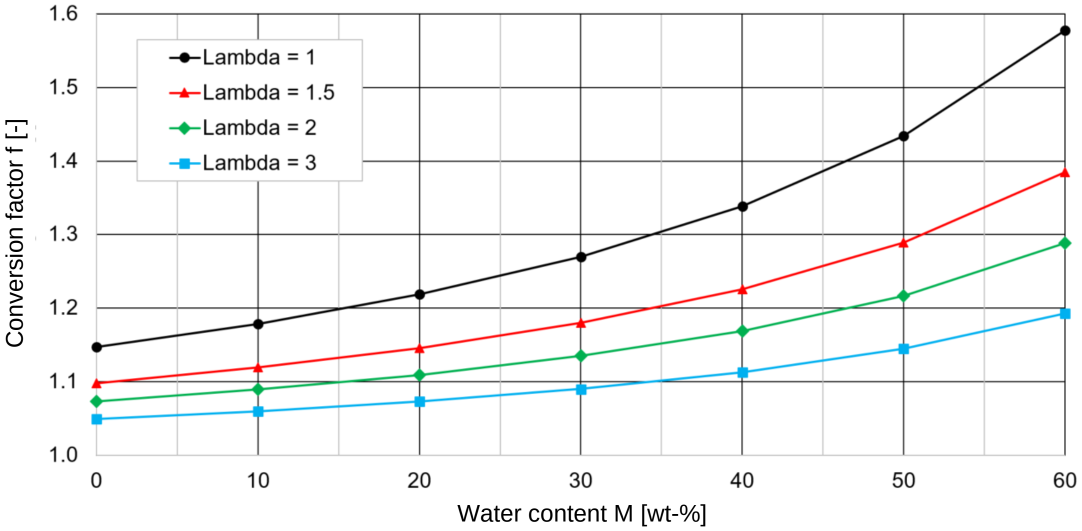


Figure 20.1 Conversion factor f as a function of fuel water content M.

Example: Conversion of the hydrocarbon concentration from moist exhaust gas to dry exhaust gas

Measured values:	Hydrocarbon concentration in wet exhaust gas HC_w	=	100 ppm
	Water content M	=	35 wt-%
	Oxygen (O_2)	=	7.0 vol-% (λ = 1.5)
	Reference oxygen content $O_{2,ref}$	=	11 vol-% (λ_{ref} = 2.1)
	Conversion factor f from Figure 20.1	=	1.2
	Calibration gas Propane (C_3H_8) standard density	=	1.62 kg/m^3

Calculation:

$$\text{hydrocarbon concentration} = \text{hydrocarbon concentration wet } HC_w * \text{conversion factor f} * \text{standard density} * \frac{\lambda}{\lambda_{ref}}$$

$$= 100\text{ ppm} * 1.2 * 1.62\ \frac{kg}{m^3} * \frac{1.5}{2.1} = 139\ \frac{mg}{m^3}\ \text{at } 11\%\ O_2$$

Note: With many commercially available measuring instruments based on IR and UV detection for CO, NO_x, CO_2, as well as based on paramagnetism for O_2, the measurement is carried out in dry exhaust gas; the conversion from moist to dry exhaust gas is not necessary in this case.

20.6 Determination of nominal heat output

The nominal heat output is the heat capacity delivered by a firing system to the boiler water when the firing system is operating at nominal load. It can be measured directly by means of a heat meter:

$$\dot{Q}_N = (T_{flow} - T_{return}) * c_{pW} * \dot{m}_W$$

The nominal heat output can also be determined by the boiler efficiency, the calorific value and the fired fuel mass flow:

$$\dot{Q}_N = \eta_{boiler} * NCV * \dot{m}_{fuel}$$

If the fired fuel mass flow rate is not known, it can be determined indirectly by measuring the excess air and the volumetric flow rate of the combustion air or the dry flue gases.

With

$$\dot{m}_{fuel} = \frac{\dot{V}_{exh-gas\,d.b.} * \left(1 + \frac{M}{100 - M}\right)}{\lambda * V_{air\,min}}$$

follows

$$\dot{Q}_N = \eta_{boiler} * NCV * \frac{\dot{V}_{exh-gas\,d.b.} * \left(1 + \frac{M}{100 - M}\right)}{\lambda * V_{air\,min}}$$

with:	$\dot{Q}_N$	=	nominal heat output	[kW]
	T_{flow}	=	flow temperature	[°C]
	T_{return}	=	return temperature	[°C]
	c_{pW}	=	specific heat capacity of water = 4.182	[kJ/kg K]
	$\dot{m}_W$	=	mass flow (boiler) water	[kg/s]
	η_{boiler}	=	boiler efficiency	[-]
	NCV	=	net calorific (lower heating) value	[kJ/kg]
	$\dot{m}_{fuel}$	=	mass flow of the wet fuel	[kg/s]
	$\dot{V}_{exh-gas\,d.b.}$	=	dry exhaust gas volume flow	[m^3/s]
	M	=	fuel water content	[wt-%]
	λ	=	excess air ratio	[-]
	$V_{air\,min}$	=	stoichiometric combustion air volume = 4.58	[$m^3/kg_{fuel\,d.b.}$]

The dry exhaust gas volume flow cannot be measured directly. By measuring the velocity, e.g. using a pitot tube, with the knowledge of the composition of the exhaust gas, the wet volume flow can be discovered. The conversion to dry exhaust gas requires the value of the exhaust gas water content, which is either determined (directly) in the exhaust gas or (in-directly) via the fuel water content.

20.7 Determination of fuel mass flow

The wet fuel mass flow in kilograms per hour is given by the nominal heat output of a combustion plant, the boiler efficiency η_{boiler} and the net calorific value NCV:

$$\dot{m}_{fuel} = \frac{\dot{Q}_N}{\eta_{boiler} * NCV} = \frac{3600}{1000} * \frac{\dot{Q}_N}{\eta_{boiler}} * \frac{1 + \frac{M}{100 - M}}{18.3 - 2.442 \frac{M}{100 - M}}$$

with:	$\dot{m}_B$	=	wet fuel mass flow	[kg/h]
	$\dot{Q}_N$	=	nominal heat output	[kW]
	η_{boiler}	=	boiler efficiency	[-]
	NCV	=	net calorific (lower heating) value	[MJ/kg]
	M	=	fuel water content	[wt-%]

The fuel mass flow necessary to generate a desired nominal heat output depends essentially on the water content or calorific value of the fuel.

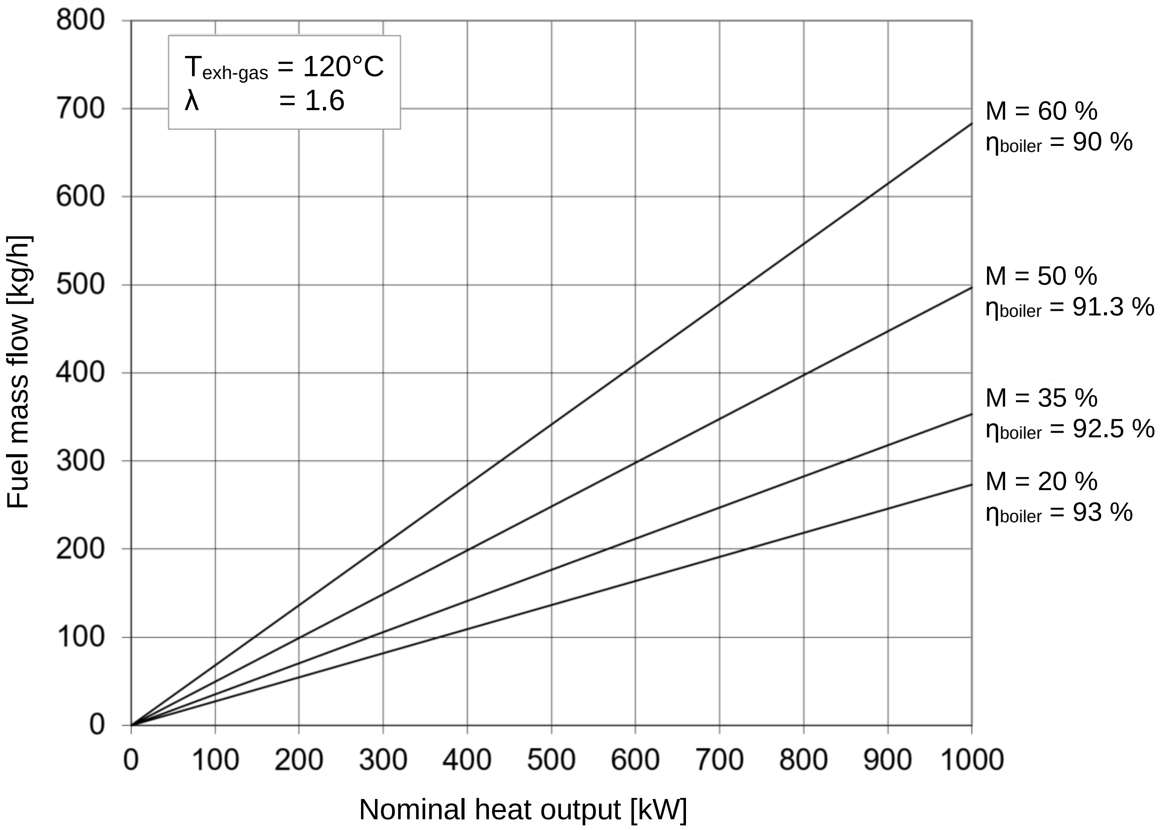


Figure 20.2 Fuel mass flow as a function of the nominal heat output.

