Chapter 6
Flexible Heat Provision from Biomass

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Abstract Heat demand in households always depends on the building, the behavior of the inhabitants, the weather conditions as well many other factors. Therefore, there is always a fluctuating and often not very predictable need for heat. As heating systems have solved this problem for some time now, all heat generators are basically demand-based. Depending on the technology, heat buffering systems are sometimes required. Generally speaking, improved efficiency and low emissions were often achieved in the past by reducing start and stop procedures and applying some kind of base load heat generation. These kind of systems are very commonplace, providing the majority of renewable heat – not only in Germany but also in many other countries. In the future, heat from biomass will have to compare with other renewable heating options and will assume the role of securing heat provision at those times when temperatures fall considerably, when there is limited electricity available in the grid from renewables or when solar thermal systems are not working. This means that the biomass heat generators have to become more flexible in load changes over the total load range without increasing emissions and without significant efficiency losses. Basically, an appropriate design of the conversion system and its conceptual integration will enable a flexible heat supply through solid biomass. The available technologies and concepts for heat supply from solid biomass can be optimized by improved control units, automatic feeding, as well as additional heat storage systems. Consequently, there are a number of options to support the transition to a more renewable-based energy supply, also taking into account better insulation and a fall in the demand for heat in the housing sector. Nevertheless, this transition is more of a vision for decades to come and is still only just emerging in Germany.

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6.1 Introduction

Heat is an important final energy use, which can be provided from biomass by different bioenergy carriers and technologies. While the previous chapters included concepts for the combined heat and power provision from biomass, this chapter focuses on the heat-only provision from biomass and the demand for transition in this field. The first section provides an overview of the existing bioenergy carriers and concepts for heat from biomass and future demands for more flexibility are discussed in Sect. 6.2. A more detailed analysis is then provided on the technologies and concepts of heat supply from solid biomass as the most important bioenergy carrier by far for heat provision (Sect. 6.3). Based on the state of the art in Germany (Sect. 6.4) options for a more flexible heat provision in existing plants are then explored (Sect. 6.5) and technical options for new concepts are illustrated (Sect. 6.6).

Finally conclusions are drawn with regard to the more important fields of flexible heat supply during a transition of the energy system and the effects of stronger relationships between power, biofuels and heat markets are demonstrated (Sect. 6.7).

6.2 Heat Supply from Biomass: An Overview and Clarification of "Flexibility"

General Aspects The conversion of biomass to heat is by far the biggest application field of bioenergy worldwide. Even in industrialized countries such as Germany, the heat supply from biomass represents the greatest field of application regarding bioenergy.

Nevertheless, the field of bioenergy will face extensive changes. This assumption is based on recent developments, such as rising costs for oil and natural gas, more stringent regulations in terms of energy saving as well as energy use in building (European Standards, energy saving regulations, laws regarding the minimum amount of energy used from renewable sources) and the increasing amount of partial oversupply of electricity in the grid from renewables. Unlike a combined power and heat supply, which always has to be equipped with a large heat buffer, the heat supply from a flexible operated firing can provide the possibility of optimized overall economic efficiency. In the future, this kind of optimization will become increasingly important due to:

(A) the need for adaptation to a fall in the demand for heat through improved building insulation and
(B) the need for an increased integration of fluctuating, alternative and renewable energy sources.

In most parts of the world a heating system is required for at least some time of the year. However, the allocation of heat usually underlies seasonal fluctuations. On the contrary, domestic hot water (DHW) or process heat is needed throughout the

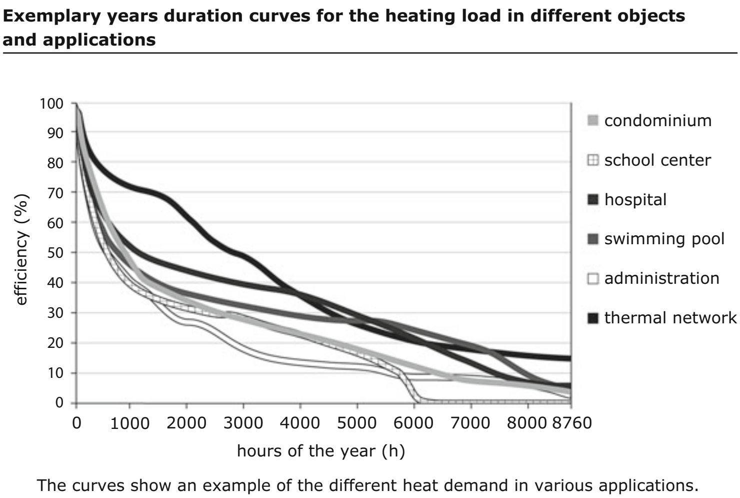

Fig. 6.1 Average heat consumption curves for space heat and DHW in Central Europe [10]

year (see Fig. 6.1). This leads on the one hand to a long-term variation in the average (space) heat demand per day and on the other to a demand for space heat, DHW or process heat that can change rather drastically during the day.

Seasonal fluctuations in demand for heating as well as the possible supply of renewables can only be compensated through heat buffering, which involves tremendous effort and high energy losses or the storage of biomass for demand-oriented conversion. However, short-term fluctuations can partly be balanced through the thermal inertia of heat distribution, user behavior or a well-organized heat buffer size. Even small heat buffer storage tanks can result in investment costs and thermal losses. Therefore, an economic and energetic optimum between the size of the buffer, the frequency of use as well as the flexibility of the boiler has to be found.

Heat Provision Options from Biomass The heat supply from biomass can be based on solid, liquid or gaseous bioenergy sources:

1. Biomethane will be used as a natural gas substitute, obtained through the natural gas distribution system or a gas tank. Furthermore, the same conversion plants are used with the standard start-up and stopping time, extremely small thermal masses and the ability to provide DHW (with a temperature of 70 °C) in less than 1 min. With respect to the great quality of fuel gas used in combined heat and power engines, it is rather unusual in Germany to only use biomethane gas for the purpose of heat production. Globally, biogenic gas is more frequently used for cooking or lighting as opposed to only heat allocation [9].
2. From a current day perspective, the use of biogenic oil as a general source for heat production is not to be expected (excluding niche applications such as bio-ethanol stoves) [6].

