BEcoop

UNLOCKING THE COMMUNITY
BIOENERGY POTENTIAL

Technical catalogue on biomass direct heating

JANUARY, 2022

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About

Over the last years, the EU has witnessed some remarkable steps in Renewable Energy (RE) deployment. However, at the same time, we see an increasingly uneven penetration of RE across the different energy sectors, with the heating and cooling sector lagging behind. Community bioenergy schemes can play a catalytic role in the market uptake of bioenergy heating technologies and can strongly support the increase of renewables penetration in the heating and cooling sector, contributing to the EU target for increasing renewable heat within this next decade. However, compared to other RES, bioenergy has a remarkably slower development pace in the decentralised energy production which is a model that is set to play a crucial role in the future of the energy transition in the EU.

The ambition of the EU-funded BECoop project is **to provide the necessary conditions and technical as well as business support tools for unlocking the underlying market potential of community bioenergy.** The project's goal is to make community bioenergy projects more appealing to potential interested actors and to foster new links and partnerships among the international bioenergy community.

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Project partners

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1. Introduction

This report focuses on presenting bioenergy heating solutions in the form of technical catalogue. It provides a comprehensive study of direct heating implementation in households. The work presented here is based on extensive review of the literature and existing solutions using biomass boilers for direct heating purposes.

In the first part, the report presents to the reader, in an easy-to-understand manner, the principle of operation of the direct heating system in a single-family house and a multi-family house. Furthermore, this work discusses the technical aspects of this type of installation, the basic elements of this system, and the thermal conversion methods of biofuels. Based on existing solutions, it shows the construction of boilers powered by the following forms of solid biofuels: pellets, briquettes, chips, logs, bales/cubes. The report presents the best solutions for biofuels storage, both outside and inside buildings, to maintain the good quality of the material. The report also provides guidelines for estimating the capacity and maintenance of direct heating installations that should be followed by a person interested in implementing this solution in his household. The methodology of the economic efficiency assessment of the installation and the factors that influence it is also discussed. The need for engagement of different stakeholders in the example of: biomass producer/provider, biomass boiler producer/seller, biomass boiler and heating system installer, and adviser specialized in founding acquisition are also determined.

Finally, some examples of direct heating systems in small and medium scale operating in pilot areas are presented to demonstrate the usefulness of a given heating solution.

The key findings of this work shed light on aspects that need to be further inspected (in dependence on the kind of stakeholder), different steps or activities should be taken concerning the promotion of direct heating installation. This is vital information upon which BECoop can better target and fine-tune the project's foreseen actions.

Summarising this report should help the reader to understand the concept of direct heating in the buildings. The task's specific goals include:

- overview of the process based on literature as well as technical tools to determine the best available technologies in biomass fuels storage and combustion;
- making a preliminary selection of a biomass boiler suitable for a given form of biomass to avoid potential system failures;
- enabling preliminary calculation of the boiler thermal power as well as the amount of the biofuel required to cover annual heat demand
- identification of crucial stakeholders for direct heating implementation and defining essential aspects/issues requiring deeper analysis to uptake this solution in other Project Pilot Areas;
- review of successful cases of direct heating implementation which enable the analysis of the strengths and weaknesses of a given project to avoid potential errors during the construction and operation of the bioenergy installation.

Important: This technical catalogue is based on general recommendations to be taking into account and facilitate the conversation at the time of establishing the first contact with the energy services /engineering companies that will carry out the project, being them finally, the ones that will decide how the installation should be distributed and the type of equipment and technologies they will count on.

2. Direct Heating concept

Biomass direct heating/cooling refers to the systems in which the conversion of energy into heat takes place in the independent boiler at the site to be heated. In other words, in the direct heating systems the heat generation and consumption is realized in the same object. Therefore, the direct heating system may take place not only in the strictly single households, but also in smaller family buildings, institutional buildings or offices, where the heating unit is located within or by the building. Whereas, district heating/cooling systems distribute thermal energy from a centralized source to many residential and commercial buildings through a network of pipes to provide space heating/cooling and/or hot water [1]. Examples of direct heating systems are shown in Figure 1.

a) b)

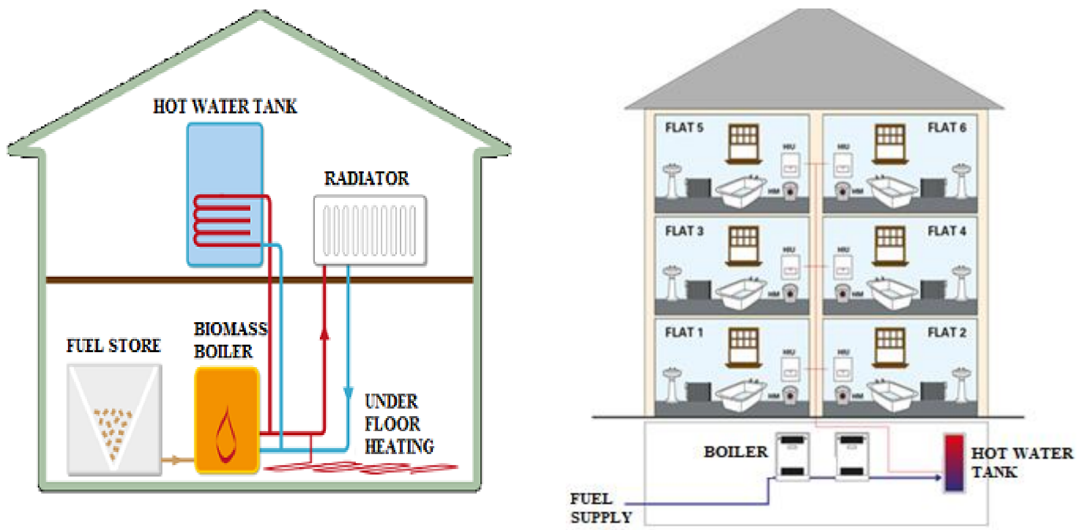


Figure 1. Scheme of direct heating system:
a) single-family house [2], b) residential block [3].

3. Technical considerations

3.1 Main elements of a direct heating installation

In general, direct biomass heating installation consists of (Figure 2): (i) fuel storage/feeding system, (ii) the device for solid biofuel combustion, and (iii) heat distribution system in the object.

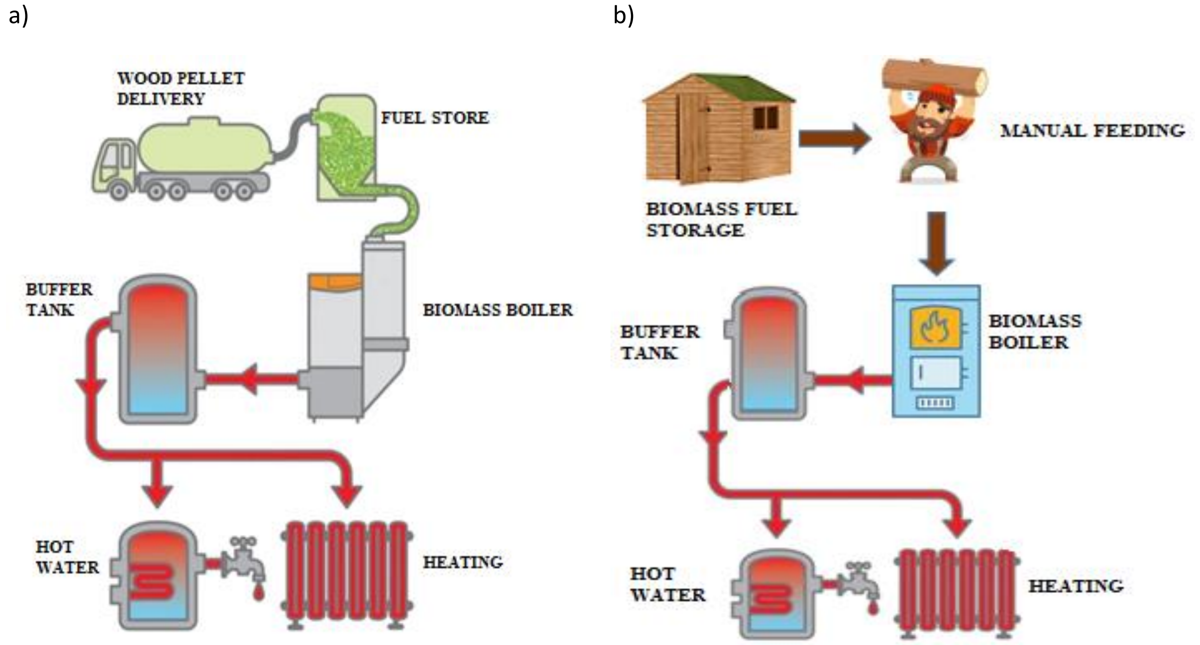


Figure 2. Main components of typical biomass direct heating installations [4]: a) automatic system of direct heating; b) manual system of direct heating.