20.8 Determination of combustion air volume

The combustion air volume, i.e. the volumetric flow of the combustion air corresponds approximately to the volumetric flow of the dry exhaust gas:

$$\dot{V}_{air} \approx \dot{V}_{exh-gas\,d.b.}$$

Therefore, according to chapter 20.6:

$$\dot{V}_{air} = \frac{\dot{Q}_N * 100\%}{\eta_{boiler}} * \frac{\lambda * V_{air\,min} * \left(1 + \frac{M}{100 - M}\right)}{18.3 - 2.442 \frac{M}{100 - M}} * \frac{3600}{1000}$$

with:	$\dot{V}_{air}$	=	combustion air volume	[m³/h]
	$\dot{V}_{exh-gas\,d.b.}$	=	dry exhaust gas volume flow	[m³/h]
	$\dot{Q}_N$	=	Nominal heat output	[kW]
	η_k	=	boiler efficiency	[%]
	M	=	fuel water content	[wt-%]
	λ	=	excess air ratio	[-]
	$V_{air\,min}$	=	stoichiometric combustion air volume = 4.58	[m³/kg$_{fuel\,d.b.}$]

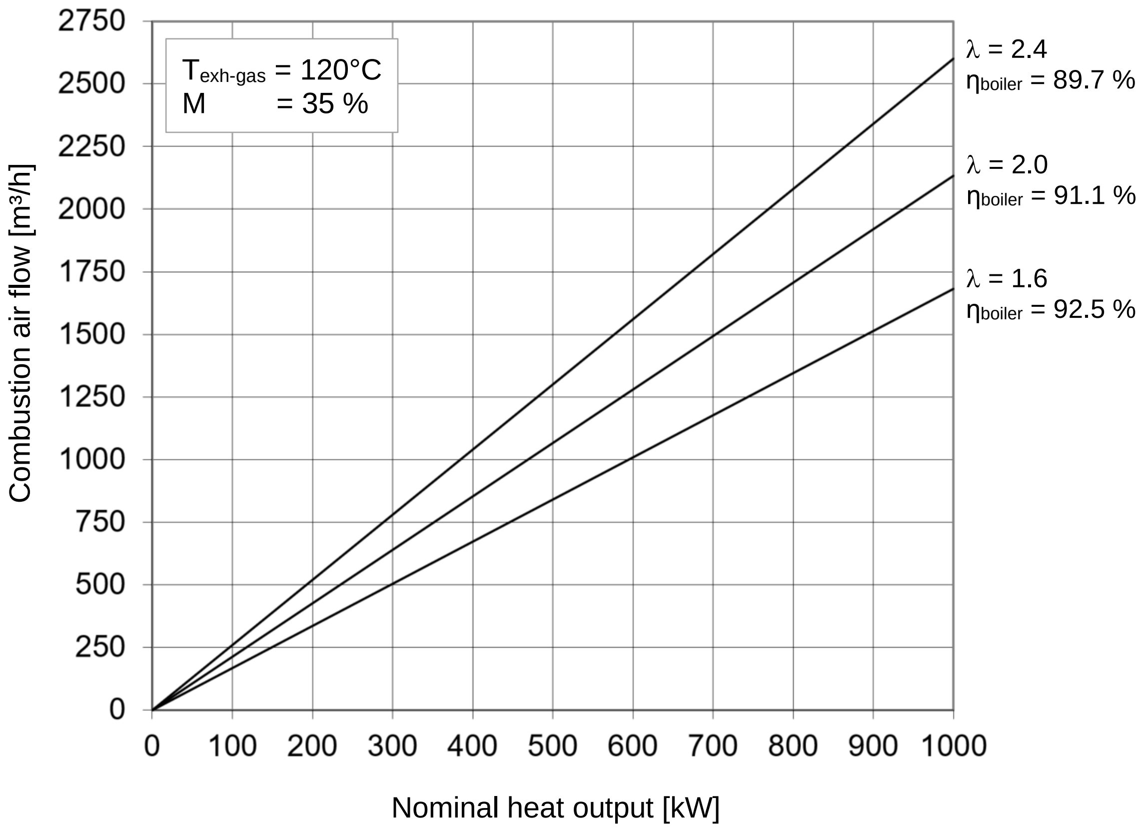


Figure 20.3 Combustion air volume flow as a function of nominal heat output and excess air ratio.

The amount of combustion air required to produce a desired nominal heat output depends, to approximately the same extent, on the excess air ratio and the calorific value or water content.

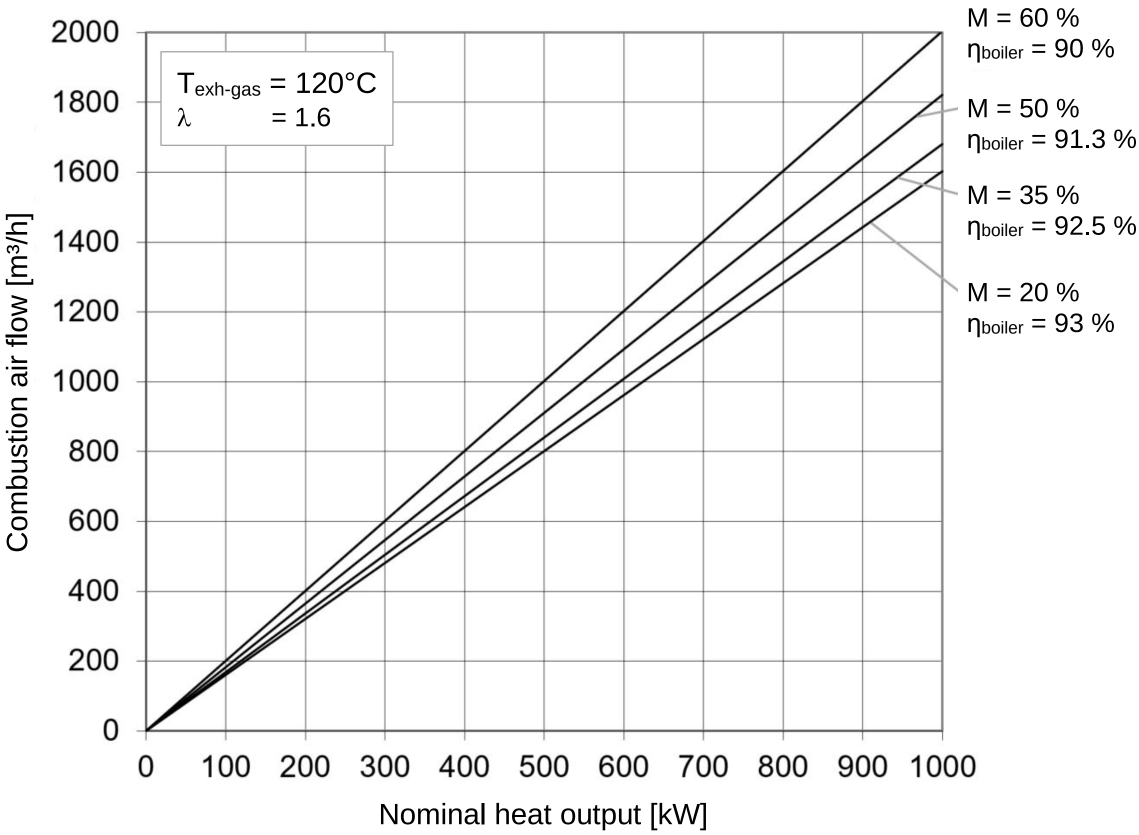


Figure 20.4 Combustion air volume flow as a function of nominal heat output and fuel water content.

20.9 Determination of exhaust gas volume flow

The dry exhaust gas volume flow of a biomass system at standard conditions (0 °C and 1013 mbar) corresponds approximately to the combustion air volume flow required to generate a certain nominal heat output.

$$\dot{V}_{exh-gas\,d.b.} \approx \dot{V}_{air} \qquad \left[\frac{m^3}{h}\right]$$

The exhaust gas volume flow in operating conditions, i.e. wet exhaust gas at exhaust gas temperature and ambient pressure, can be determined by converting from dry to wet exhaust gas (see chapter 20.5) and by converting from standard to operating conditions:

$$\dot{V}_{exh-gas} = \dot{V}_{air} * f * \frac{273 + T_{exh-gas} * 1073}{273 * p} \qquad \left[\frac{m^3}{h}\right]$$

with:

$\dot{V}_{air}$	=	combustion air volume flow	[m³/h]
$\dot{V}_{exh-gas\,d.b.}$	=	dry exhaust gas volume flow at standard conditions (0 °C, 1013 mbar)	[m³/h]
$\dot{V}_{exh-gas}$	=	wet exhaust gas volume flow at operating conditions ($T_{exh-gas}$ and p)	[m³/h]
f	=	conversion factor, wet exhaust gas to dry exhaust gas	[-]
$T_{exh-gas}$	=	exhaust gas temperature	[°C]
p	=	ambient pressure	[mbar]