3. Heat supply from solid biofuels can involve manually or automatically-fed furnaces with the most common fuel being wood. Solid fuels have numerous advantages such as almost unlimited storage stability in the right places, ease of storage on site and their associated flammability at all times. Due to these advantages solid biomass seems to be a very promising option for a flexible heat production.

On closer inspection of the technologies available, it is easier to identify their limitations. For example, fireplaces or burn-through wooden log boilers can only stop their heat supply (once ignited), when the entire fuel batch has been fully combusted. Besides which, for a long time the efficiency and the reduction of emissions was the main priority of automatically-fed boilers. Other related goals include long, undisturbed operating phases and only a few starting and stopping cycles. To meet these targets, many combustion chambers were fully faced with fireclay. This however also means reduced ability to adjust the power. With respect to the supply of DHW, the difference between gas and solid biomass furnaces becomes very clear. A gas furnace is able to produce heat immediately according to the user's requirements. However, a solid biomass boiler usually needs a DHW tank to be regarded as an as efficient heat supply. Hence, there is still tremendous scope for research on the flexible and demand-oriented provision of heat from solid biomass, and enormous potential for its optimization. Consequently, this chapter will concentrate on solid as opposed to gaseous or liquid biofuels.

Evaluation Basics for Flexible Heat Provision from Solid Biofuels The flexibility of heat provision technology is defined by the time needed from the first occurrence of a control signal to the stable output of the heating power required. As heat provision from biomass always has to be compared with gas or oil boilers, the time perspectives were oriented to these technologies. Further limitations were presented by the typical inertance found in heating systems, e.g. a central heating system requires a certain amount of time to transfer the hot water from the boiler to the radiators, so a few additional minutes are not really noticed by the customer, whereas a time lag of more than 6 min would be noticeable. With some internal buffers and some forecasting, up to a 30-min time-lag could be acceptable, especially for space heating. Anything longer than this time lag would be considered a problem in most cases with the need for further investment. For a time lag over 6 h, these investments would become considerably high (see Table 6.1).

Table 6.1 An overview regarding the flexibility evaluation depending on the time needed to achieve a stable command variable

Evaluation factor	Symbolic acronym	Time between the control signal and reaching the demanded heating power
Very high	++	Less than 30 s
High	+	More than 30 s and up to 6 min
Medium	0	More than 6 min and up to 30 min
Low	–	More than 30 min and up to 6 h
Very low	––	More than 6 h

6.3 Technologies for Heat Provision from Solid Biomass

In particular wood with different qualities is used within the biogenic solid fuels. Nationally, the amount of wood used to provide heat from biofuels exceeds 99 % [7]. Depending on the regional conditions, other biomass is also used such as waste products from the food industry (e.g. nut shells, seeds, damaged grain, husks, grain strip waste, brewer's spent grain, grape marc and mash from breweries) or different kinds of straw. Especially in developing countries, dung is frequently used for cooking and heating purposes.

With respect to the flexibility of the different plants, the whole conversion chain (fuel to thermal use) has to be considered:

- Type of biomass and biomass quality (water content; dimension; ash content; homogeneity)
- Biomass conversion technology (heat generator)
- Plant concept/operation concept
- Heat storage on site
- Type of heat utilization (among other things internal heat storage of the user)

The single elements are displayed in Fig. 6.2.

All of the elements mentioned have their individual time constant in terms of flow capacity as well as the ability to store intermediates. Furthermore, they also have their own options in terms of an ongoing transition to a flexible heat supply.

6.3.1 Type of Biomass and Biomass Quality

In most cases wood as log wood, chips, pellets or briquettes is used for heating purposes. Agricultural fuels as for example straw or energy grain are used only in very few cases and especially in furnaces with more than 100 kW nominal load. Solid biomass can be converted into heat with the appropriate technology, as long as the gross calorific value of the wet and ash-containing biomass is positive. The water content, the fragmented size and shape of the biomass, but also the ash content and conformity of the fuel will all determine the appropriate technology.

The quality of the fuel affects the storage properties. Table 6.2 shows some of the most important relationships.

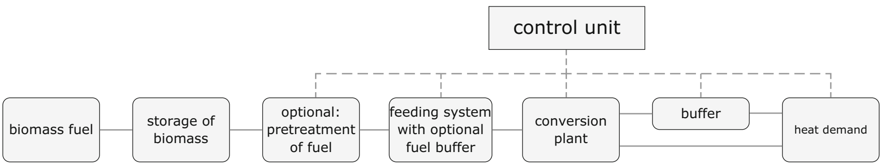

Fig. 6.2 Basic components of heat generation from biomass

Table 6.2 Storage effects of wooden biomass depending on the fuel quality

Parameter	Connection	Effect on storing
Higher water content	A water content higher than 30 % leads to a higher biological activity of the bacteria, causing a reduction of the biomass by heat release. In a huge pile the released heat can hardly be managed, leading to an increased temperature of the pile.	Increased danger of degradation, mass loss or self-ignition
Rougher fragmented size	Without measures to make bulk material more compact, a rougher fragmented size usually causes more openings within the pile. Therefore, the gross caloric value regarding the volume decreases.	More space required to store a certain amount of energy
Higher ash content	The ash bound or attached to the fuel reduces the gross calorific value in terms of the mass and in the end also the gross calorific value in terms of the volume.	More space required to store a certain amount of energy
Higher heterogeneity of the fuel	Heterogeneous fuel dimensions lead to an easy creation of nests or bridging.	Increased danger of transportation disturbances in the fuel storage and in the feeding systems

Table 6.3 Relationships between fuel quality and the flexibility of the operating state of the combustion plant

Parameter	Connection	Effect on flexibility
Higher water content	Additional drying areas within the combustion are needed; more internal buffering to maintain the temperature is necessary	Higher minimum power during operation and slower power adaptation
Rougher fragmented size	A higher amount of fuel is necessary in the combustion plant; a greater variation of the feeding dosage; a greater variation during combustion	Longer reaction time to change the heating power output
Higher ash content	Gross calorific value decreases; afterglow of a comparatively large amount of material in the firebed; partly-burned fuel needs longer to reach the necessary temperature	Difficulties stopping and reigniting the combustion
Higher heterogeneity of the fuel	Fuel-related variation of the primary reaction has to be balanced by internal buffering and sufficient fuel	Longer reaction time to change the heating power output

These factors in addition to the conversion technology used are crucial for safe combustion, low emissions and the time needed to achieve a stable transition of the operating state in terms of heat output. Some of the most important relationships are listed in Table 6.3.