Depending on the form of biomass, thermal heat conversion technologies and final heat source carrier, the following devices for biomass combustion can be defined:

a) biomass boilers with water heating system (water is a heat carrier),
b) biomass ovens/stoves with air heating system (air is a heat carrier),
c) biomass gasifiers with water heating system (water is a heat carrier),
d) biomass gasifiers with air heating system (air is a heat carrier),
e) hybrid systems.

In practise, most of the solutions where biomass is used for direct heating purposes are characterized by its combustion in the boiler to heat the water. In these systems the buffer tanks (heat tanks, heat accumulators, thermal stores) are built-in to insure stable and effective operation of the heating system (the role of the biomass boiler is to boost temperatures in the tank rather than starting from cold each time heat is required). Hot water (heat) accumulated in the tank is distributed to various types of the radiators located in the rooms (heat exchangers) or directly to the collection points for sanitary purposes.

In case of biomass boilers the storage and/or feeding systems have to be foreseen that will insure the access to the biomass for a defined period of time (from few days to whole heating season). Depending on the form of the fuel (pellets, briquettes, logs, chips, bales, cubes) there are different solutions and possibilities related to the biomass storage and feeding systems.

The generated heat in the boiler from biomass combustion is distributed to the heated rooms/object. Different heat exchangers in the room are in use. It depends on many factors, such as temperature of the heating medium and technical solution of the system (floor heating, wall heating, roof heating, radiators under the windows, hot air heating). It is important that every kind of biomass boiler can be adapted to the existing/planned heating solution in the building.

3.1.1 Biomass boilers technologies

In dependence of the form of biomass, different biomass boilers/technologies are developed. The biomass boiler can be powered by the following forms of solid biofuel:

a) pellets,
b) briquettes,
c) chips,
d) logs,
e) bales/cubes.

Additionally, the heat generation during thermal biomass utilization can be realized by its combustion process or gasification process. According to the EU Directive, all new boilers (lower than 500 kW for heating water or lower than 50 kW for heating air) must comply with the requirements of ECODesign [5].

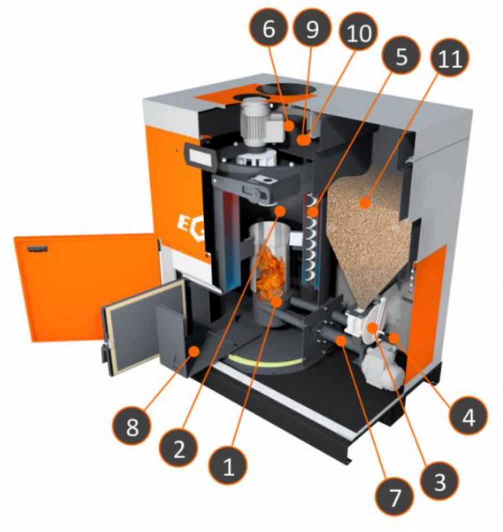
3.1.1.1 Biomass boilers fired by pellets

Pellets are a biomass fuel made from compressed sawdust, produced from various type of forestry and agricultural resources. Their shape is achieved by compression at the pellet processing plant and their shiny surface is from the natural glues found in the sawdust. In case of wood pellets, they should be accredited to the ENPlus A1 or A2 Standard, 5-30 mm in length, 5-6 mm in diameter, with a water content of 8-10% and ash content of 0.5%. This gives a bulk weight of 650 kg/m^3 and produces heat 4.9 kWh/kg. If produced pellets do not meet ENPlus A1 or A2 Standards, they can still be burnt in the boiler but it can require some more activity by the customer (i.e. more ash is generated, more frequent boiler cleaning is recommended).

The stabilized form and calorific value of pellets make such biomass fuel attractive for combustion in boilers. The specific and standardized form of fuel is very important from the point of view of its use for heat production, because it allows the use of the technology of full automation of the boiler with the ignition system and control of its operating parameters, without the need for periodic (daily) loading of the furnace or ash removal, which has so far been a significant disadvantage in relation to maintenance-free installations powered by gaseous or liquid fuel. The basic condition is that the size of the biomass does not exceed the permissible values for the fuel supply system from the place of storage (container) to the combustion chamber. An additional advantage of pellet-fired boilers is the possibility of building a thermal circuit in a closed (pressure) system as well as with the flue gas condensing system, as in the case of boilers powered by gas or liquid fuels. As a result, there is no need to install an overflow vessel and a separate open system. Furthermore, these boilers are characterized by higher efficiency.

The example of the pellet biomass boiler construction EG-PELLET is shown in Figure 3, and the main technical parameters are presented in Table 1.

a)



b)

Figure 3. Pellet boiler EG PELLET with a power of 10-60 kW [6]:
1 – burner, 2 – combustion chamber, 3 – rotary sluice for pellet dosing, 4 – ignition device managed by a microprocessor, 5 – turbulators, 6 – exhaust outlet, 7 – burner feed screw, 8 – ash container, 9 - flue gas temperature sensor - controls the ignition and also manages the boiler power, 10 – lambda probe - optimizes combustion efficiency depending on the characteristics of the granulate, 11 – pellet tank.

Table 1. Technical parameters of EG PELLET boilers [6].

Model	EG-10	EG-10P	EG-15	EG-15P	EG-25	EG-25P	EG-40	EG-40P	EG-60	EG-60P
Power, kW	10	10	15	15	25	25	40	40	60	60
Mass, kg	320	340	320	340	320	340	375	395	420	440
Width, mm	1155	1460	1155	1460	1155	1460	1155	1460	1155	1460
Height, mm	1275	1360	1275	1360	1275	1360	1375	nd	nd	nd
Depth, mm	765									
Efficiency, %	91-95									

3.1.1.2 Biomass boilers fired by briquettes

Briquettes are produced in the process of pressure agglomeration and take a shape with specific geometrical dimensions. All types of waste biomass, lignocellulose materials, wood and straw, including energy crops, can be used for the production of briquettes. After appropriate preparation, initial grinding, drying and basic grinding, the material is compacted without adding a binder. The size of briquettes varies from 25 mm to over the dozen of cm. Mechanical or hydraulic presses are most often used for the production of briquettes. Depending on the design of the working elements, the briquettes can be produced in the following shapes: cylinder, cube or octagon (fireplace).

The use of briquettes has many advantages, such as: high bulk density, easy storage and transport, high calorific value, low pollutants emission to the atmosphere during the combustion. Briquettes are biomass with favourable utility values, it can be burnt in many furnaces, which previously used coal, coke or firewood. They are also often used for firing in central heating boilers in smaller boiler rooms, kitchen and tiled stoves, mainly due to the slow combustion process and increased energy density in relation to non-compacted biomass [7]. However, in the domestic boilers it requires a manual feeding of the boiler. Figure 4 shows an example of a briquette boiler and its basic parameters.

Figure 4. ATMOS DC 24 RS briquette boiler [8].