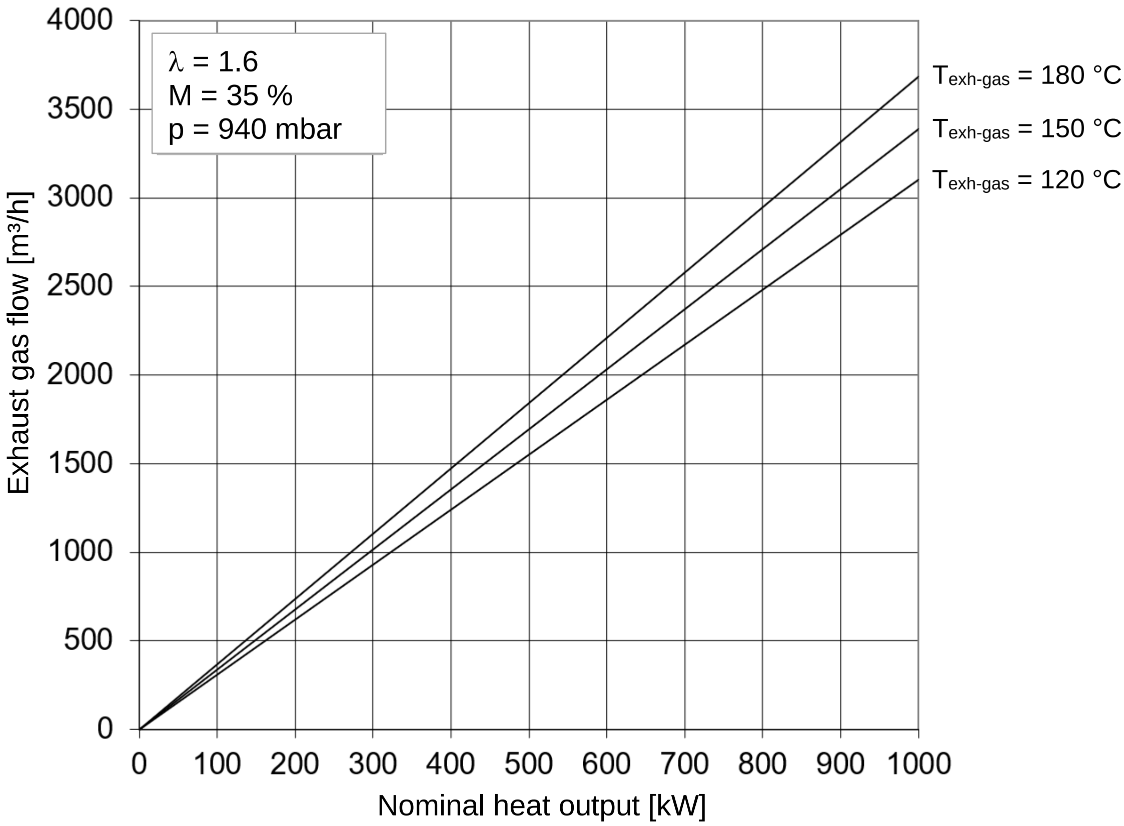


Figure 20.5 Exhaust gas volume flow in operating conditions as a function of the nominal heat output.

20.10 Determination of NO_x mass flow

As a rule, nitrogen oxides (NO_x) only have to comply with an emission limit value as soon as they exceed a specified NO_x mass flow. In Switzerland, for example, an emission limit value of 250 mg/m^3 (at reference oxygen content) must be complied with as soon as the NO_x mass flow exceeds 2,500 g/h. In the planning phase of a biomass heating plant, it is therefore important to estimate the NO_x mass flow, to decide whether an NO_x reduction process will be necessary (see chapter 13.9.2).

The NO_x mass flow is calculated from the exhaust gas volume flow at nominal load and the NO_x concentration at the measured oxygen content:

$$\dot{NO}_x = \dot{V}_{exh-gas\,d.b.} * \frac{NO_x}{1000} \left[\frac{g}{h}\right]$$

If the NO_x concentration with the measured oxygen content is not known, it can be estimated by using an NO_x concentration with a reference oxygen content and the assumption of an oxygen content as follows:

$$NO_x = NO_{x\,O_2\,ref} * \frac{21 - O_2}{21 - O_{2,ref}} \qquad \left[\frac{mg}{m^3}\right]$$

with:	$\dot{NO}_x$	=	NO_x mass flow	[g/h]
	$\dot{V}_{exh-gas\,d.b.}$	=	dry exhaust gas volume flow at 0 °C, 1013 mbar	[m^3/h]
	NO_x	=	NO_x concentration in dry exhaust gas at measured oxygen content	[mg/m^3]
	$NO_{x\,O2\,ref}$	=	NOx concentration in dry exhaust gas at reference oxygen content	[mg/m^3]
	O_2	=	oxygen content (measured at nominal load)	[vol-%]
	$O_{2,ref}$	=	reference oxygen content	[vol-%]

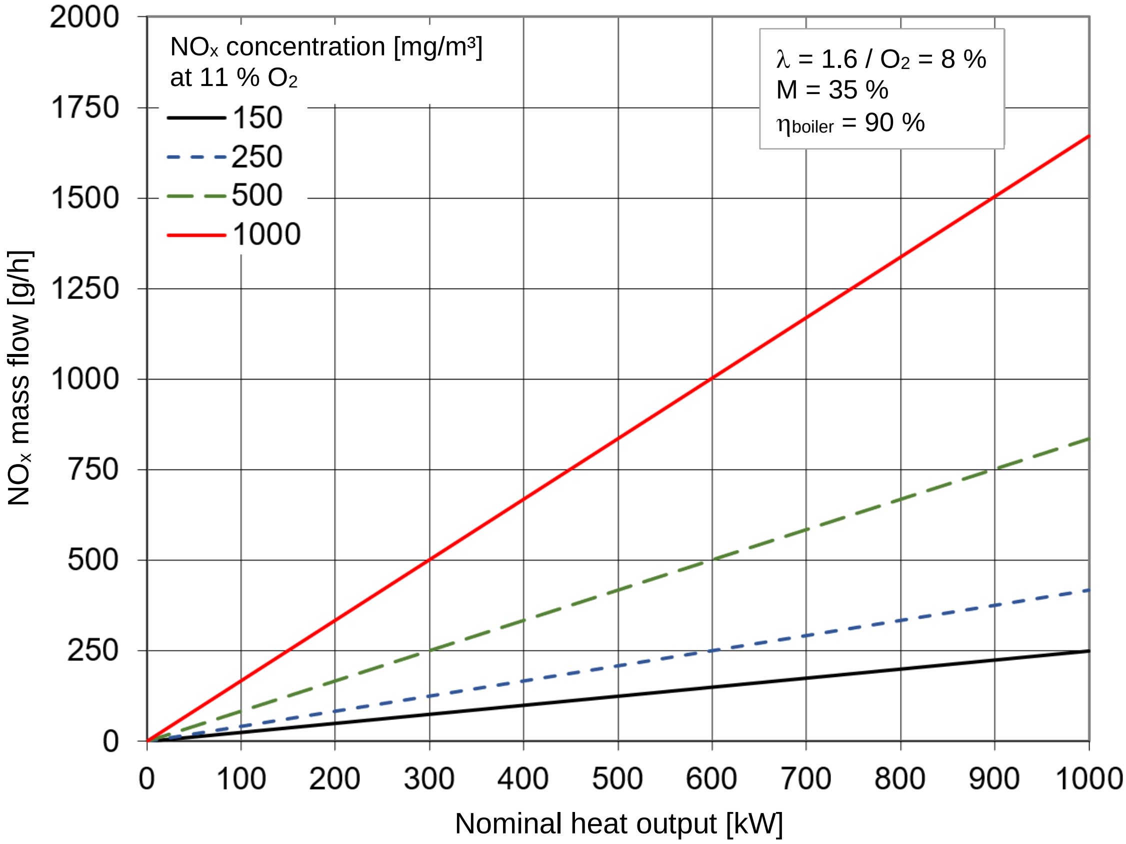


Figure 20.6 NO_x mass flow in g/h as a function of the nominal heat output in kW and various NO_x concentrations.