Besides the above-mentioned points (Table 6.3) the fuel and its quality affect the combustion technology. For example, moist fuel is usually burnt in a grate firing to enable an internal drying zone to be integrated. Because of the slower reaction time compared to underfeed furnaces, the reaction times to changes in demand increase significantly without any additional measures.

6.3.2 *Biomass Conversion Technology (Heat Generator)*

Biomass-based heat supply in industrial countries is usually subjected to requirements other than technological ones (e.g. aesthetics in the living space). Therefore, a number of different technologies are available with the main principles in common of drying, primary conversion and following combustion (in a technical facility) (e.g. underfeed furnaces, site feed firing, grate firing and dropping firing). Each of the technologies has its own advantages and disadvantages regarding the flexibility of heat production (see [5]).

Due to the wide range of biogenic fuels available and the scope of demand for thermal power output, further variations can be added to the large number of technologies available.

For example, the combustion plant can be used as a sole firing or base load boiler. Depending on the type of application, the fireclay lining of the combustion chamber will vary. Therefore, the thermal inertia of the plant will also vary as will the adjustment speed to different heat demands (see Fig. 6.3).

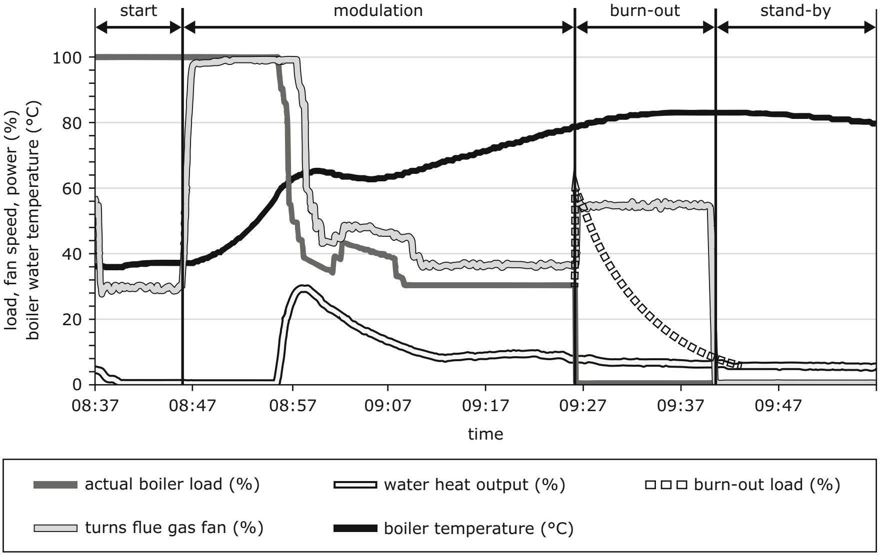

Fig. 6.3 Example of the reaction time of a pellet boiler on start up, load change and burn-out (turns flue gas fan means measure for the speed of the flue gas fan counted in numbers of full turn around compared to the maximum number of turn around possible; burn-out load means thermal power output during the burn-out phase without new fuel input and reduced air input until stop of thermo-chemical conversion compared to the maximum thermal power output)

All of the parameters mentioned lead to a high degree of variation in the time constants needed to evaluate flexibility. Table 6.4 shows some of the most common combustion technologies with their average reaction times.[1]

6.3.3 Plant Concept/Operation Concept

The plant concept[2] focuses on different aspects and is usually decided upon at the onset of a project. The central part of the concept is the technology of the biomass conversion unit and whether it is used as a stand-alone heat source or in combination with other heat supply units. The plant/operation concept is influenced by a variety of factors like for example available fuels, space, logistic options, existing heat sources, heat demand structure, personnel.

Based on the heat supply only, some of the basic concepts can be summarized as follows:

Single room fireplace for additional heating. Solid biomass is used in a batch operation mode meaning that the manually-fed fuel is burnt in the combustion chamber one load after the other. Heat is transmitted by radiation through a window and by convection through the walls of the furnace to the surrounding room. The technical development status can vary from one furnace to the other. However, all furnaces have one thing in common. If a combustion load is ignited, it cannot be shut down easily. The heat output of single-room fireplaces usually varies within the range of a few kilowatts (kW). Most of the single-room heaters are not connected to the central heating system and are used only as a separate additional heat source. No buffers or control units are integrated.

Monovalent, mono-fuel central heating system. By means of a biomass boiler heat is produced at a central point. After that, it can be distributed by a suitable heat transfer medium within the building. The plant is designed to guarantee the required heat supply (including DHW supply) throughout the year without an additional heat generation unit. The fuel can be fed to the biomass boiler in two different ways. The log wood boiler is fed in batches with a maximum of two loads per day. An automatically fed boiler (e.g. pellet or woodchip boiler) is fed automatically from the fuel storage as necessary. Most systems have a DHW tank as well as a hot water tank for heating purposes. In most cases, the heat distribution is carried out through hot water but in some cases hot air is used. The combination

[1] According to the wide range of different technologies and constructions, all of the given values are only an average of the total, describing as many of the technologies and constructions without becoming too unspecific.

[2] For the evaluation of the flexibility of heat generation from biomass it is important to understand the difference between conversion technology and the plant/operation concept. The conversion technology is only the heater or the boiler. The plant/operation concept is the conversion technology in addition to all of the components to integrate the heat production into the total heat supply system, e.g. a buffer tank, a second boiler for biomass or even for non-biomass fuels, solar-thermal heat supply and the system control unit.

Table 6.4 Comparison of flexibility for state of the art heat generators

Conversion technology	Fuel quality	Typical thermal power	Start-up time[a]	Range of part load	Time to adjust load	Option to close down	Close down time[b]
Chimneys, stoves and heating inserts	Log wood; w < 20 %	4–12 kW	10–30 min from cold	No	No	Only after full batch	Up to 1 h
Underfeed boiler	Pellets, chips	4–300 kW	10–30 min from cold	30–100 %	5–15 min	Fuel stop and air control to stop the pyrolytic decomposition of the fuel	10–30 min
Grate firing with conversion chambers with fireclay and water cooling	(Wet) wood chips, alternative fuels possible	100 kW to some MW	from 60 min up to 12 h	30–100 % (with very difficult fuels 50 to 100 %)	5–10 min per 10 %- point load change	Either fire keeping without heat output or full cool down program	30–90 min for fire keeping; about 12–24 h to cool down

[a]Start-up time is defined as the time from the signal to start a cooled down boiler from zero power output to the time when the boiler is running constant with a full load power output. Restarting times for a stationary warm boiler can be drastically shorter.