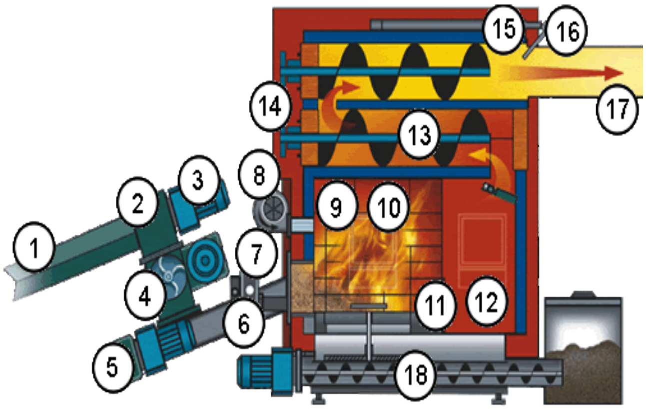
3.1.1.3 Biomass boilers fired by chips

Chips differ depending on the source of origin (forest, short rotation coppice) and the chipper used for their production. It is recommended that wood must be fully seasoned to a maximum moisture content of 30% prior to chipping. The chips are most often 20-50 mm long, but some particles can reach even 100 mm long. It is important that the chips do not exceed this length due to the potential for blockages and breakdowns in the chip supply system [9].

Chips boilers, due to the type of fuel feeding system, are often classified as multi-fuel, as they can also be fired with pellets, and in some cases also with energy plants. Wood chip boilers are therefore characterized by high flexibility and safety, because in the absence of one fuel supply, it is easy to switch to the other with similar quality. These boilers currently have an efficiency greater than 90%, which makes them highly efficient [10]. These boilers belongs to the group of fully automated ones.

An exemplary view of the wood chips boiler as well as its construction and technical parameters are presented in Table 2 and Figure 5.

a)



b)

Figure 5. RH-AK 30-990 kW Wood Chip Boiler Cross Section [11]:
1 – discharge channel, 2 – maintenance flap, 3 – discharger system motor, 4 – rotary valve, 5 – feed auger motor, 6 – ignition, 7 – primary combustion blower, 8 – secondary combustion blower, 9 – combustion chamber, 10 – combustion chamber door, 11 – post combustion/drop out chamber, 12 post combustion chamber door, 13 – heat exchanger tuber with de-ashing, 14 – drive for de-ashing auger, 15 – flue gas temperature sensor, 16 – lambda sensor, 17 – flue gas blower/connection, 18 – ash cleaning system.

Table 2. Technical parameters of RH-AK Wood Chip boiler series [11].

Model	RH-AK 30	RH-AH 60	RH-AK 100	RH-AK 155	RH-AK 204	RH-AK 300	RH-AK 400
Heat capacity, kW	0-36	0-60	0-101	0-149	0-199	0-300	0-400
Weight, kg	900	1150	1500	2865	3108	5400	6200
Length, mm	1700	2100	2200	2865	3290	3490	3990
Width, mm	860	860	1085	1150	1565	1880	1880
Height, mm	1585	1585	1645	2065	1895	2035	2035

3.1.1.2 Biomass boilers fired by logs

Wood logs, as a biomass fuel, are typically 50 cm in size and 12-15 cm in thickness. They should be seasoned for minimum 1-2 years to ensure a moisture content below 20% (4 years storage is recommended). Unseasoned or wet logs burn inefficiently, reducing the heat produced, and lead to production of excessive soot and tar which can cause unexpected flue fires. Logs to be burned as biomass fuel should not contain any coatings and preservatives. Logs can be loaded directly into the log boiler without any other fuel handling process, like exists with wood pellets or wood chips. Logs must be manually loaded into the boiler, so day to day activity is required (even few times per day during the winter season). Most modern log boilers are characterized by 90% of efficiency.

Example of the wood logs fired boiler is presented in Figure 6.

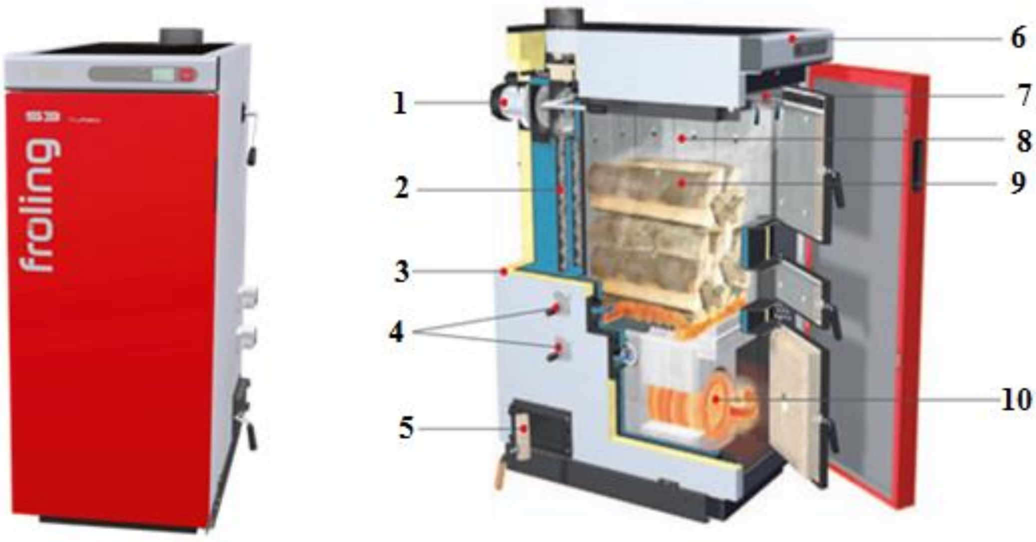


Figure 6. Construction of the wood logs fired boiler [12]:
1 – speed-regulated induced draught fan for maximum ease of use, 2 – EOS (efficiency optimisation system) for high efficiency and easy cleaning, 3 – top quality thermal insulation, 4 – manual adjusters (actuators with Lambdatronic) for primary and secondary air, 5 – large maintenance openings for easy cleaning, 6 – S-Tronic controller or Lambdatronic controller, 7 – carbonisation gas extraction system prevents flue gas from escaping during reloading, 8 – aprons (hot cladding) to protect the inner wall of the boiler for a longer service life, 9 – large fuel loading chamber for half-meter logs ensures long reloading intervals, 10 – separate pre-heating chamber door for easy pre-heating.

3.1.1.2 Biomass boilers fired by bales/cubes

In the form of bales or cubes, mainly straw and branches coming from trees/shrubs of permanent crops can be burned, the dimensions of which are usually: pressed rectangular cubes (80x40x40 cm, 180x70x120 cm or 250x120x80 cm), cylindrical bales (diameter: 30-120 cm and height 40-120 cm). It is recommended that the moisture of straw or branches intended for combustion in low and medium power boilers amounted to 13-17%.

Due to the usually limited space of the boiler room and the lack of space for building a line for continuous feeding of pressed straw to the combustion chamber, these are grateless batch boilers with bottom combustion, relatively simple in their construction and requiring periodic loading with fresh fuel. The combustion process is carried out until the fuel burns out completely. Using this type of boilers, the heating installation should be equipped with an appropriately sized heat tank in which heat is accumulated for heating purposes [13]. Example of the cubes/bales fired boiler is presented in Figure 7.

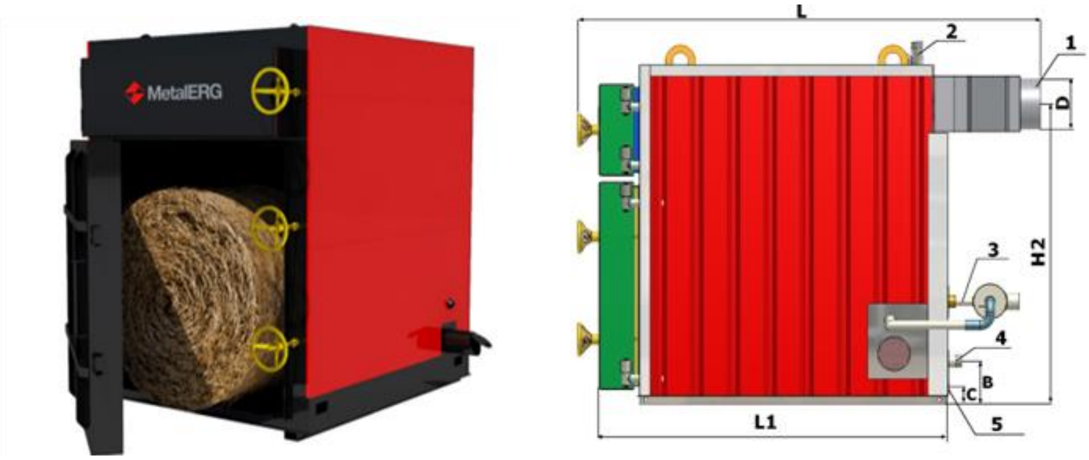


Figure 7. Construction of the straw bales fired boiler [13]:
1 – combustion flare, 2 – the outlet of water to the tank, 3 – air collector, 4 – the return pipe to the tank, 5 –drain plug, 6 –opening light.