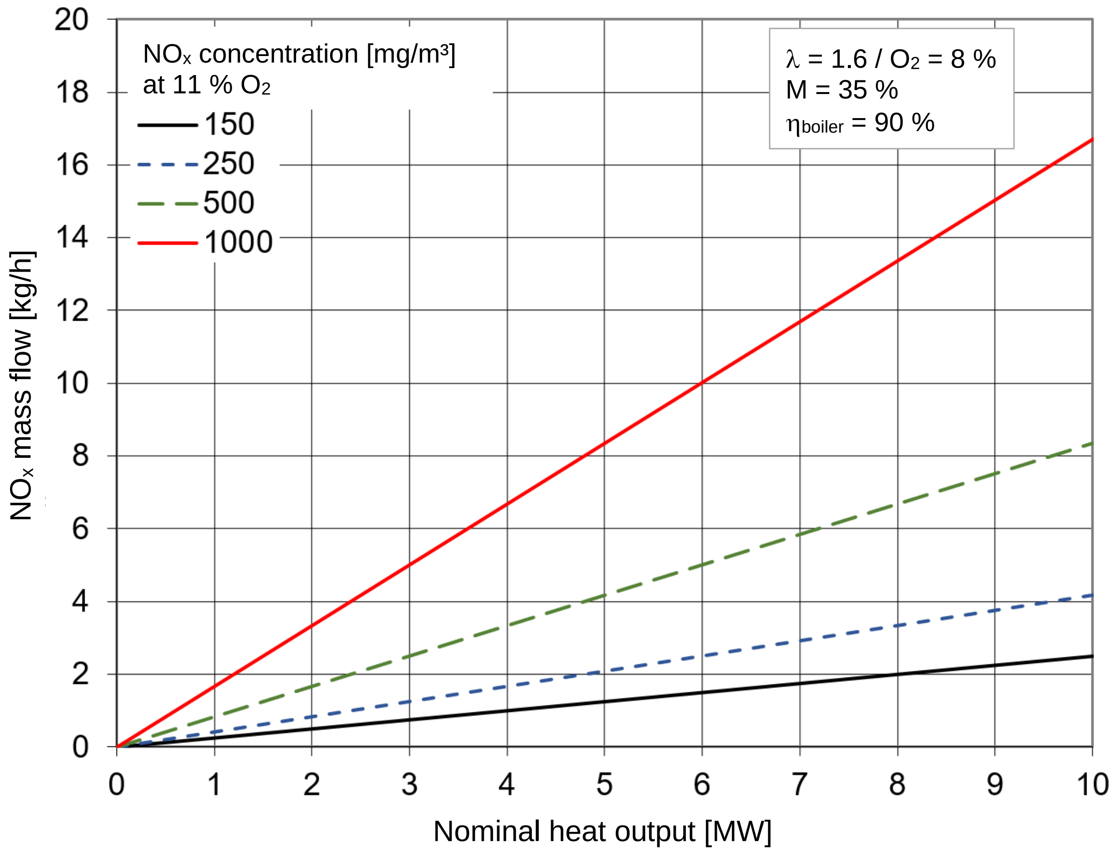


Figure 20.7 NO_x mass flow in kg/h as a function of the nominal heat output in MW and various NO_x concentrations.

20.11 Determination of combustion efficiency

To calculate the combustion efficiency, the energy content of the individual flue gas components is determined. Based on the combustion equation of wood, the thermal and chemical flue gas losses can be calculated. Nussbaumer and Good [60] have derived a simplified formula for wood fuels, which gives a sufficiently high accuracy for technical applications. In the range CO < 0.5 vol-%, CO_2 > 5 vol-%, flue gas temperature < 400°C, the following applies to the combustion efficiency of biomass systems:

$$\eta_{combustion} = 100 - L_{thermal} - L_{chemical} \qquad [\%]$$

where: $L_{thermal}$ = thermal losses due to sensible heat of the exhaust gases [%]

$L_{chemical}$ = chemical losses due to incomplete combustion [%]

$$L_{thermal} = \frac{\left(T_{exh-gas} - T_{ambient}\right) * \left(1.39 + \frac{122}{CO_2 + CO} + 0.02 * \frac{M}{100 - M}\right)}{\frac{18300}{100} - 0.2442 * \frac{M}{100 - M}} \qquad [\%]$$

$$L_{chemical} = \frac{CO}{CO_2 + CO} * \frac{11800}{\frac{18300}{100} - 0.2442 * \frac{M}{100 - M}} \qquad [\%]$$

Lambda λ: $$\lambda = \frac{21}{21 - O_2 + 0.4\,CO} = \frac{20.4}{CO_2 + CO} \qquad [-]$$

If O_2 is measured instead of CO_2: $CO_2 = 0.98\,(21 - O_2) - 0.61\,CO$ [vol-%]

with:

$T_{exh\text{-}gas}$	=	exhaust gas temperature	[°C]
$T_{ambient}$	=	ambient temperature	[°C]
O_2	=	oxygen concentration	[vol-%]
CO_2	=	carbon dioxide concentration	[vol-%]
CO	=	carbon monoxide concentration	[vol-%]
u	=	wood moisture content in relation to absolutely dry wood	[wt-% d.b.]
M	=	Water content of the moist wood	[wt-% w.b.]
λ	=	excess air ratio	[-]

Note: The nomogram Figure 20.8still uses the fuel moisture content u. To calculate the moisture content u from the water content M, the following conversion can be used:

$$u = \frac{M}{1 - M} \quad [-]; \qquad u = \frac{M}{100 - M} \quad [\%]$$

or

$$M = \frac{u}{1 + u} \quad [-]; \qquad M = \frac{u}{100 + u} \quad [\%]$$

This method provides comparable values with the calculation according to DIN EN 14394:2008-12 [146]. If necessary, the formula can be adapted for fuels with compositions deviating from wood [60]. A quick estimation of the numerical values can also be performed graphically with the corresponding nomograms (Figure 20.8).

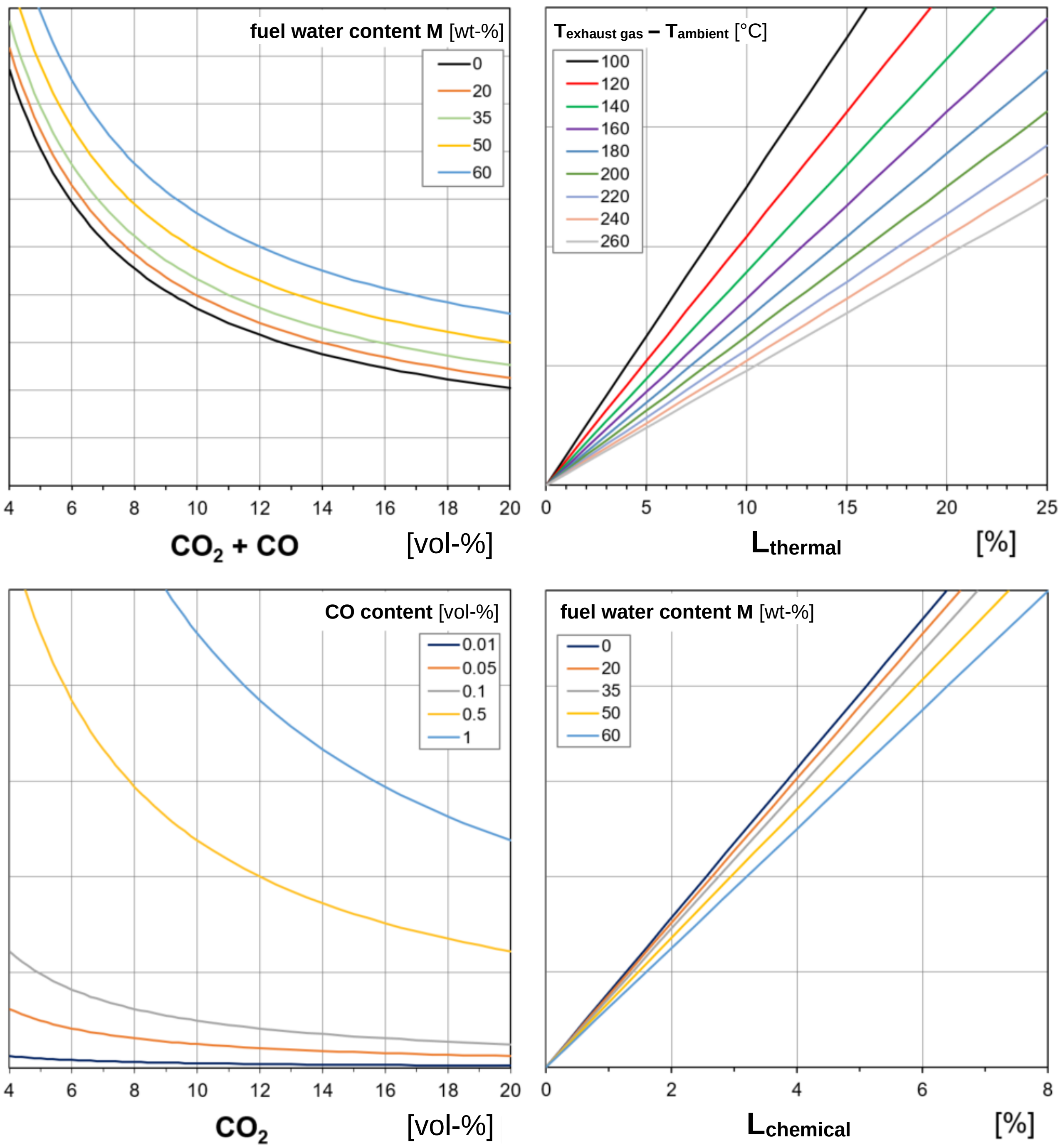


Figure 20.8 Nomograms for the determination of the combustion efficiency with $\eta_{combustion} = 100 - L_{thermal} - L_{chemical}$ [%].

20.12 Determination of annual efficiency

With the following calculation method, the annual efficiency η_a can be determined with an accuracy of approx. ± 5 %, provided that a heat meter is available in the boiler circuit. The annual efficiency depends on the losses, the utilisation α and the average load level (L) of the firing plant. The calculation assumes a furnace with boiler efficiency η_{boiler} based on average operating parameters. For firing systems with other operating parameters, the boiler efficiency η_{boiler} is adjusted using correction terms. With the load factor α, the boiler efficiency η_{boiler} and the average load level L, the annual efficiency η_a can be calculated ([136], [147]).