[b]Close down time is defined as the time from the signal to stop the combustion until zero heat output of the boiler. Due to the thermal inertia it could be possible that the boiler still produces heat when the combustion has already finished. In some cases this heat has to be cooled down actively to make the boiler safe. As long as this heat output to the system is running, the close down time is counting.

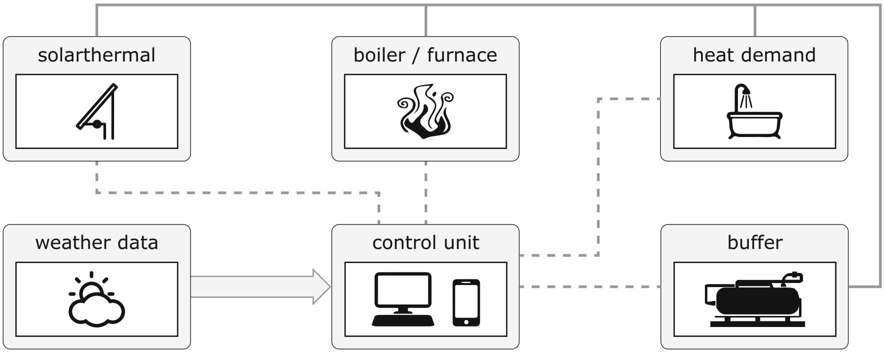

Fig. 6.4 Basic principle of a small-scale biomass mono-fuel heating system combined with a solar-thermal system

of biomass boilers and a solar heating system is quite common. The typical heat output ranges from 4 kW to a few 100 kW. Figure 6.4 illustrates a typical system at present.

Dual-fuel, dual-boiler heating system. To provide enough heat to cover the demand of complex buildings such as office buildings, schools, hospitals or an entire district in the most economical way, different heat generation options can be combined. For example, the system could consist of a biomass boiler to cover the basic load (30–50 % of the possible peak load) and a gas- or oil-fueled boiler to cover the peak load. The comparatively expensive wood boiler is operated using well-priced fuel for most operating hours. The few peaks (on very cold days) can be covered with the far less expensive gas or oil boiler. Hence, the maximum amount of heat provided by the expensive fuel (natural gas or oil) adds up to 30 %. For the overall system, the heat output usually exceeds 300 kW. The heat output of the biomass boiler ranges between 100 kW and some MW. One economic advantage of the concept is when the heat output of the biomass boiler is higher than 300 kW (complete system 600 – some MW).

Besides these three basic concepts, there are also numerous exceptions, new developments and niche applications that are not covered in this book. Nevertheless, the plant/operation concepts mentioned show the main cases that influence flexibility characteristics of heat provision from biomass. The flexibility of these three exemplary concepts is shown in Table 6.5.

6.3.4 Heat Storage on Site

Another decision made within the conceptual design regards the use and size of a heat buffer. Generally speaking, heat can be buffered cost-effectively using different technologies. Depending on the technology used, the costs, storage time and losses can vary. The most important concepts are listed in Table 6.6.

Table 6.5 Comparison of the flexibility of three exemplary state of the art heat provision units for biomass

Heating concept	Surroundings	Start-up time [a]	Range of part load	Time to adjust load	Option to close down	Close down time[b]
Single room fireplace for additional heating	4–12 kW	10–30 min from cold	No	No	Only after full batch	Up to 1 h
Monovalent, mono-fuel central heating system without buffer	4–300 kW	10–30 min from cold	30–100 %	5–15 min	Fuel stop and air control to stop the pyrolytic decomposition of the fuel	10–30 min
Monovalent, mono-fuel central heating system with buffer	4–300 kW	1–5 min	0–100 %	1–5 min	Switch from system heat output to buffering the burn-out heat	Less than 30 s
Dual-fuel, dual-boiler heating system with buffer and system control unit	100 kW to some MW	5–15 min	0–100 %	5–30 min	Either fire keeping without heat output or full cool down program; fossil boiler with fast reaction time	2–5 min

[a]Start up time is defined as the time from the signal to start a cooled down boiler from zero power output to the time when the boiler is running constant with a full load power output. Restarting times for a stationary warm boiler can be drastically shorter.
[b]Close down time is defined as the time from the signal to stop the combustion until zero heat output of the boiler. Due to the thermal inertia it could be possible that the boiler still produces heat when the combustion has already finished. In some cases this heat has to be cooled down actively to make the boiler safe. As long as this heat output to the system is running the close down time is counting.

Table 6.6 Comparison of different heat buffers [3–5]

Technology	Principle	Energy density in kWh/m³	Storage rate in MW	Release rate in MW	Heat loss[a]	Typical size in MWh	Costs in €/kWh
Hot water storage tank	Thermal capacity	<60	<10	<10	10–50 %	<100	0.07–9
Latent heat storage tank	Phase change	<120	<10	<10	10–25 %	<10	9–46
Hot water storage tank with a vacuum insulation	Thermal capacity	<60	<10	<10	2–5 %	<100	28–70

[a]Depending on storage time

Even if heat can be stored more or less easily, Table 6.6 shows that there are significant costs, requirements of space and also energy losses that affect the efficiency of the entire concept. Therefore, the sizing of the buffers is also an important aspect when optimizing a heat supply concept. According to flexibility aspects, the buffer and the buffer integration (heat exchanging capacity) have some additional side conditions in the sizing process. It is most appropriate to use thermal simulation programs that check the efficiency, the costs and flexibility criteria.

6.3.5 Type of Heat Utilization

The heat supply requirements are determined by the use of heat and the convenience demand of the user. Usually, DHW should immediately be available at a temperature of 70 °C and a high flow rate is necessary within a short period. However, the user is accustomed to the thermal inertia of the space heating system. Even if heat is emitted from the radiator within a short space of time, it will take up to several hours to heat cold rooms. Therefore, the DHW supply has to be flexible, whereas the response time of the space heating system can add up to 10–30 min. The thermal inertia of the heating system is accepted because the heat demand can be predicted with a high degree of accuracy. The data used to estimate the required amount of heat relies on data such as indoor temperature measurements and outdoor temperature data. Furthermore, a comfortable indoor temperature requires the heat distribution system to show a certain degree of stability (avoiding air draught). Due to slow cooling, an inert mass (internal heat storage) can be beneficial. It leads to a longer uniform temperature distribution of the room in terms of convection and radiation.