3.1.2 Storages and feeding systems

There are many solutions for the storage of solid biofuels, depending on the size, construction and form of biomass. The storage area should be large enough to be filled max. 3-4 times per year. To maintain the good quality of fuel, the storage method should prevent ingress of moisture and be free from any contaminants (stones, animal carcasses, metals, coatings or preservatives). The storage room requires proper ventilation to avoid rooting, decomposition and insure air access for maintenance of the proper hygienic/climatic conditions. It is recommended to clean a storage room once a year (after the heating season).

3.1.2.1 Storage/Feeding systems for pellets

Pellets are free flowing and so the fuel stores are built at a slant and fed into the boiler. Pellets should be stored in purpose-built and enclosed stores with an access and inspection hatch. External filler tubes support the usually ‘blown’ delivery of pellets (delivered by tanker in a similar manner to oil) (Figure 8). These vehicles are equipped with compressed air supply devices so that pneumatic transport through the external filler pipe is possible.

Figure 8. Pellets delivery process with the use of a tanker [14]:
1 – tanker, 2 – delivery pipe, 3 – prefabricated silos.

Pellet supply systems for heating devices

a) stored in tanks integrated with the heating device (the capacity of the tank is usually enough for several hours of operation),
b) storage in tanks adjacent to the main component of the heating device (the capacity of the tank should ensure operation for up to several days),
c) storage in separate tanks (the capacity of the tank may be sufficient for monthly work in the winter),
d) storage in a specially designed room or external tank (capacity even for a whole year of operation).

Supplying the boiler with solid biomass throughout the heating period requires a sufficiently large utility room that will serve as a pellet storage or an external tank (above-ground or underground) for storing pellets or other forms of fragmented biomass.

The most frequently used storage systems are above-ground based systems. They are available in various shapes and sizes, so that the tank can be easily adapted to the existing room where the pellets are to be ultimately stored. The most common are square, rectangular and pyramidal tanks. The tanks can be made of various materials (polyester fabric, metals or plastics). The most commonly used silos are shown in Figure 9.

a) b) c)

Figure 9. Most commonly used pellet silos [15]:
a) conical; b) flat bottom; c) trough.

Conical silo is similar in appearance to an inverted pyramid. Pellet extraction takes place at the lowest point. This tank is usually closed with a shutter placed between the silo and the pellet conveyor to the boiler. Flat bottom silo has no slope. Pellets are taken from above (by suction), or from below (by screw conveyor). Their disadvantage is that they cannot be completely emptied. Trough silos are volume-optimized conical silos that are used in narrow spaces where they provide high capacity. Pellets are extracted by a screw conveyor that transports them directly to the boiler or the blowing system.

Underground storage tanks (Figure 10) are not so popular as they must meet strict technical requirements (be watertight and protected against hanging on the groundwater). Pellet extraction is carried out solely by suction (from the top or the bottom).

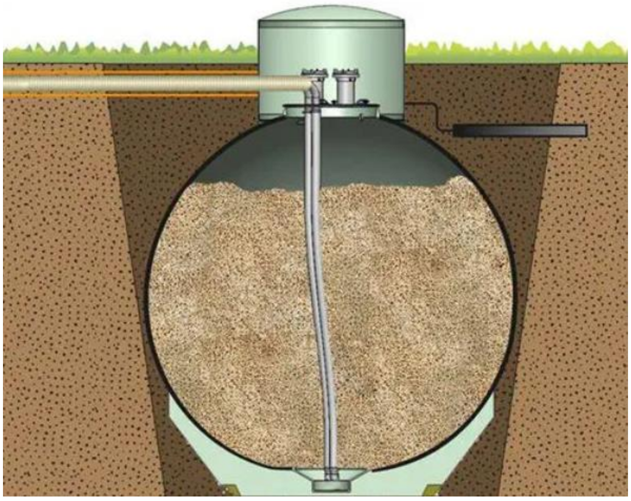


Figure 10. Underground pellet storage silo [16].

The pellets can also be stored directly in the storage room. It should be oblong or rectangular in shape. It is also important to ensure good access to the injection and suction connections. The storage room should not include electrical installations, air ducts and water installations. The walls of the storage room should be covered with an appropriate mat to protect them against the effects of pellets [17], [18].

Due to the fact that pellets are a material that easily absorbs moisture, special care should be taken that the storage room is dry all year round, and the air humidity should be around 80%. When there is a risk of damp walls, pellets should be stored in a prefabricated silo. However, when this risk does not exist, the pellets can be stored directly on a specially constructed sloping floor, which is designed to drive the pellets by gravity towards the auger/suction system, thus facilitating emptying the storage.

Sloping floor should have a slope of 40^0 - 50^0. A lower slope may prevent the fuel from sliding over the surface. A sloping floor should be made of appropriate materials, preferably wood with a smooth surface, 20-25 cm thick (Figure 11). A stable structure should be provided by supports that can support the weight of the pellets (the bulk density is within the range of 650-700 $kg \cdot m^{-3}$) [17] [18].

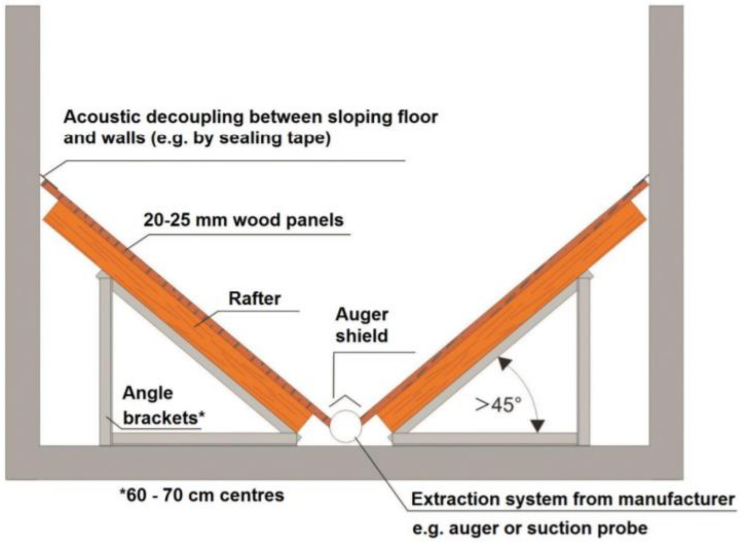


Figure 11. Sloping floor dedicated for pellets storage [18].

The combination of a storage system with a pellet boiler depends on the technical capabilities of the end user. The heating device and the storage system can be placed in the same or in separate room (Figure 12). However, the appropriate distribution of cables is required to not interfere with the functionality at home.

a) ***b)***

Figure 12. Examples of connecting a pellet boiler with a storage system [19].