It is assumed that the boiler efficiency η_k is constant over the entire load range. The higher relative share of radiation losses in partial load operation is compensated by lower flue gas temperatures.

Utilisation factor α

$$\alpha = \frac{\text{Operating time firing}}{\text{Switch-on duration firing}} = \frac{t_{Operation}}{t_{On}} \; [-]$$

The switch-on duration comprises the regular operating time and the standby time (ember bed maintenance) of a firing system between firing at the beginning of the heating period and switching off at the end of the heating period. Operating and standby time are usually recorded with an operating hours counter or via the PLC control.

Boiler efficiency η_{boiler}

The boiler efficiency η_{boiler} for an automatic wood chip furnace with the following operating parameters equals:

Operating parameters:	Exhaust gas temperature	$T_{exh\text{-}gas}$	=	120 °C
	Excess air ratio	λ	=	1.6
	Fuel water content	M	=	38 wt-%
	Wood moisture	u	=	60 % d.b.
	Combustion efficiency	$\eta_{combustion}$	=	93 % (nomogram in Figure 20.8)
	Radiation losses	q_{rad}	=	1.5 %
	Boiler efficiency	η_{boiler}	=	$\eta_{combustion} - q_{rad}$ = 93 - 1.5 = 91.5 %

A possibly existing difference of the real to the assumed radiation losses q_{rad} of 1.5% can be added or subtracted directly to the boiler efficiency η_{boiler}. If the radiation losses q_{rad} are not known, it can be assumed approximately that they amount to half of the standby losses $q_{standby}$. For the other operating parameters, the following correction summands apply:

per Δ u	=	10%	moister wood	0.4% lower boiler efficiency η_{boiler}
per Δ λ	=	0.1	greater excess air	0.6% lower boiler efficiency η_{boiler}
per $\Delta T_{exg\text{-}gas}$	=	10°C	higher exhaust gas temperature	1.0% lower boiler efficiency η_k

The correction totals also apply in reverse.

Average load level L

The average load level L at which the furnace runs on average over the operating time can be calculated as follows:

$$L = \frac{\Delta HM * 100\%}{\dot{Q}_N * t_{Operation}} \quad [\%]$$

with:	Δ HM	=	heat meter final value - heat meter initial value	[kWh]
	$t_{Operation}$	=	Operating time of the furnace	[h]
	$\dot{Q}_N$	=	Nominal heat output	[kW]

Standby losses $q_{standby}$

Standby losses occur in the standby phases, i.e. after each switch-off of a biomass boiler. They include the losses due to cooling of the biomass boiler and the fuel input (ember bed maintenance) to keep the biomass boiler at temperature ready for operation. The standby losses are lower for biomass boilers with a light design without ember bed maintenance (standard devices with automatic ignition), and higher for biomass boilers with a heavy design with ember bed maintenance (industrial boilers).

For a modern plant of medium size, the standby losses $q_{standby}$ amount ot approx. 3%. The data in Table 20.4can be used as guide values for other plant sizes.

Table 20.4 Guide values for standby losses $q_{standby}$.

Firing type	Standby losses $q_{standby}$
Series device up to 300 kW	$q_{standby} \geq 1\% - 3\%$
Industrial boilers up to 300 kW	$q_{standby} \geq 3\% - 5\%$
Industrial boilers > 300 kW	$q_{standby} \geq 1\% - 3\%$

Annual utilisation factor η_a

With the time load α, the boiler efficiency η_{boiler}, the standby losses $q_{standby}$ and the average load level L, the annual efficiency η_a can be calculated with the formula below as follows (see Figure 20.9):

$$\eta_a = \eta_{boiler} \frac{1}{1 + \frac{q_{standby} * (1 - \alpha)}{L * \alpha}} \qquad [\%]$$

With:

α	=	utilisation factor	[-]
η_{boiler}	=	boiler efficiency	[%]
$q_{standby}$	=	standby losses	[%]
L	=	average load level	[%]

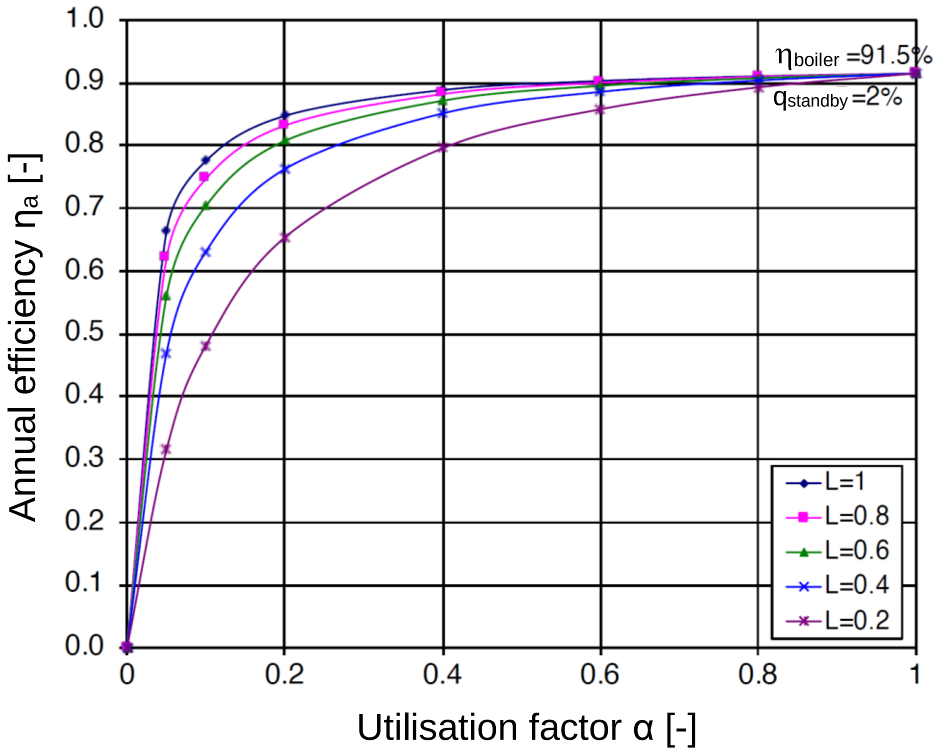


Figure 20.9 Annual efficiency of a biomass boiler as a function of its utilisation [147]
with η_{boiler} … boiler efficiency; $q_{standby}$ … standby losses; L … average load level.

Calculation example

Heat meter	**Firing**	
Difference at the heat	Nominal heat output	700 kW
meter over one heating period	Excess air ratio	$\lambda = 1.6$
Δ HM = 997,647 kWh	Exhaust gas temperature	$T_{exh\text{-}gas} = 120$ °C
	Wood moisture	u = 60 % d.b.
	Fuel water content	M = 38 wt-%
	Radiation losses	$q_{rad} = 1.5$ %
	Standby losses	$q_{standby} = 2.0$ %
	Switch-on duration	Heating period
	Operating time	2,036 h

Calculation of the utilisation factor α:

Switch-on duration: Heating period: 15th September to 4th April = 202 days = 4,848 h; Operating time: 2,036 h

$$\alpha = \frac{\text{Operating time firing}}{\text{Swith-on duration firing}} = \frac{2{,}036\text{ h}}{4{,}848\text{ h}} = 0.42$$

Determination of the boiler efficiency η_{boiler}:

Combustion efficiency	$\eta_{combustion}$	=	93% (determination with nomogram Figure 20.8)
Radiation losses	q_{rad}	=	1.5%
Boiler efficiency	η_{boiler}	=	93% – 1.5% = 91.5%

Calculation of the average load level L:

$$L = \frac{\Delta\text{ HM} * 100\%}{\dot{Q}_N * t_{Operation}} = \frac{997{,}647\text{ kWh} * 100\%}{700\text{ kW} * 2{,}036\text{ h}} = 70\%$$

Calculation of the annual utilisation factor η_a

$$\eta_a = \eta_{boiler} \frac{1}{1 + \frac{q_{standby} * (1 - \alpha)}{L * \alpha}} = 91.5\% * \frac{1}{1 + \frac{2\% * (1 - 0.42)}{70\% * 0.42}} = 88\%$$

20.13 Common units and conversions

Table 20.5 Common units of measurement for solid biomass fuels. See Table 20.6 for conversion.

Symbol	Meaning
m^3	Cubic metre (solid mass of wood without interspace), 1 m^3 = 1 fm ≈ 2.5 ... 2.8 LCM
fm	Solid cubic metre (solid mass of wood without intermediate space), 1 fm = 1 m^3 ≈ 2.5 ... 2.8 LCM
LCM	Loose cubic metre, CH: Schnitzelkubikmeter Sm^3, AT/GE: Schüttraummeter Srm
Solid cubic metre	1x1x1 m stacked logs (with spaces) = 0.7 fm = 0.7 m^3

Table 20.6 Conversion table (guide values for wood with M = 15 %).