The demand for hot water steam is rather common in industrial areas and yet steam heating systems have mostly disappeared by now. The demand for vapor can vary considerably depending on the technical process. Usually, the amount and time of vapor demand are known and the necessary response time is incorporated.

However, the efficiency of the overall system depends on its ability to respond quickly to demand fluctuations. Since steam generation and steam quality require a much more detailed explanation and discussion, they will not be considered at this point.

6.4 State of the Art

Globally, solid biogenic fuel is mostly converted by means of fireplaces for individual rooms. The range of technologies used is exceptionally diverse, covering everything from simple open fireplaces (traditional biomass use) to high-end stoves (modern biomass use) (Fig. 6.5).

Developing and newly industrialized countries still use individual combustion plants to provide heat, which is often their only option. By contrast, industrialized countries, such as Germany, use combustion plants as an additional heat source or even as a luxury good. Pellet stoves are often used as the only heat source for an entire building in developed countries with a low heat demand throughout the year (e.g. Italy). If a higher space heating demand is given (e.g. in Germany or Austria), automatically-fed boilers using wood pellets or chips are used. These boilers are usually able to operate without any assistance and can be compared to an oil or natural gas combustion system. Most of the biomass heat units in the world are however open fireplaces or very cheap stoves or cooking stoves. Even in industrialized countries like Germany however there are still about 14 million single room heaters while there are only about one million boilers installed.

Although there is a lot of discussion about greater efficiency regarding all aspects of the energy supply, there have been no obvious significant changes in the installation numbers of the different heat supply technologies using biomass as a fuel. There has indeed been an increase in the number of pellet boilers installed in Germany every year by a factor of four over the last 10 years. Nevertheless, a total

< 10% | ca. 30% | 80-90% | 83%

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Fig. 6.5 Variety of wood stoves with varying degrees of efficiency (Open fireplace Pakistan; Heating and Cooker Pakistan; Typical stove Germany; High-end stove Germany) [2, 8]

Table 6.7 Evaluation of existing operation flexibilities (for description of symbols see Table 6.1)

System	Biomass combustion plant			Plant concept		
	Start-up	Close down	Thermal power variation	Start-up	Close down	Thermal power variation
Single room fireplace	0	–	Not possible			
Monovalent, mono-fuel heating system without heat buffer	0	+ to 0	+ to 0	0	+ to 0	+
Monovalent, mono-fuel heating system with heat buffer	0	+ to 0	+	+	++	+
Dual-fuel, dual-boiler heating system with heat buffer	– to ––	0 to ––	0	+ to 0	+ to 0	+

of 28,000 units recorded for 2013 is still a very small figure compared to the grand total of 300,000–500,000 new stoves installed per year.

Typical influences on the development of technology are coming from air quality regulations. The combustion of biomass using poor technologies leads to high emissions of e.g. particles. For Europe (including Germany), action has been taking place to reduce the concentration of airborne particles. Therefore, the small-scale combustion regulation [1] in Germany was modified in March 2010 with a significant impact on biomass boilers. Because the boilers will have to achieve very low particle emissions in their everyday operation, there will be improvements to better control the combustion units and greater automation in terms of cleaning, combustion adjustment and emission reductions.

Until now, the flexibility of the combustion units has only been a question of reducing emissions and improving efficiency and competitive advantage by avoiding a heat buffer. In heat supply concepts, the flexibility of the heat supply has in most cases often been a question of buffer size. Hence, little attention has been given to improving the flexibility of the biomass-based heat supply. According to the time values given in Sect. 6.2 and the evaluation criteria of Table 6.1 the state of the art of flexibility of the most common options are listed in Table 6.7.

6.5 Options to Improve Flexible Heat Provision in Existing Plants

Improvements of existing plants are always limited to cost-effectiveness. As the biomass-based heat supply is related to rather high investments, in many cases it can take over ten years to break even. Therefore, adjustments to the installations should not change the basic installations. As a result, in most cases only adjustments to the conversion units and the links between the components are possible, as well as some modifications to the system control.

Single Room Fireplaces as Additional Heating If one considers the flexibility of the heat supply, single room fireplaces fuelled by wood logs (not pellets) are characterized by batch combustion. Therefore, an open combustion can simply be stopped by extinguishing the fire. Otherwise, one would have to wait for the combustion process to complete to ensure safety and low-emissions from the heat supply. Nowadays, the furnaces installed do not allow significant power adjustment. The delay between the ignition of a wood log and the maximum output is also significant. Nevertheless, as an additional heating source, the most critical point in terms of flexibility is a reduction or even stopping of the heat output as even the quickest of central heating systems cannot compensate the overheating of the fireplace in the state of the art fireplace installations. There have been several attempts to equip single-room fireplaces with automatic ventilation flaps. Currently, the main focus has not been on power regulation but on the optimization of the combustion process. Under certain circumstances, the user is able to influence the heat output as well as the combustion period of the firing. E.g. if the allowed amount of wood in the firing is not completely exploited or if the firing is refilled with small amounts of wood. Until now however there are still no sufficient technologies available on the market.

Monovalent, Mono-Fuel Heating Systems As shown in Fig. 6.4, these systems consist of a biomass heat unit that is integrated into a central-heating system. Regarding the heat supply to the heat distributor, it can be distinguished between the response time of the firing unit and that of the overall system, possibly with a heat buffer. Boilers used in combustion plants without a hot water storage tank usually have little internal mass capacity. This leads to a higher reaction rate to power adjustments. Concepts including a hot water storage tank usually feature a higher thermal inertia to stabilize and optimize the combustion process. Therefore, slight differences with respect to firing and strong differences related to the concept of the plant arise and are presented in Table 6.7.