3.1.2.1 Storage/Feeding systems for briquettes

The quality of the briquettes is badly damaged if they are exposed to the weather (sun, rain) without protection. Strong solar radiation or storage in warm places causes the briquettes to dry out, which loosens the packaging straps. The following instructions must be noted and implemented for fire prevention and the maintenance of optimum levels of briquette quality [20].

a) *the temperature of briquette packs must be checked during delivery. only cooled and dry goods may be stacked,*
b) *for reasons of stability, the pallets must be stacked in a group on a solid base. the result is a stepped and graduated stack,*
c) *in the interests of fire protection, stability, and quality, the height of the stack must be limited to a maximum of four pallets at the retailer,*
d) *the walkways must be suitable for pallet trucks,*
e) *a gap of approx. 20 cm must be left between each pallet row when putting goods into storage.*
f) *a gap of 5 to 10 cm (hand width) must be kept between the pallets in one row,*
g) *a moist storage environment (air moisture > 60% if possible), must be provided (this is achieved by lightly spraying the ground), it is not acceptable to moisten the briquettes directly,*
h) *the storage stack must be accessible from all sides at all times (for fire extinguishing),*
i) *if horizontal liners are inserted to protect the goods, the material used must allow the air to circulate freely between the layers,*
j) *should moist, or heated pallets be detected during checks, these must be removed from the stack and stored separately. the sales partner must be contacted without delay,*
k) *should, however, the straps around the pallets become slack during correct storage, the vertical strap may be retightened by using a handheld tensioning device (electric or pneumatic). damaged packs must be replaced during remedial action.*

Do store your briquettes in [21]: watertight shed, dry garage, porch or conservatory, inside house, dry outbuildings, some plastic garden stores, as long as they are watertight. Examples of storage options for briquettes are shown in Figure 13.

a) b)

Figure 13. Examples of storage options for briquettes [22], [23]:
a) foiled pallets inside the room; b) bags.

3.1.2.1 Storage/Feeding systems for chips

Fuel stores for chips should be covered and enclosed. It is recommended to build a large store in order to minimise the number of fills. The store should have an access and inspection hatch and the floor should be level with the agitator sweep arms. The stores should be cleaned out annually, during summer when the boiler may not need to be operational. It is also important to visually inspect any delivery of wood chips. As part of the delivery paperwork, the moisture content of each load should be stated on your receipt.

Depending on the technical capabilities of the end user, delivery can take place in various ways. One of the most common delivery options is tipped delivery into a bulk fuel store, where a moving floor truck delivers the wood chips to an intermediate storage area, which is most often covered with a shim. However, the customer must have a tele handler/loader to move the fuel to the final storage. Another method of delivery is also delivery including chip blowing, where a vacuum pipe driven by a hydraulic pump, included in the delivery vehicle, blows the chips into the storage through the access hatch. Customers can also use a mechanical auger and trough delivery. The purchased fuel is poured directly into the trough, and the screw conveyor transfers it to the fuel storage. However, it should be remembered that this option is dedicated to smaller installations, as unloading wood chips from a truck would take much longer than in the case of classic deliveries [24].

For installations with a capacity of 100 kW or more, it is also possible to deliver chips to an underground or above-ground storage facility via a ramp and to discharge the chips by a fuel delivery vehicle. However, it is required to build a larger ramp, which may be associated with greater financial outlays. However, the design should be consulted with a structural engineer to ensure proper construction. Fuel deliver options, depending on the storage scenarios, are shown in Figure 14.

Figure 14. Chips deliver options, depending on storage scenarios [24]:
a) tipped delivery into a bulk fuel store with tele handler chips moving; b) fast feed auger delivery; c) ramped delivery; d) blown delivery.

The wood chips should be stored under a roofed, dry place to reduce the risk of moisture absorption by the fuel. The storage location is properly ventilated and easily accessible. For this purpose, you can use the existing farm buildings (sheds, roofed drive-through silos, small household buildings, arched halls) or use one of the rooms located directly in the heated building.

The choice of the storage location and options should depend on the technical capabilities of the end user, the scale of the project and financial possibilities. Outdoor storage in underground and above-ground warehouses is dedicated to larger installations, while the use of small outbuildings and rooms in heated buildings as warehouses is [25] dedicated to smaller installations (Figure 15).

a) b)

Figure 15. Outdoor chips storages for larger installation [25] [26]:
a) arched hall; b) shed.

Wood chips are stirred by an agitator, made up of a rotating disk with sprung arms. Then, fuel drops into an auger, and a corkscrew moves the fuel smoothly from the store to the boiler. Depending on whether the storage system is on the same level or the boiler (as well as the distance between the storage and the boiler), different feeder systems can be used to optimally match the loading of chips to the boiler. Examples of storage and loading solutions for wood chips are shown in Figure 16.

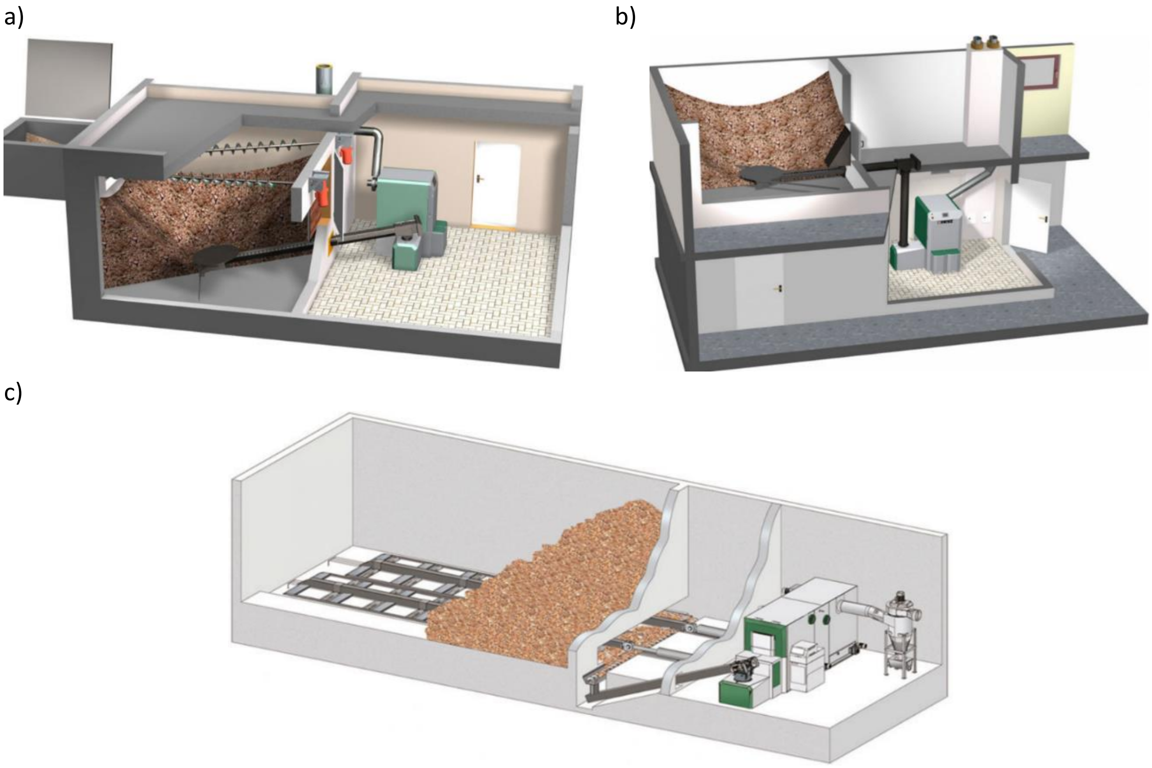


Figure 16. Examples of storage and loading solutions for chips [27]:
a) chips store and the boiler room are on the same level (leaf reel and 2 feeders); b) chips storage and boiler at different levels: horizontal leaf reel, feeder, slope system; c) hydraulic floor systems.

3.1.2.1 Storage/feeding systems for logs

When using logs, the fuel needs to be manually fed into the boiler. In the cold winter months, the fire or log burner will require a ready supply of quality, dry (seasoned) logs to work effectively. The following instructions for storing woof logs outside in a practical, convenient and safe way that will keep them dry all winter long.:

a) *stack logs neatly* - seasoned logs are traditionally stacked neatly, close to (not touching) a wall or fence, it is important to be quite precise as tight stacking will ensure that only the top layer will get damp if it rains,
b) *consider location carefully* -think about the location, if the prevailing winds usually blow rain in a certain direction then place the logs in an area that it as sheltered as possible; remember to always place them on a flat and stable surface,
c) *avoid tree cover* - don't place log stacks under trees as these will drip water down and also avoid low lying areas which can be prone to dew, mist or fog,
d) *don't leave logs in a heap* - never just dump the logs in a heap (especially on grass) as they will get wet and be useless; careful stacking will pay dividends in the long run.
e) *use pallets where possible* - preferably, logs should be placed on wooden pallets as these keep them off the ground and provide a free flow of air underneath; the ideal height of the wood stack (including the pallet) should be no more than 3ft (1m) as the logs can become unstable if piled too high,

f) *provide good circulation* - remember to leave a good amount of space between your logs and any wall, fence or shed to help with air circulation, a gap of about 4 Available online (10cm) all round is ideal, remember also that a log pile is a potential fire risk so consideration should be made to its placement.