	Softwood WH Spruce/Fir	Hardwood HH Beech
Solid wood	2.5 ... 2.8 LCM	2.5 ... 2.8 LCM
1 m^3 = 1 solid cubic metre (fm) corresponds to	1.4 cubic metres	1.4 cubic metres
	550 kg wood	750 kg wood
	200 litres heating oil extra light	280 litres heating oil extra light
	2000 kWh 7200 MJ	2800 kWh 10080 MJ
Wood chips	0.36 m^3 (fm)	0.36 m^3 (fm)
1 loose cubic metre (LCM) corresponds to	0.5 cubic metres	0.5 cubic metres
	160 - 200 kg wood	250 - 270 kg wood
	70 litres heating oil extra light	100 litres heating oil extra light
	700 kWh 2520 MJ	1000 kWh 3600 MJ

Table 20.7 Prefixes and their symbols

Kilo	**k**	10^3
Mega	**M**	10^6
Giga	**G**	10^9
Tera	**T**	10^{12}
Peta	**P**	10^{15}
Exa	**E**	10^{18}

Megawatt hour:	1 MWh = 1,000 kWh
Gigawatt hour:	1 GWh = 1 million kWh
Terawatt hour:	1 TWh = 1 billion kWh

Table 20.8 Units for energy and power

Joule	**J**	for energy, work, heat quantity
Watt	**W**	for power, energy flow, heat flow

1 Joule (J) = Newton metre (Nm) = 1 Wattsecond (Ws)

Binding for Germany as legal units since 1978. The calorie and units derived from it, such as the hard coal unit and the crude oil unit, are still used as an alternative.

Table 20.9 Conversion factors for energy units

		kJ	kcal	kWh
1 Kilojoule	kJ	1	0.2388	0.000278
1 Kilocalorie	kcal	4.1868	1	0.001163
1 Kilowatt hours	kWh	3,600	860	1
1 kg hard coal unit (German: Steinkohleneinheit)	SKE	29,308	7,000	8.14
1 kg crude oil unit (German: Rohöleinheit)	ROE	41,868	10,000	11.63

The figures refer to the net calorific value.

21 Glossary

Term	Meaning
Ambient heat, environmental heat	Ambient heat or environmental heat is a renewable and natural form of energy that is widely available and usually occurs at relatively low temperature levels. Sources of ambient heat are the air, the upper soil as well as groundwater, lake and river water. With heat pumps, ambient heat can be raised to a higher temperature level and made usable. This requires the supply of high-quality energy in the form of electricity or high temperature heat from another source. Environmental heat from deep geothermal or volcanic origins can also provide directly usable heat at a higher temperature level.
Annual COP	The annual COP (coefficient of performance) describes the ratio of the annual heat production to the electrical or thermal energy supplied to a heat pump during the same period. It thus describes the efficiency of a heat pump over a longer operating period in contrast to the instantaneous value of the coefficient of performance (see also coefficient of performance).
Annual heat demand	The annual heat demand of a consumer is the annual useful heat demand at the heat transfer point. For a district heating network, the annual heat demand is the demand at the supply point (interface between heat generation and heat distribution network) and also includes the heat losses of the district heating network.
Annual heat production	The annual heat production is the sum of the heat production of all heat generating plants (independent of the energy source) in one year.
Annual operating hours	Effective number of hours per year during which a plant is operated. In contrast to full load operating hours, the counting of annual operating hours is independent of the respective load condition, i.e. an annual operating hour at 50 % capacity is considered an annual operating hour (cf. full operating hours).
Base load, base load coverage	Base load refers to the constant power required, i.e. during the entire operating period (heating season or the entire year (8760 hours). The base load of a district heating network is made up of the seasonally independent heat capacity required by the consumers (e.g. for domestic hot water heating, process heat, etc.) plus the network losses. Base load coverage refers to a heat generation unit that is primarily used to cover the base load (e.g. a CHP system).
Biomass (wood fuels)	Biomass comprises all organic matter produced by plants, animals and humans. Biomass for energy purposes comes from agriculture, forestry and biogenic residues (waste). Biomass suitable for combustion is referred to as biogenic solid fuel such as woody biomass (forest residues, small dimensioned wood, industrial residues, ...), stalky biomass (straw, ...) and others (whole grain plants, husks, kernels, ...). In contrast to combustion, biomass can also be used energetically by fermentation. For this purpose, fermentable, i.e. non-woody biomass such as liquid manure, dung, corn and grass silage, and various biogenic residues from agriculture, the food industry, and even biowaste are used.
Bivalent heat generation	Heat generation with at least two different energy carriers; in the context of QM Biomass DH Plants, bivalent refers primarily to the central heating plant with one or more biomass boilers and a fossil fuel backup for peak loads coverage and failure reserve. In a broader sense, however, it refers to any type of heat generation system that uses 2 or more different energy sources (e.g. wood and solar thermal energy, wood and waste heat, etc.).
Boiler efficiency	The useful energy produced by a boiler (on the water side) divided by the energy supplied with the net calorific value of the fuel. The determination is made either for a stationary state without storage effects (e.g. in the case of automatic firing systems) or over an entire combustion process (e.g. in the case of manually fed firing systems).
Boiler inlet temperature	Temperature of the heat transfer medium measured in the pipe directly at the inlet to the boiler (downflow the boiler return flow temperature protection!).
Boiler outlet temperature	Temperature of the heat transfer medium measured in the pipe directly at the outlet from the boiler. The boiler outlet temperature is a basic control variable for the boiler.
Coefficient of Performance (COP)	The coefficient of performance (COP) is the ratio of the generated useful heat output to the supplied electrical or thermal power input of a heat pump. It describes an instantaneous value or a value determined over a short-term observation period. The thermodynamically (theoretically) maximum achievable coefficient of performance is referred to as Carnot-COP. This can be converted to the actual COP of a heat pump using a product-specific quality factor. The annual performance factor is used for evaluation over a longer observation period (see annual performance factor).
Combination valve	Combination valves are special valves that are mainly used in district heating transfer stations in order to limit the flow rate as well as to control the differential pressure with only one valve. The maximum possible flow rate and thus the maximum capacity (= subscribed connected load) of the transfer station is set via the adjustable flow rate limiter. Furthermore, the differential pressure and thus the flow rate on the primary side is controlled depending on the measured secondary flow temperature in order to achieve the required set flow temperature on the secondary side.
Combined Heat and Power (CHP) plant	Energy generation plant for the simultaneous production of heat and electrical power. Thermal machines such as an ORC system or a gas engine are used for this purpose, whereby usable heat is produced in addition to electrical power. Compact plants with engines or small gas turbines are also referred to as block heat and power plants or block heating stations, while thermal power plants with waste heat utilisation are referred to as combined heat and power plants or cogeneration plants (see chapter 13.6.3).

Term	Meaning
Concurrency (concurrency factor)	In a heating network, concurrency describes the effect that, in the case of a large number of heat consumers, they never all draw the maximum contractually guaranteed heat output at the same time. The concurrency factor is 1 for a single heat consumer and becomes smaller than 1 for several heat consumers. It describes the ratio between the effectively expected maximum heat capacity demand of all heat consumers and their total subscribed connected load.
Connected load (subscribed connected load)	The connected load or subscribed connected load is the contractually agreed maximum heat demand of a heat consumer (district heating customer) connected to a district heating network. The connected load (also total connected load) of a district heating network is the sum of the connected loads of all heat consumers.
Consumer's installation	The consumer's installation consists of the distribution system in the building for the distribution of space and process heat as well as domestic hot water.
Demand assessment	The demand assessment is an analysis of the energy and power demand for heat (space heating, hot water and process heat), the structural situation for the routing and the potential heat supply area (see chapter 11).
Design planning	Project phase in which the technical solution of the project is planned and defined. In CH this is also called "pre-project", while in DE and AT it is sometimes also referred to as system and integration planning.
District heating	District heating describes a piped heat supply to the connected customers with centrally generated heat from one or more heating centres. The pipeline system with all the necessary additional equipment (excluding generation) is referred to as the district heating network. Water (only rarely steam) is used as the heat transfer medium to transport the heat via central district heating pumps and a closed pipeline circuit to the heat transfer stations. District heating networks cover a wide performance range with connected loads from less than 100 kW up to over 1 GW.
Local heat	For smaller grids, the term local heat (local heating networks) is sometimes used (especially in AT and DE), whereby there are no fundamental technical differences apart from the size of the plant. In Germany, it is used to describe the transfer of heat for heating and hot water between buildings with capacities between 50 kW and several megawatts [78]. Minergie® also uses the term local heating when the heat production plant supplies a few buildings or building complexes, although there does not necessarily have to be a sale to third parties [148]. There is no uniform definition or boundary between local and district heating and both terms are used in this planning manual. In international linguistic usage, this distinction does not exist. Other synonyms for district heating network are heat distribution network, heat network, thermal network or local heating network.
Double Pipe	Special construction method of a factory pre-insulated district heating pipe. The flow and return pipes (service pipes) are installed in a common plastic casing pipe with PUR foam as thermal insulation. Rigid and flexible versions with steel medium or plastic medium pipe are available.
Economiser	An economiser is a heat exchanger for heat recovery by utilising waste heat from a wide variety of thermodynamic or industrial processes. In firing and boiler technology, the economiser is used to recover heat from the hot flue gas downstream of the boiler, thereby reducing the flue gas temperature and increasing the efficiency of the overall plant.
Efficiency	The efficiency of a technical system describes the ratio between useful energy and supplied energy. Under stable conditions without storage effects, the efficiency can also be determined as the ratio between useful power and supplied power. In this manual, the term efficiency is used for an instantaneous value determined via the power or a value determined over a short observation period. For the evaluation of the plant operation over a longer period of time, the utilisation factor describes the ratio between the useful power summed up over a determined period and the supplied power summed up over the same period (see utilisation factor).
Energy Efficiency Index (EII)	The basis for determining which pump models are allowed to be used in the future is the so-called energy efficiency index (EEI). It is determined according to a calculation method defined in Regulation (EC) 641/2009. The average performance of the pump, determined by means of a load profile, is considered in relation to a reference pump, i.e. an average pump with the same hydraulic power.
Energy reference area	The energy reference area is an important building indicator and is the sum of all above-ground and below-ground floor areas of a building where heating or air conditioning is necessary. The energy reference area is calculated gross, i.e. from the external dimensions including limiting walls and parapets. For deviating room temperatures, high rooms, etc., there are country-specific correction factors. As an approximation, the heated gross floor area can be taken as the energy reference area.
Execution phase	Project phase in which the realisation of the plant takes place. In the course of execution/realisation, professional construction supervision or local construction supervision is to be carried out.
Fuel bed	In combustion technology, the fuel bed refers to the fuel in the form of a uniform bulk ("bed") on a combustion grate or in a combustion chamber.