The heat buffer mainly contributes to the shortage of the response time, supplying heat to the distributor. To ensure an optimized operation of both boiler and buffer, the most important facts are: a very specific design of the buffer size, a suitable connection of the boiler and the buffer as well as a working control system. When evaluating a monovalent combustion plant with a heat buffer, three things are fundamental. Firstly, the flexibility of the overall system, secondly, the additional costs for pipe installations and the control system and lastly the additional heat losses of the buffer are essential. These concepts usually provide enough flexibility for common heating and DHW applications. If other technologies, such as solar heat or heat pumps are included in the system, a heat buffer is in any case essential. The heat supply of these systems not only competes against biomass combustion plants, but is also able to provide heat irrespective of the actual demand. In terms of the high initial recognition costs of the solar heating system, the system can only be operated economically if most of the heat produced is used.

To improve the flexibility of the system without changing the boiler, a heat buffer can be integrated if it has not already been installed. Together with an adjusted control unit, the response time to fluctuations in heat demand can be reduced. It has to be recognized that light boilers typically operating without a heat buffer are usually not made to operate at full loads for a long time. Therefore, it is important not to oversize the buffer, to avoid increased abrasion. For a typical house, additional costs including installation are about 1,500–2,500 € for the buffer and the control unit. Besides improved emissions, there could also be an increase in annual efficiency of up to 5 %-points.

To continue to operate a monovalent, mono-fuel biomass heating system without a buffer, it can be upgraded with a power-to-heat unit. With this technology, a continuous-flow water heater can be combined with the biomass combustion plant. The integrated control system will recognize whether or not the heat demand is covered by the electricity or the biomass combustion unit or both. The electrical heater and the control system add further installation costs of about 1,000 € for a typical house. As the electrical heater can start very quickly, the start-up time to deliver heat is drastically reduced. For shut down it is only a help, if a prognosis tool shuts down the biomass boiler in advance and adds the missing heat generation from the electrical heater.

A less technical option to increase the flexibility of an existing system is to change the biomass fuel from a varied fuel (e.g. wood chips) to a more definite fuel (e.g. wood pellets, see Chap. 8). In combination with an adjustment of the boiler and the system control unit, reaction times can then be reduced significantly.

Dual-Fuel, Dual-Boiler Heating Systems The basic idea behind a dual-fuel, dual-boiler heating system consists of the biomass combustion covering most of the full load hours of a year (at least 3,000 h per year). Since a biomass combustion plant is rather expensive, it has to be extremely well-sized, compared to an oil or gas combustion system. The obtainable operational mode also allows the use of biomass of a lower quality, e.g. wood chips with a higher water or bark content. It is mostly grate firings with a fireclay lining of the combustion chamber that are used. These have a high thermal inertia and react very slowly to a change in the demand for heat output. The necessary flexibility of the overall system is usually ensured by the oil or gas combustion plant or a heat buffer. Normally, bi-fuel heating systems with a higher heat output do not operate with a separate hot water storage tank but by using the heat transfer medium within an extensive distribution system (heat pipes between buildings; hydraulic separator). Therefore, the reaction rate is lower compared to a monovalent heating system with a heat buffer (see Table 6.7).

The state of the art of these bi-fuel systems is not very flexible according to the biomass heat generator. If the oil or gas use should be reduced or replaced by other renewable energies such as solar thermal, heat from heat pumps working with renewable energy or even from using the excess of renewable energy from the grid, the flexibility of the system can no longer be guaranteed by the oil or gas component. Therefore, the biomass unit, the system control unit or the buffer possibilities have to improve according to flexible work.

One option for the boiler can be to change the fuel to a more standardized one. A major problem for these systems that economically depend on cheap biomass fuels is the increase in biomass costs. Another option is to add a small and flexible biomass boiler that reacts to all load changes while the basic biomass boiler continues to run with reduced power output at a more or less stable level. If there is enough space for installation, this means additional costs of approx. at least 100,000 € for a 100–150 kW boiler. Additionally, the system control unit has to be improved and in many of the state of the art systems even exchanged. Last but not least, more thermal buffer capacity can be integrated with quick heat exchangers. Again however, costs and additional losses will imply both technical and economical limitations.

General Aspects of Heating Systems The optimization of the system controller is very important. From better forecasting, the contribution from other heat sources such as solar heat or excessive electricity in the grid, a better planning of buffer loading and combustion operation is possible. This results in fewer limitations of the firing flexibility. The predictive presumption of a changing heat demand decreases the response time of the overall system. Therefore, manageable costs for measurement and control devices as well as the connection to the internet arise, allowing a higher flexibility of the heat supply.

Another interesting option is the use of excess heat to dry the fuel during storage (e.g. with high water content), which is partly practiced today. In this way, losses through cooling or fuel residual heat can be used effectively. This leads to a shorter starting phase through dry fuel and a shorter stopping phase.

Table 6.8 shows the flexibilities that could be achieved by the improvements described to existing systems.

Table 6.8 Evaluation of operation flexibility of improved existing heating systems (for description of symbols see Table 6.1)

		Plant concept		
System	Measures	Start-up	Close down	Thermal power variation
Single room fireplace	Automatic air control or fuel amount change by user	0	0	+
Monovalent, mono-fuel heating system without heat buffer	Fuel change to more standardization	0 to +	+ to 0	+
	Integration of a heat buffer	+	++	+
	Integration of an electrical heater with improved control unit	++	+ to 0	+ to ++
Monovalent, mono-fuel heating system with heat buffer	Fuel change to more standardization, better control unit and integration of an electrical heater	++	++	+ to ++
Dual-fuel, dual-boiler heating system with heat buffer	Integration of an additional flexible biomass boiler with standardized fuels; improved control unit with prognosis tool	+	+ to 0	+

6.6 New Concepts for Improved Flexible Heat Generation from Solid Biomass Fuels

In the future, renewable energies alone are supposed to be able to provide almost the entire heat supply. Furthermore, the electricity supply is going to include more energy from renewable sources leading to a temporarily higher fluctuation as well as more favorable prices. Therefore, the priorities for the use of biomass are going to shift, focusing on the heat supply. Energy sources such as solar thermal and geothermal will primarily be used at low and medium power costs and power-to-heat with a current surplus in the power grid. Biomass is going to close the remaining gaps due to a lack of supply or because of economic favorability. Therefore, a future heat provision from biomass will need new concepts.