Although logs can be left in the open space, they do benefit from the extra protection of a cover or dedicated storage area. However, never cover your logs completely with tarpaulin (this will create a seal to stop the air circulating round), ensure the sides stay uncovered for proper ventilation. An extra effective protection against moisture is to use the dedicated, made of various materials, log stores (Figure 17).

a) b) c)

Figure 17. Examples of storage solutions for logs [28] [29]:
a) wooden log store; b) tarpaulin cover; c) metal log store.

3.1.2.1 Storage/Feeding systems for bales/cubes

For power generation purposes, the straw harvested from the field, in the form of bales (round or cuboid), should be stored under the roof to avoid wetting. The boilers can burn only dry straw with a maximum moisture content of up to 20%. In the front part of the boiler is a gate that permits bales of straw to be manually stoked easily into the combustion chamber [30].

A way to reduce the risk of a straw fire is to ensure that stored straw remains dry [31]:

a) when storing straw inside (Figure 18b), make sure the barn or storage area is weathertight and has proper drainage to prevent water from entering the barn,
b) when storing straw outside (Figure 18a), cover it with plastic or another type of waterproof material. If you cannot cover the bales, arrange the bales so that air can circulate between them to promote drying. Bales can be protected from ground moisture by storing them on a bed of gravel or lifting them off the ground on used tires, poles, or pallets,

a)

b)

Figure 18. Examples of storage solutions for logs [32]:
a) storing outside; b) storing inside.

Straw bales/cubes can be transported to the boiler in two options (Figure 19): manually using the strengh of human hands, or automatically using the conveyor or other machinery.

a)

b)

Figure 19. Straw bales/cubes feeding systems [33] [34] :
a) manual ; b) automatic.

3.2 Power of your installation

In general, the thermal power of the boiler is determined from the balance of thermal needs of the facilities supplied from the boiler room. It depends on many factors, such as: the type of the object, operation time (seasonal or full year), heat losses (house insulation), parameters of the heating medium, heating circuits, daily heat distribution (constant or variable power), ventilation system, technology and preparation of central hot water, the size of the heat buffer, or the proportion of individual components of the demand. As a result, the accurate estimation of the power and capacity of the biomass boiler is complex. However, there are some methods and indexes that enable the calculation of the thermal power of the boiler, for example:

a) European standards (EN 15316-3:2017),
b) approximate power of the boiler regarding the heat losses of the object,
c) cumulated boiler power determination regarding the biomass potential (i.e. in the region).

The power of the heating installation (boiler) and the amount of required biomass using European regulations and standards EN 15316-3:2017 [35] are determined based on the calculation of heat demand, efficiency of heat acquisition, storage, transfer, and total efficiency of the heating system. Its power is obtained by analysing the needs for specific purposes for a specific time (e.g. winter, summer, transition periods, etc.) according to the general formula:

$$Q_B = Q_{CH} + Q_{Vent} + Q_{Tech} + Q_{HW}, \tag{1}$$

where:
Q_B – boiler room power, kW
Q_{CH} – heating power demand, kW
Q_{Vent} – demand for thermal power for ventilation or air conditioning, kW
Q_{Tech} – demand for thermal power for technological purposes, kW
Q_{HW} – heating power demand for domestic hot water preparation, kW.

The heat power demand for heating Q_{CH} is calculated according to the current standards or according to cubature indices. The demand for ventilation Q_{Vent} is determined according to air exchange ratio in the building (with possible reduction of ventilation intensity at low outside temperatures). Heat demand for domestic hot water preparation Q_{HW} is determined according to the consumption of hot water (e.g. for individual hygiene activities or according to the average indicators of daily consumption per inhabitant or user of a public facility). The components Q_{CH} and Q_{Vent} are a function of the outside temperature, while Q_{Tech} and Q_{HW} usually do not depend on the outside temperature. This procedure requires some professional knowledge and should be performed by expertise person.

Less accurate, but much simpler method of thermal power of the biomass boiler estimation refers to the required unit power of the heating source necessary to cover heat losses per 1 m^2 of the surface (or per 1 m^3 of cubature) in the considered object. The formula is, as follow:

$$Q_B = UPD_{SA} \cdot SA \tag{2}$$

alternatively:

$$Q_B = UPD_{BC} \cdot BC \tag{3}$$

where:
Q_B – thermal power of the boiler, W,
UPD_{SA} – unit thermal power demand to heat the object's surface (Table 3), W/m^2,
UPD_{BC} – unit thermal power demand to heat the object's cubature (Table 3), W/m^3,
SA – surface area of the heated object, m^2,
BC – cubature of the heated object, m^3.

Table 3. The unit power and energy demand for heating the buildings [36] [37] [38].

Energy class	Energy rating	Unit thermal power demand UPD		Final energy consumption FE, kWh/(m²·year)	Year of construction
		W/m²	W/m³		
A+	Passive	<25	<10	<20	today
A	Low energy	40	15	20-45	2019-today
B	Energy saving	50	18	45-80	2010-2018
C	Medium energy efficient	60	22	80-100	2000-2010
D	Moderately energy-intensive	70	25	100-150	Up to 1999
E	Energy-consuming	100	37	150-250	Up to 1998
F	Highly energy-consuming	120	48	over 250	Up to 1982

Additionally, based on the yearly heat demand by the object it is possible to determine the amount of biomass fuel required for heating purposes:

$$M_B = \frac{\mathrm{FE} \cdot \mathrm{HS}}{LHV \cdot \eta_b \cdot} \cdot 3.6 \quad (4)$$

where:
M_B – the required amount of biomass to cover the annual heat demand by the object, kg/year,
FE – final energy consumption by the object, kWh/(m^2·year),
HS - heated surface of the object, m^2,
η_b – thermal efficiency of the boiler (η_b=0.85-0.92), -,
LHV – lower heating value of the biomass fuel, MJ/kg.

In case of lack of knowledge/data about the annual heat demand by the object, the approximate estimation of the thermal power of the biomass boiler can be estimated based only on the value of the heated surface area of the object/building/household. The example of such relationship for temperate climate is shown in Figure 20. It should be noted that under certain circumstances/conditions this value may differ significantly from the actual demand, and should be consulted with a specialist.

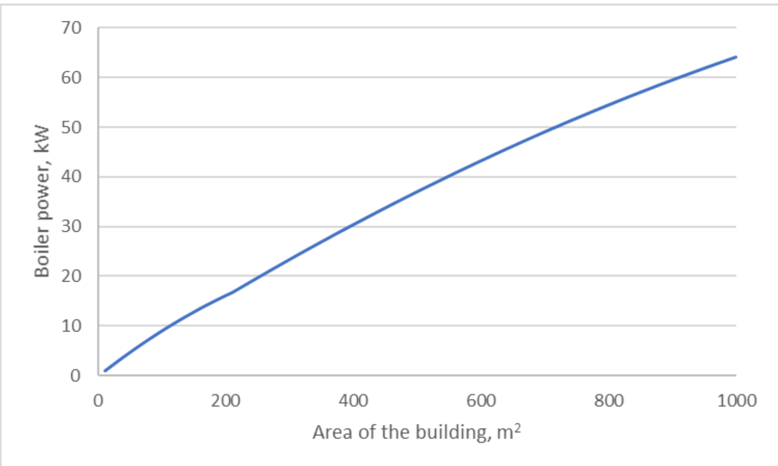


Figure 20. Thermal power of the boiler vs. Heated surface area of the building (in a temperate climate)[1].