Term	Meaning
Full load operating hours and number of full load operating hours	The number of full operating hours is the annual energy requirement divided by the nominal heat output. It is an important parameter for system dimensioning for an individual consumer (number of full operating hours for heat consumers), a boiler or the entire heat generation. A full operating hour corresponds, for example, to one hour of operation at nominal load or two operating hours at 50 % load and the following applies: number of full operating hours ≤ number of annual operating hours (see annual operating hours).
Geographical Information System (GIS)	Data processing application for the acquisition, processing, organisation, analysis and presentation of spatial data. For the planning of district heating networks, it can be used to determine the routing, taking into account the geographical conditions and any other existing supply systems (water, gas, electricity, etc.). In addition, the GIS can also be used to estimate local energy and power requirements.
Gradient	Minimum temperature difference between a heat-emitting, hot medium and a heat-absorbing, colder medium at a heat exchanger. Among other things, it is used to determine the technical quality of a heat transfer process. As a rule, this temperature difference should be as low as possible (e.g. especially in the case of district heating transfer stations in order to achieve a low return temperature in the heating network). When designing a heat exchanger, however, the benefits and costs (due to larger heat exchanger surfaces) must be assessed.
Heat consumer, (connected) customer	Buildings/properties (and their owners) connected to a district heating network that receive heat from the heating network or the central heating plant (and thus from a heat supply company) in accordance with the agreements in the heat supply contract.
Heat demand density	The heat demand density is the annual heat demand of all buildings in a supply area in relation to the size of the supply area (see chapter 12.2.2).
Heat distribution losses	Heat distribution losses are an important parameter for heating networks (and are also referred to as network losses). They are defined as the difference between the heat supplied to a heating network (from generation) and the total heat consumption of all heat consumers. The heat distribution losses can be presented as an absolute value (= difference of quantities of heat) or as relative value (percentage network losses). In the case of relative network losses, the difference between feed-in and consumption is divided by the quantity of heat fed in. The network losses are determined by the prevailing heat distribution losses capacity in the network, which depends on the temperature difference between the district heating medium and the environment (ground), the insulation quality of the district heating pipes and the pipe dimension.
Heat exchanger	A heat exchanger is a device in which thermal energy is transferred from one warm material flow to another, colder material flow via heat transfer surfaces (e.g. plates or tube bundles).
Heat production costs	The heat production costs are the ratio of the annual costs for heat production to the useful heat produced annually and represent the specific production costs for heat in CHF/MWh or €/MWh (see chapter 10.4.2). The annual costs are usually determined using the annuity method according to VDI 2067 [100] and include capital costs (annuity from the investment), operating costs (maintenance/service and personnel costs), energy costs (fuels and auxiliary energy) and other costs (e.g. planning).
Heat supply companies (heat suppliers)	Company (operating company) that operates the heat supply system (heating centre, heating network) and is responsible for the provision of the secured heat supply to the heat consumers as agreed in a heat supply contract.
Heat supply contract	The interface between the heat supply company (supplier) and the heat consumer (customer) is contractually agreed in the heat supply contract. It also contains the following contractual components: General Terms and Conditions, Technical Connection Requirements (TAV) and a tariff sheet.
Heat transfer medium	The medium used for heat transport, such as water, steam or thermal oil.
Heating plant District heating plant Central heating plant	Central system for the provision of heat for larger properties/buildings/businesses, a small heating network or a district heating network.
Hot water (warm water)	The term hot water is used differently in building services engineering and in district heating engineering as follows: • In district heating technology, warm water describes the circulation water in the district heating network when the temperature is up to 110 °C, while circulation water above 110 °C is referred to as hot water. Compared to warm water systems, other standards, guidelines and regulations apply to hot water systems, and in particular higher safety precautions. The water in the district heating network does not have to be of drinking water quality and should therefore not be confused with (domestic) hot water in building services. • In building services engineering, hot water stands for heated drinking water (also called domestic hot water), which is made available at around 60 °C. The heating and provision of domestic hot water is carried out with water heaters. This can be a storage tank (storage water heater, boiler) or an instantaneous water heater.
House connection (pipeline)	Connection pipeline between heat distribution network and heat transfer station.

Term	Meaning
House substation	The house substation consists of the heat transfer station and the consumer's installation. It is used to adapt the heat supply to the consumer's installation in terms of pressure, temperature and volume flow. When designing the house substation, a distinction must be made between direct or indirect connection (with/without heat exchanger for hydraulic separation).
Key customers	District heating customers with large heat demands, who contribute significantly to the total heat demand of a network and are therefore of great importance for the project development (focus on potential key customers - see chapter 3.2.4), the overall planning and dimensioning of the heat network and the generation plants.
Linear heat density, connection density	The linear heat density (see chapter 12.2.6) is the ratio between the annual quantity of heat sold in MWh/a and the total route length of main, branch and house connection pipes in metres. The linear heat density can also be calculated for individual sub-networks or connected networks and used for assessment.
Load characteristic	The load characteristic curve is the representation of the heat output demand as a function of the daily mean value of the outdoor temperature. For the outdoor temperature, the 24-hour average value must always be used, whereas the heat output demand can be a daily average value (e.g. for residential buildings) or a peak value (e.g. for office buildings). The load characteristic of the overall system results from the stacking (summing up) of several load characteristics (see chapter 11.3.2).
Loose cubic metres (LCM)	Bulk volume of the chipped material in cubic metres (German: Schüttraummeter [Srm], CH: Schnitzelkubikmeter [Sm^3])
Lumpiness	Specifies the dimensions and geometry of solid fuels and is an essential part of the characterisation of biomass fuels. The lumpiness is specified according to fuel standards such as EN-ISO 17225 [23].
Main planner	Planning person who is responsible to the plant owner for the quality of the overall system. For project planning in accordance with QM for Biomass District Heating Plants, a main planner must always be designated in the Q plan.
Maximum continuous operating temperature	Maximum permissible operating temperature without time restriction.
Maximum permissible operating temperature	Maximum permissible operating temperature of a system (heat generation, heat networks, ...) over a short period of time.
Milestone	QM Holzheizwerke sets 5 milestones for quality assurance at the end of the most important project phases (see chapter 2.3.3): 1. Establishment of QM for Biomass DH Plants and Q-planning as conclusion of project phase 1 2. Q-checks and Q-control at the level of preliminary studies as conclusion of project phase 2 3. Q-checks and Q-control at tender project level as conclusion of project phase 3 4. Q-checks and Q-control at the acceptance level as conclusion of project phase 5 5. Q-checks and completion of QM for Biomass DH Plants after one year of operation as conclusion of project phase 6
Monovalent heat generation	Heat generation with a single energy carrier, e.g. heating system operated exclusively with biomass boilers (cf. bivalent heat generation).
Network critical node	Position in a heating network with the lowest differential pressure between flow and return. This point is usually located at a transfer station far away from the heating centre(s), but can move depending on the operating status of the heating network (discharging or feeding). The network critical node serves as a defined variable for the network pumps (main pump unit). By installing differential pressure sensors at the critical node in the network, the network pumps can also be controlled depending on the differential pressure at the critical node.
Network pressure	Network pressure is the pressure in the district heating pipeline.
Network separation	Network separation refers to the separation of two network sections or the network from the generation units. This can be realised, for example, by a heat exchanger (technical separation, separate heat transfer media) or a hydraulic separator (hydraulic separation, common heat transfer medium).
Network temperature	Network temperature is the joint specification of the flow and return temperature in degrees Celsius (e.g. 80/50) and is to be understood as a typical value for a heating network (possibly with differentiation between summer and winter operation).
Nominal diameter DN, nominal size, nominal diameter	The nominal diameter specifies a reference diameter for a piping system, which is used to define the size and compatibility of components. The nominal diameter is part of the designation of the component according to EN ISO 6708 [150] and is not identical with the inner or outer diameter of a pipe or component.
Nominal heat output	Highest continuous output of a system (e.g. biomass boiler) for which it is designed according to the manufacturer's specifications and the fuels defined therein without time restrictions.