Single Room Fireplaces Preliminary attempts have been made to further develop single room fireplaces to enable a more flexible operation, even if wood logs are used. Options that enable power adjustment in a single room fireplace using wood logs include: the installation of ventilation flaps, a targeted ventilation duct with a separation of pyrolysis, gasification and combustion air, the integration of burn-off sensors and an automatic control system.

The integration of a water pocket in the firing influences the heat output to the surrounding area, benefiting the heat distribution through the hot water system. Connected to the heat buffer and a centralized heating system, the flexibility of the single room fireplace is similar to that of boilers with a heat buffer. Moreover, a combination with other renewables also becomes possible (e.g. a heat pump with a single room fireplace with a water pocket).

Table 6.9 shows the most important differences in terms of operation flexibility compared to changing investment costs.

Monovalent, Mono-Fuel Biomass Boilers In the future, new installations with this particular heating system concept will only be applied in exceptional cases.

Renewable Heat Station The existing dual-fuel, dual-boiler systems with a base load biomass boiler for cheap biomass fuels together with very flexible oil or gas

Table 6.9 Technical development concepts of single room fireplaces in terms of flexibility and investment costs (for description of symbols see Table 6.1)

Development	Principle	Start	Stop	Alteration of load	Additional costs[a]
Automatic log wood combustion	Wood gasification for single room fireplaces	0	–	+ to 0	100–200 %
Water pocket	Heat output loading the buffer	0	0[b]	+ to 0	50–100 %[c]

[a]Further costs compared to a similar plant without an alteration in %
[b]In terms of a power reduction to 10 % in the room
[c]Without cost for heat buffer or further heat distribution

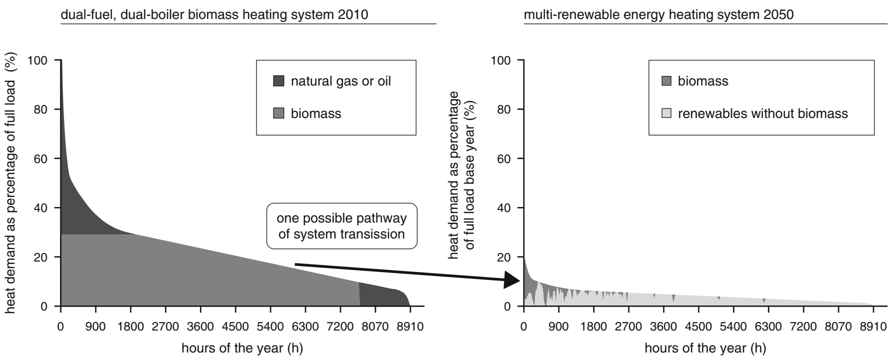

Fig. 6.6 Changing a dual-fuel, dual-boiler system to a renewable heat station

boiler for peak heat demand will become rare in the future. Under the precondition of a strong political target to cover most of the heat supply in the future by renewable energies, there will be a preferred heat use from solar thermal systems, heat pumps and heat from surplus electricity. One option for bioenergy could be to use it only for the missing provision. Due to high fluctuations of the heat sources mentioned, the production of biomass heat must become much more flexible to fill the gap (see Fig. 6.6).

At the nucleus of the renewable heat station is a central control unit that checks all the data of the current and the future heat input of different non-biomass sources as well as the data on demand and the buffer loading. By calculating the missing production, a control signal is sent to the biomass conversion plant. Due to quick changes in the provision from other renewables and differences between real production and prediction, a short response time from the control unit is important to minimize energy costs and losses.

To enable a prioritized use of other renewable energies and to achieve the necessary flexibility, one possible option is to limit the access rights of the biomass combustion for the heat storage volume by the control unit. This does mean however that an optimization of the boiler is necessary in terms of short starting and stopping phases as well as a shorter retention period.

To reach these goals the first step is to develop new ***high-end fuels*** (see Chap. 8). It is hoped that more defined fuels will display better ignition, dosing and burning properties. These properties can result in a smaller firing and less material used to create thermal inertia and therefore shorter response times. A popular method is the transition from wet wood chips to a pre-dried fuel that is easier to use in doses such as wood pellets according to DIN EN 14961–2 and DIN EN 14961–4. Future fuels such as advanced solid biofuels (see Chap. 8) have a higher volumetric energy density, enabling more defined ignition and gasification conditions. Due to a small concentration of volatile compounds or oxygen (from an interrupted primary air supply), it should be easier to terminate the combustion process. To exploit the full potential of these new fuels, an adaptation of the combustion units is necessary.

Compared to premium-wood-pellets, additional costs will arise. These costs will add up to 20–30 % and will be passed on to the customer.

For low thermal outputs in particular, the controllability has to be high. One way of achieving this focuses on the size reduction of the fuel particulates. For example, pellets with a 4 mm diameter and 10 mm length are possible. Furthermore, granulates or pressed fuel balls with a 5 mm diameter are also suitable. This would lead to additional production costs (about 5–10 % of today's production costs), which are feasible.

New boiler developments were necessary not only to exploit the potential of new fuels but also to build units with much greater flexibility according to changes in demand. One trend considers the realization of less inert firing systems with less fireclay or refractory concrete inside the combustion chamber. Besides that, other approaches are also possible.

With the concept of gasification, a primary and secondary separation of the combustion chamber can be carried out more clearly. By means of an optimal integration of a controllable flue gas recirculation with variable water injection, the flue gas production can be altered quickly to a certain extent. In connection with a modular heat exchange concept, allowing an adjustment of the heat exchanger performance, the velocity of the power adjustment will increase. If necessary, an injection of biogas from a network or a cartridge will increase the power for a short period of time, allowing the starting time to be reduced.

To reduce the cold start-up time, the primary reaction zone can be heated by the circulating hot flue gas just like a "small cooling circuit". The primary reaction zone can also be pre-heated by the heat from the hot water storage tank and the primary and combustion air can also be pre-heated.

An improved flexibility of the firing at low combustion capacity is particularly necessary to keep the partial heat buffer costs within an acceptable range.

There are also quite promising options to increase the flexibility of the biomass boilers where the response times required will only be achieved in combination with a buffer. Existing installations have some disadvantages that should be solved within a ***new heat buffering concept.*** The fixed size of the existing heat buffers is a limitation for adjusting the system to the different storage needs over the seasons of a year. In large buildings, cascade connections for buffering systems are already used. This concept can also be applied to smaller plants, but should still involve one closed component. One possible solution could be to integrate vertical separators into the buffer tank, to reduce or to extend the active buffer volume depending on the storage demands.