[1] Own evaluation basing on database of Ministry of Technologies and Development: https://rejestrcheb.mrit.gov.pl/

3.3 Operational and maintenance of a biomass boiler

Operation and maintenance of a biomass boiler is highly sensitive to the quality of the biomass. The appropriate quality of biomass ensures safe and trouble-free operation of the boiler while maintaining high emission standards and a minimum involvement of use in the household heating process. In turn, It should be underlined, that the use of sub-standard fuel or municipal waste for heating can cause a range of issues/problems like:

- burning instability,
- increased pollutant emission,
- low combustion efficiency and increased fuel consumption,
- joking of conveyors,
- corrosion,
- slagging.

To avoid exploitation problems biomass boilers should be selected according the biomass fuels that will be consumed. Additionally, these biomasses should be sourced from sustainable suppliers. Some of the parameters of the biomass fuels that should always be considered are the following:

- moisture content – boilers are optimized for fuels with a moisture content within a specific range. Improper moisture can cause inefficient combustion, and excessive smoke and tar, as well as lead to increased emissions.
- particle size – boilers are designed for specific particle dimensions. Using a fuel with another dimensions than the one for which the boiler has been designed, can cause problems in the feeding or storage system.
- chemical composition of the biomass - for some fuels it may be also important to check for sulphur and chlorine content (to estimate corrosion hazard) and the amount of potassium and sodium (those alkali metals cause slagging and fouling).

A properly planned maintenance of a biomass boiler should ensure:

- the safe operation of the system.
- minimized breakdowns (failures).
- maximization of the operation lifetime of the boiler.

To plan the exploitation properly:

- the boiler’s overhauls should be made minimum once a year,
- only high quality biomass should be used,
- the biomass moisture, size and chemical composition should comply with the technical requirements of the boiler.

The main exploitation recommendation still remains an advice to read the service or maintenance documentation of the boiler, although the biomass quality and chemical composition should be controlled as well.

4. Profitability of a direct heating

The profitability of the heating system basing on biomass utilisation depends on many factors, such as: range of the modernization work, the size of the system, how often it is used, a chosen fuel type or the reference fuel and heating system (to be compared with: oil, gas, coal, electricity etc.). Actually, each case requires to be assessed as an individual case study. However, taking into consideration some assumptions, the simple payback time period (SPBT) can be calculated from following formula:

$$SPBT = \frac{I_o}{AC_a} \tag{5}$$

where:
I_0–the value of the investment outlays, €,
AC_a – annual avoided costs, €.

The formula of annual avoided costs is as follows:

$$AC_a = (HP_2 - HP_1) \cdot EC_a \tag{6}$$

where:
HP_2 – unit heat price from conventional energy source, €/GJ,
HP_1 – unit heat price from biomass fuel, €/GJ,
EC_a – annual energy consumption, GJ.

Table 4. Estimated unit heat prices depending on the type of the fuel (Poland) [39].

Fuel	Unit heat price,	
	€/GJ	€/kWh$_t$
Eco-pea coal	9.56	0.03
Culm coal	6.19	0.02
Hard coal	8.26	0.03
Pellet class A1	11.05	0.04
Pellet class A2	10	0.04
Pellet class B	10	0.04
Briquette	7.65	0.03
Wood	5.71	0.02
Gas (methane)	8.82	0.03
LPG	21.6	0.08
Oil	15.79	0.06
Electricity	36.1	0.13

Therefore, it is difficult to give the annual running costs of a biomass boiler without knowing the specifics of the project, the local fuel prices and servicing options.

In case of the investment outlays in heating unit, the cost of the biomass boiler (ca. 20-25 kW) for a single household is in the range of €1300-4500, which is very similar to coal, gas or oil boilers (in case of simple solutions), or likely higher (in case of more sophisticated and fully automatic solutions).

The small capacity boilers (up to 100 kW) used for space heating may require only one single service per year. In case of larger boilers with more extensive utilization for process heating, more frequent maintenance is required/recommended (2-3 times per year).

It terms of biomass fuels, wood chips are cheaper than wood pellets, so this will influence the running costs. If owners have their own fuel supply (own forest/woodland, straw from field, pruning from orchards) then wood logs/straw bales/pruning (if they contain low moisture content) can be directly used for energy purposes which leads to significant reduction (30-50%)[2,3] of heating costs.

Besides the economic aspects, there are many other benefits relating to the use of biomass for energy purposes, especially over fossil fuels:

a) combustion of biomass residues reduces the disposal and removal costs,
b) biomass from local resources is cheaper, and the fuel price is more stable,
c) the process is carbon neutral (the amount of CO_2 released during its combustion is the same as the amount of the CO_2 absorbed during the plant growing),
d) it is a sustainable and renewable fuel that can reduce the pollutants emission by up to 96%[4,5,6],
e) supports local development (job creation, taxes) of the whole biomass chain market,
f) much lower ash generation than coal (reduction of the problem of furnace waste management),
g) biomass ash can be used as fertilizer avoiding disposal costs,
h) biomass contains much less ash reducing the frequency of emptying the ash bin in the boiler,
i) no or much lower sulphur oxides emission during combustion (in comparison to coal or heavy oil).

The approximate environmental savings/differences for most common fuels used for heating are shown in Table 5 and Table 6.

[2] Biomass Boilers | Wood Pellet | Wood Chip | Log | Treco
[3] https://naturequebec.org/wp-content/uploads/2019/05/Depliant_biomasse_Chaudiere_WEB-1.pdf
[4] http://www.globalbioenergy.org/uploads/media/0904_Environment_Agency_-_Minimising_greenhouse_gas_emissions_from_biomass_energy_generation.pdf
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[6] Biomass District Heating Advantages | Treco

Table 5. Characteristics of commonly used solid fuels and electricity [40] [41].

Fuel	Density, kg/m^3	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/kg
Wood chips	250	7	3.5
Wood pellets	650	15	4.8
Wood logs	350	7	4.1
Miscanthus (chopped, 25% MC)	140-180	8.3	3.6
Wheat grain (15% MC)	760-780	86	3.9
Hard coal	800-1000	354	7.5-8.6
Peat	400	382	3.8
Coke	450-650	461	8.0
Electricity	n/a	530	n/a

Table 6. Characteristics of commonly used liquid and gaseous fuels [40] [41].

Fuel	Litres	Unit CO_2 emission, g CO_2/kWh	Unit calorific value, kWh/l
LPG	1	323	6.6
Heating oil	1	350	10
Natural gas (methane)	1	330	11.4

5. Stakeholders needed

In case of direct heating of households using biomass boilers the need of engagement of different stakeholders might be required, in example:

a) Biomass producer/provider,
b) Biomass boiler producer/seller,
c) Biomass boiler and heating system installer,
d) Adviser specialized in founding acquisition.

Biomass producer/provider.

In terms of the development of local cooperatives or energy communities, heating households and other buildings with biomass depends on its availability in the region and the final form/shape that is required by the boiler. Therefore, the identification of the local biomass potential (amount and type of biomass available), suppliers (farmers, forest owners, national forest authorities, wood processing companies) and producers (companies processing biomass into pellets, briquettes or wood chips) is of key importance from the point of view of planning the heating system/installation. In some cases, biomass (straw bales, logs and even wood chips) can be sourced directly from the biomass producers, which reduces fuel costs and, therefore, it could improve the project profitability since intermediate steps with other stakeholders are avoided. These data are needed for the selection of the boiler structure, storage system and investment scheme. Moreover, in the case of demand for larger quantities of biomass, long-term contracts for its supply may be required (ensuring continuity of supplies, determining fuel costs, agreeing on the requirements as to its type, form and quality). In case you need to contact local biomass producers/suppliers, it is recommended to visit the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) where you can find local biomass suppliers.

Biomass boiler producer/seller.