Term	Meaning
Nominal pressure PN (Pressure Nominal)	The nominal pressure is a reference value for the design pressure of a piping system. It is specified according to DIN, EN and ISO by the designation PN (Pressure Nominal) followed by a number indicating the design pressure in bar at room temperature (20 °C). Definition and selection is made according to EN 1333 [149].
Operation optimisation, optimisation of plant operation	With operational optimisation, the functioning of the plant is systematically checked and optimised after the plant has been handed over to the owner. With QM for Biomass DH Plants, operational optimisation is the responsibility of the companies carrying out the work under the direction of the main planner (see chapter 18).
Peak load	Maximum heat output demand that usually occurs only for a short time (e.g. at very low outdoor temperatures, peak load of a heating network in the morning). The peak load of a system is usually many times higher than the daily or annual average output. The occurring peak load has a significant influence on the plant configuration and dimensioning of all plant components. By integrating load balancing storage tanks, the effective peak load to be provided by the generation plants can be reduced. Additional (often fossil fuel) peak load boilers are also used to cover peak loads. These should have a wide control range and be able to be switched on and off quickly. As additional redundancy, the peak load boiler(s) are often designed to be large in order to compensate for the failure of one or more base load boilers (failure backup).
Period of operation between cleaning	Operating period (cleaning interval) of a firing or boiler plant between two planned shutdowns for the purpose of (manual) cleaning.
Pipelines	The term includes sewer, water, wastewater, and power lines of a municipality, city, or corporation.
Preliminary study (preliminary planning, feasibility study)	Early project phase in which the project variant that best meets the requirements is determined. On the basis of the preliminary study, a decision is made on the continuation of the project (investment decision). Depending on the country/region, the preliminary study is also called preliminary planning, feasibility study or project and preparatory planning (see also chapter 3.2).
Pressure maintenance	A sub-system in the hydraulic system (heat generation and heat distribution) which absorbs the change in volume of the hot water between minimum and maximum temperature and thus keeps a pre-set static pressure largely constant (pressure maintenance).
Primary side	The primary side of a heat transfer station is the heating network side, i.e. the part of the system through which the district heating medium flows. The terms primary flow and return temperature are the temperatures prevailing on the primary side (network side) of the heat exchanger. Analogously, the term primary pressure (see also secondary side).
Project phases	QM Holzheizwerke divides the project process into the following 6 project phases: 1. Preliminary study 2. Design planning 3. Tender planning 4. Tendering and contracting 5. Execution and approval 6. Operation optimisation The project phases of QM Holzheizwerke describe a typical project sequence, however, the terms and the detailed scope of work of the individual project phases may differ in different countries/regions. For this purpose, the respective country-specific standards and guidelines must be taken into account.
Project-related quality management (PQM)	Ensures that the desired quality is defined and tested in a time-limited project involving several companies. PQM must not be confused with company-related quality management (certification according to ISO 9000) and the testing of product samples (type testing). However, PQM can of course be applied within the framework of company-related certified QM systems of companies involved in the project. (QM Holzheizwerke is a PQM system; see chapter 2.1).
QM for Biomass District Heating Plants	Project-related quality management system for biomass plants. The focus is on the professional conception, planning and realisation of the heat generation plant and the heating network to ensure high operational safety, precise control, low emissions and economic fuel logistics. The goal is an energy-efficient, environmentally friendly and economical operation of the entire plant.
Q-manager	Ensures that the quality management system "QM for Biomass DH Plants" is established and maintained. Its activities are: quality planning, quality control and quality checks.
Q-plan	The Q-Plan is the central document of QM for Biomass DH Plants in which the quality requirements (incl. instrumentation, measuring method and tolerance) and the responsibilities are defined before the realisation of the plant and are regularly checked and updated during the further course of the project. The Q-Plan consists of two documents: • Main document, created during the establishment of QM for Biomass DH Plants in milestone 1 • Additional document, with an EXCEL table, which is created by QM for Biomass DH Plants when each further milestone is reached. The additional document is used for quality control and quality steering during the project (see chapter 2.3.4).

Term	Meaning
Quality (Q)	Relation between the standard of the material or immaterial object (here: the biomass heating plant and the heating network) and the expected quality (usually consisting of a sum of individual quality requirements). Good quality means here that the realised project fulfils all quality requirements agreed in the Q-Plan within the agreed tolerances.
Quality checks	Ongoing checks during the course of the project and in particular at the end (final check) to determine whether the quality requirements agreed in the quality plan are within the agreed tolerance.
Quality control (Q-control)	Definition of measures in the project process, which ensure that quality deviations are detected and corrected in time.
Quality Management (QM)	Includes the methodology and all activities that define the quality requirements and responsibilities and implement them through quality planning, quality checks and quality control.
Quality planning (Q-planning)	Unambiguous definition of the quality requirements including responsibility, instrumentation, measurement method and tolerance in a Q-plan. It ensures that the individual requirements listed in the Q-plan comply with the recognized rules of construction and the current state of the art.
Quality requirements (Q-requirements)	Individual requirements that are placed on the quality of a system. In QM Holzheizwerke, the quality requirements for a biomass heating plant are defined in the Q plan. The quality requirements are formulated in detail in the Q-guideline.
Quench	The quench is an optionally integrable part of a flue gas condensation plant. In a quench, a hot flue gas stream is cooled down to the saturation point by injecting water. This allows a better heat recovery (heat transfer) from the flue gas. The saturation of the exhaust gas also ensures that the downstream condenser is always operated wet to prevent fouling and corrosion. The water injection also "washes" dust out of the exhaust gas. Quenches are therefore also a component of flue gas scrubbers, where the injection of water binds dust in the flue gas flow and separates it in downstream droplet separators (e.g. centrifugal separators).
Redundancy	Provision of an additional functional unit that is not required in regular operation as a backup to increase operational safety (e.g. installation of a second pump of identical design).
Route Route length Routing	The route is the premises required for the laying (routing) of the district heating pipeline. The determination of the route is part of the planning of the district heating network and has a significant influence on the development of the supply area and future network expansion as well as the investment costs of a heating network. The route length is the total length of the route of the main, branch and house connection pipes in metres (in German also referred to as “Trassenmeter” - trench metres [Trm]). For one pipe each for flow and return, the pipe length is twice the route length.
Secondary side	The secondary side of a transfer station is the building side, i.e. the part of the system through which the heating medium of the domestic system flows. The terms secondary flow and return temperature are those temperatures that prevail on the secondary side (building side) of the heat exchanger. Analogously, the term secondary pressure (see also primary side).
Service life	Service life is the period of time during which systems, machines or tools can work until the next maintenance, cleaning or similar has to be carried out. It is the period of time during which the system (machine, tool) can work without interruption.
Stack	In forestry, the term stack or wood pile is used to describe stacked logs of the same length which are stored in collection or timber yards.
Stoker (stoker screw)	Conveyor unit with which the fuel is fed directly into the combustion chamber or onto the combustion grate. It is thus the last link in the fuel transport from the fuel storage to the furnace. The stoker can be designed as a screw conveyor, hydraulic insertion or others (e.g. throw feeding with spreader stoker). The stoker must ensure a uniform fuel feed and meet special requirements with regard to air exclusion, backfire prevention and temperature resistance.
Target value	Value that has been demonstrated in comparable, successful projects. If a target value is given for a Q-requirement, this means that this value should be aimed for. However, there may be good reasons to deviate from this target value, but deviations should be justified. (In contrast, a limit value may not be exceeded or undercut).
Tariff (tariff sheet)	The tariff sheet is part of the heat supply contract and regulates the prices, tariffs and other conditions for the provision of heat (see also heat supply contract).
Technical Connection Requirements (TCR)	The technical connection requirements (also technical connection standards) ideally regulate all technically relevant connection conditions to a district heating network such as pressure, temperature, material, measuring equipment, billing and others. These apply to the planning, connection and operation of the district heating network. The TCR are part of the heat supply contract (see chapter 8.9.2).

Term	Meaning
Temperature spread	Difference between flow and return temperature or inlet and outlet of an appliance. In a district heating network, it is mostly the temperature spread of the primary side that is of interest, i.e. in the district heating network, in the case of heat generators between inlet and outlet and in the case of storage tanks between top and bottom.
Tendering and contracting	Project phase in which the tender project is put out to tender and awarded. The term tender planning is also commonly used. This includes the preparation and dispatch of the tender documents, the preparation of the awarding contract (bid comparison, price comparison) and the participation in the awarding of the contract. The basis for the preparation of the tender is the tender project, which represents the planning status of the plant at the time of the tender.
Transfer station (district heating transfer station, heat transfer station)	The transfer station is the link between the house connection pipeline and the consumer's installation. It is used for the contractual transfer of heat and the measurement of heat consumption.
Utilisation rate, annual efficiency	The degree of utilisation is the ratio between the useful energy produced in a defined longer period and the energy supplied in the same period of time. This corresponds to the total useful energy in the defined period (e.g. by reading the total heat on the heat meter) divided by the supplied energy added up over the period under consideration (e.g. the calorific value of the fuel). If the observation is made over a period of one year, this is referred to as the annual efficiency (see also chapter 20.12). If the ratio of useful energy to supplied energy is determined over a short observation period or as an instantaneous value, this is referred to as efficiency (see also efficiency).
Waste heat	Waste heat is the term used to describe heat flows that occur as a by-product of processes and are released into the environment unused and often with the help of additional energy for pumps, fans, re-cooling heat exchangers or refrigeration systems and contribute to unwanted heating (see chapter 13.7.5).

22 Literature

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