In larger facilities, a combination of biomass combustion to cover the basic load and a very flexible boiler to cover the peak load can be applied. The combustion chamber of the peak load boiler is lighter and more flexible then the basic load boiler. If necessary, a connected upstream gasification system can be used. In this way it should be possible to avoid seasonal fluctuations. Through adsorption and absorption heat pumps for generating cooling in the summer, the annual demand for heat can be adjusted and organized more efficiently.

Table 6.10 Comparison of the technical components of a newly developed heat station in terms of flexibility and investment costs (for description of symbols see Table 6.1)

Development	Measures	Start-up	Close down	Load changes	Additional costs[a]
High-end fuel	Increase energy density, homogenization	+ to 0	+ to 0	+	10–30 % considering the net fuel costs
New combustion units	Gasification and control system for the amount of gas, pre-heating, modulary heat exchanger	+	+ to 0	+ to ++	30–70 % considering typical boiler price
New heat storage	Internal cascades and adjustment to general requirements	+	+	+	100–200 % considering the usual heat buffer and buffer size
Renewable heat station	Integration of the afore-mentioned measures together with an optimized control unit	+ to ++	+	+ to ++	100–150 % considering the typical boiler price

[a]The additional costs in Table 6.10 are provided compared to actual costs of the non-modified components. From the total additional costs, all of the costs necessary to fulfill more stringent legislation (e.g. emissions) are withdrawn.

Table 6.10 summarizes the parts of a new heating station and the available data. The potential flexibility is also shown.

6.7 Conclusions

In the future, there will be quite a significant number of conventional biomass heat supply systems as base-load heat producers. Depending however on the development of electricity storage systems and on the developments in insulation and efficiency, biomass heating systems will change to peak providers with a much higher flexibility than today. Advanced fuels such as HTC-coal or torrefied wood pellets together with very light and highly adjustable combustion systems will fulfill the needs for heating security while using as many fluctuating renewables as possible such as solar thermal or renewable electricity surplus.

At the same time however an integration of the other renewables mentioned should be reviewed critically. A combination of bioenergy, solar heat and/or ambient heat could be an interesting approach for an integrated heat supply. In such concepts, bioenergy has to provide the remaining load and that will involve overcoming certain technical challenges. One precondition for a more flexible heat supply from biomass is the availability of well-controlled processes with automatic feeding systems and defined solid biofuels. The major developments that are needed are fuel preparation and standardization, pre-gasification and highly adjustable light conversion systems together with modern intelligent system regulators.

Due to a change in the interaction between power to heat demand in housing towards power, the use of micro combined heat and power units (see Sect. 4.7) will probably become more and more of an alternative compared to heat generators only. This could be of great relevance, as they could help to stabilize the electricity grid and to improve the integration of renewables into the energy system.

Additionally, with a more renewable energy supply, the opportunity will arise to generate heat at times when the electricity rate is low from surplus renewable electricity. The feasibility of such concepts will strongly depend on the specific frame conditions, i.e. compare the additional costs of the continuous-flow water heater or heating element within the heat storage tank to the fuel costs of the biomass combustion plant.

With regard to the time frame of the transition, the picture in the heat sector has not been very clear so far:

Changes to buildings and their heating systems are rather slow. At the moment, there are exchange rates of 1–2 % for buildings and 2–3 % for heating systems in Germany [11]. Therefore, establishing a higher flexibility of biomass heat generators and renewable heating systems with biomass will be a process that will last some decades. Especially as there are significant additional costs in most cases that will have currently to be borne by the final user without any clear advantages as the prices of CO_2-certificates are very low, gas and oil prices are at a rather stable level and the market does not provide sufficient refinancing for system integration.

On the other hand, electricity heating inserts in existing hot water buffers could be introduced very soon. The installation and implementation of these systems has already been initiated in combination with private photovoltaic systems with power storage. To use the surplus from summer midday hours, the power is directly transferred to heat. As this power is free of charge, it becomes economically feasible very quickly. As the heating system requires a central heat supply and a buffer to integrate the heater in monovalent biomass heating systems, up to 100 % of the total heat demand can be supplied using this option without any major changes. In the existing dual-fuel and dual-boiler systems, the amount is limited to about 20 % as otherwise the flexibility of the installed boilers is too low.

References

1. Bundesregierung: Erste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über kleine und mittlere Feuerungsanlagen - 1.BImSchV. "Verordnung über kleine und mittlere Feuerungsanlagen vom 26. Januar 2010 (BGBl. I S. 38)"
2. Hark GmbH & Co KG, Product-picture
3. A. Hauer, S. Hiebler, M. Reuß, Wärmespeicher. 5., vollständig überarbeitete Auflage. Bonn, 2013
4. Hummelsberger Schlosserei GmbH, Vakuum-Pufferspeicher. Retrieved from http://www.vakuum-pufferspeicher.de

5. M. Kaltschmitt, H. Hartmann, H. Hofbauer (eds.), *Energie aus Biomasse. Grundlagen, Techniken und Verfahren*, 2nd edn. (Springer, Berlin/Heidelberg, 2009)
6. M. Kutzscher, Biobrennstoffe. Lohnt sich das Umrüsten von Ölheizungen? (2012). Retrieved from http://www.biallo.de/finanzen/Energie/biobrennstoffe-lohnt-das-umruesten-von-oelheizungen.php
7. V. Lenz et al., Erneuerbare Energien. BWK Das Energie-Fachmagazin 4/2014 (2014)
8. S. Nienhuys, Research Report on BACIP Wood Stoves for High Mountain Areas. Gilgit, Pakistan (2000)
9. T. Romberg, Regenerative Energien. Dort Hui, hier Pfui. Die Zeit N°03/2010 (2010)
10. Viessmann Werke GmbH & Co. KG, Beispielhafte Jahresdauerkennlinien für die Heizlast in unterschiedlichen Objekten und Anwendungen. Retrieved from http://www.viessmann.de/de/Industrie-Gewerbe/Systembeispiele/Jahresdauerlinien.html
11. J. Weiß, E. Dunkelberg, Erschließbare Energieeinsparpotenziale im Ein- und Zweifamilienhausbestand. (Institut für ökologische Wirtschaftsforschung, Berlin, 2010)