In case of decision making on the type of biomass used for heating purposes, it is necessary to purchase an appropriate heating unit that will be able to provide the required thermal power and meet the current standards requirements in the context of emission of pollutants into the atmosphere or the achieved combustion efficiency. There are many solutions for biomass boilers available on the market, which differ in appearance, design, fuel supply, ignition system, flue gas cleaning, and ash removal from the furnace. The mentioned aspects have an impact not only on the usability of the boiler, but also on the final price. It should be noted that direct contact with the boiler manufacturer is recommended only in the case of installations for larger objects or a larger group of users (power above 100 kW), where heat will be produced in one heating unit of greater power. This is due to the fact that it may be necessary to individually adjust the boiler to the existing or planned boiler room or the required heat flux with specific physical parameters. It is also possible to change the design in order to adapt the boiler to the combustion of a specific biomass fuel available on the local market or adopted in a given project. In higher power boilers, their manufacturers often allow some design modifications. In the case of lower-capacity boilers, typical for households, a direct contact with the boiler manufacturer is rather unnecessary. Producers usually have their distributors and sales representatives in given regions, who are responsible for the site visit and advice on the selection of the heating unit. In this case, it is recommended to contact a sales representative and an installation and service company (ESCO) that operates in the local market. Before the final selection of the heating boiler, however, it is recommended to review (webpage visit) the existing solutions in order to gain knowledge of not only technical but also visual possibilities. The list of potential producers or suppliers of biomass boilers can be found on the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/).

Biomass boiler and heating system installer.

In order to replace the existing heating system, boiler or install a new heating system, you may need to contact the installation and service company, which has the appropriate qualifications and will professionally carry out the necessary installation works. These types of companies also provide appropriate technical advice in the selection of thermal power, the necessary additional equipment and the scope of installation works (sometimes the modification of flue gas outlet system or chimney is required). It is recommended that the entire investment process from the technical side (boiler delivery, materials and installation works) to be performed by one contractor. This will allow you to avoid possible problems related to the liability and warranty for the service provided by the installation and service company. It is also advisable that the contractor is an authorized installation company of the boiler manufacturer, which additionally guarantees the quality of service and the confirms contractor's experience. Carrying out maintenance services and having a company headquarters in a given region is an additional advantage, as it shortens the time of potential response to service requests and arrival at the customer. The e-market platform (https://www.becoop-project.eu/tools/e-market-environment/) can help in looking for local installation and service companies.

Adviser specialized in funds acquisition.

At the investment stage, it may be necessary to obtain additional funds necessary for the implementation of the project. A financial advisor has the appropriate knowledge where to look for financial support, the current national or local support programs, can propose the best financing model or banks offering convenient loans and repayment schemes. The right advisor can help you develop an appropriate business plan and project implementation strategy. It should be noted that in the area of activities related to environmental protection in the region, appropriate advisors also work at the local commune office. It is worth remembering that among consulting companies you can find institutions that help in writing applications and projects enabling the acquisition of funds from EU programs. The support can be found also in organizations such as research centres, energy cooperatives, energy clusters, etc. which can advise on the procedures and steps of the investment process. Consulting companies operating in this area can be found on the e-market platform (https://www.becoop-project.eu/tools/e-market-environment/).

6. Steps to be followed

In dependence on the kind of stakeholder, different steps or activities can be taken in relation to the promotion of direct heating installation.

In case of biomass consumer/user:

- Check if there is a heating network nearby that distributes the heat generated in the biomass combustion process,

  The direct contact with local heat distributing/operating company (if there is in the region) is recommended to validate the possibility and conditions of connection to the central heating network. The final user can contact also a local municipal office about the potential options/plans and regulations related to the heat supply of your building.

- Check if there is an interest and the possibility of creating an energy cooperative in the immediate vicinity,

  The contact with the local municipal office about the existence or potential plans related to energy community creation is recommended. Furthermore, you can ask your neighbours if they are interested to create an energy community. You can also look for local energy cluster for a help or potential engagement in this field.

- Select/choose the type and form of biomass to be used for heating your household,

  It is recommended to visit the website www.becoop.eu, where are the adequate helping/supporting materials such as: fact sheets about biomass, its form and properties. You should read point 3.1.1 including the description of biomass boiler technologies to be more familiar with the practical aspects of biomass utilization for energy purposes. It should help you make a decision.

- Determine the power of the heating boiler, It is recommended to read point 3.2. It will help you estimate the boiler power based on your heating demands. You can also visit the e-market platform to find the contact data o professional companies or energy advisors in your region, that will help you in this issue.

- Contact the company providing services in the field of heating installations for consultation and determination of the scope of installation works,

  It is strongly recommended to visit the e-market platform. It will help you find the professional company dealing with biomass boiler installation.

- Look for a local biomass supplier for your boiler,

  You should visit the e-market platform to find a local biomass fuel supplier. It is important to secure the fuel of your boiler beforehand.

- Check the space for your boiler in the technical room,

  You should familiarize yourself with the guidelines contained in the boiler's technical and operational documentation. You can also use the e-market platforms to find an installation company or a boiler supply company that will advise you on this issue. Optionally, you can contact the boiler manufacturer for the necessary information.

- Prepare a place for biomass storage during the heating season,

  It is recommended to read point 3.1.2, where you can find basic information related to storage conditions of a given form of biomass.

7. Success cases

7.1. Gospodarstwo sadownicze, Poland (600 kW_{th})

Gospodarstwo Sadownicze (Komorów, Poland) is the local pioneer that in 2013 started a commercial use of pruning biomass from apple orchards for energy purposes. In Mazovia Province there are more than 103,000 ha of orchards available, and more than 77,000 ha are apple orchards. The owner, thanks to his engagement and determination, created a whole logistics value chain of biomass utilization (Figure 21). The harvested biomass from his orchard (ca. 130 t/year) is delivered, in the form of large bales (90x120 cm), to the final users he has found during the market research.

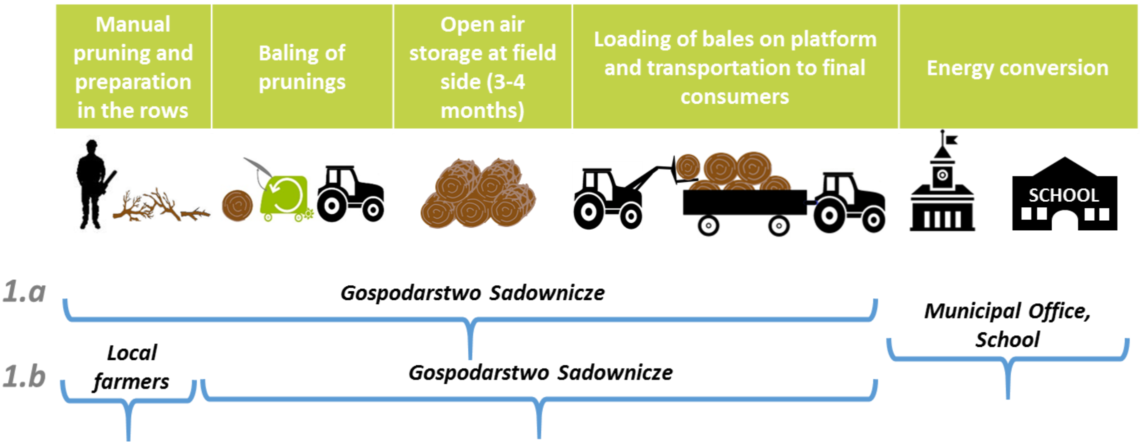

Figure 21.The logistics value chain of biomass utilization for energy purposes in rural area [42].

The bales of prunings are used for heating the municipal buildings in the village of Wieniawa (the Municipal office, the Secondary School Complex and the Healthy Centre) which are at a distance of up to 15 km from the orchards. The biomass is burnt in the medium-sized boilers (thermal capacity 250-600 kW) to heat the object and produce hot water (Figure 22).

a) bales from biomass b) heat plant c) biomass boiler

Figure 22.Use of local biomass for direct heating [42].

8. Conclusions

This report allows to acquire the basic information on direct heating of households, small public buildings, workshops and private plants using solid biomass fuel. The most important solutions of direct heating, heating units as well as methods and guidelines for storing biomass fuels of various forms were discussed. The attention was paid to the operational and environmental aspects of using biomass for heating purposes. The guidelines for the potential end-user and the issues requiring answers that are necessary when using / changing a biomass-based heating system are presented. Simple equations have been proposed that allow to estimate the required boiler power, the amount of biomass covering the annual heat demand, and to calculate the savings resulting from the use of biomass and a simple payback period. The final part contains examples of existing solutions for heating systems based on solid biomass.

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