BECOOP

UNLOCKING THE COMMUNITY
BIOENERGY POTENTIAL

Technical catalogue on biomass direct heating

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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)

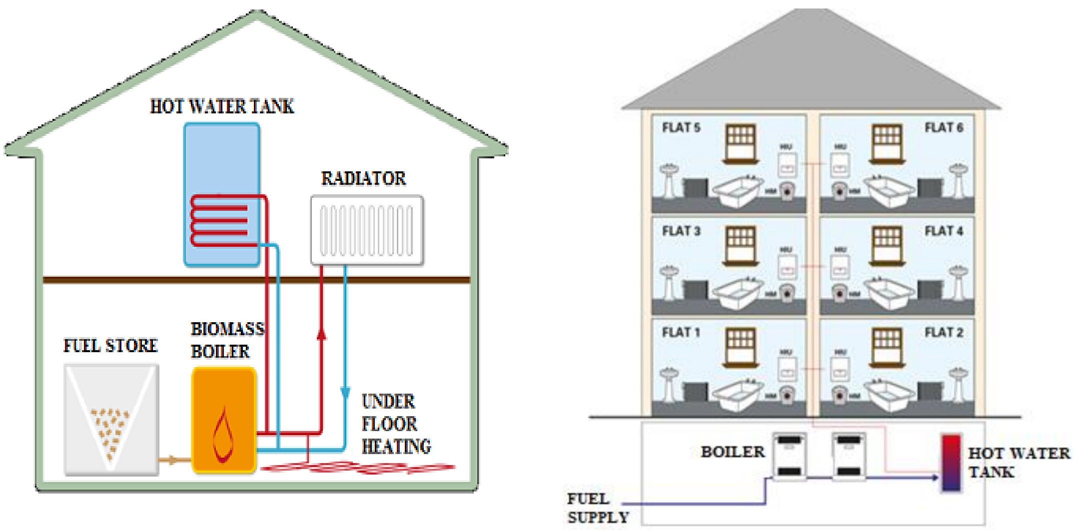

Figure 1. Scheme of direct heating system:
a) single-family house [2], b) residential block [3].

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.

a) b)

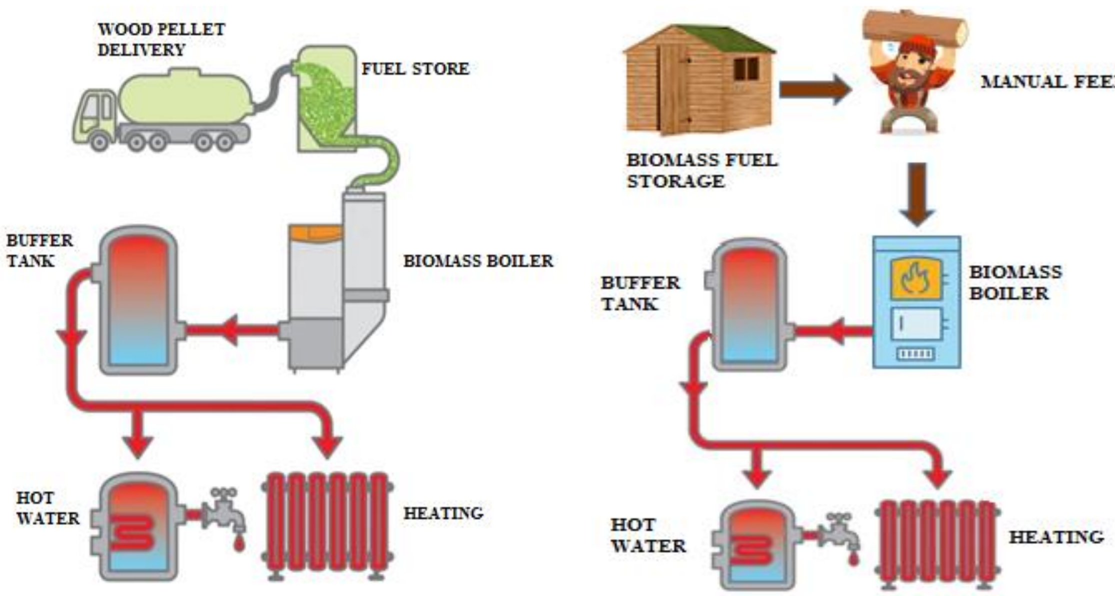

Figure 2. Main components of typical biomass direct heating installations [4]: a) automatic system of direct heating; b) manual system of direct heating.

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) [4]. 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 biofuels made of fragmented biomass (e.g., agricultural residues, forest raw materials, or other organic products) due to pressure agglomeration. The product obtained in this way is a light, smooth, glassy, and homogeneous granulate [6]. They are generally 5 to 30 mm long, and the diameter usually does not exceed 25 mm [7]. Wood pellets should meet the requirements of the EN Plus A1 or A2 standard in terms of humidity (10%), specific density (from 1.12 kg/dm3), and ash content [8]. Burning pellets without certification is still possible, but there may be problems related to removing the ash more often or changing the way the stove is used.

Pellets are an interesting and attractive biofuel for consumers due to the higher heating value and the uniform shape. By unifying the shape and form of pellets, it is possible to fully automate the boiler - which is an additional advantage of this biofuel in heat production. Technical solutions allow e.g., for feeding pellets for unlimited numbers of days of boiler operation using a screw-spiral feeder and adjusting its quantity by electronic sensors [9]. The heater is also automatically turned on, which heats the pellet to the ignition temperature [9]. The maintenance-free operation of the boilers developed in recent years, makes them comparable to heating devices powered by gaseous and liquid fuel.

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 [10]:
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 [10]:

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 fuels produced in compressing fragmented biomass (usually sawdust, shavings, or wood chips), characterized by the shape of a cylinder, cuboid or block [11]. They have different dimensions, but most often, cuboidal briquettes have dimensions of 15 x 10 x 7 cm, while cylindrical briquettes are up to 30 cm long and do not exceed 8 cm in diameter [11]. The production process includes several stages - preparation of raw material, drying, grinding and preparation of fractions, briquetting, conditioning, packaging, and folding [12]. Most often, hydraulic and mechanical presses are used to produce briquettes. Usually, hydraulic presses [13] are considered the most reliable devices for briquetting.

Biomass briquettes has many advantages, such as: increased energy density, ease of handling, transport and storage, stable combustion, lower particle matters emission, uniform size, high density and consistent quality [14-17]. Briquettes are biomass with favourable utility values, it can be burnt in many furnaces, which previously used coal, coke or firewood [18]. 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 [19].

However, a certain disadvantage of using briquettes for domestic boilers is the fact that they require manual loading. Figure 4 shows an example of a briquette boiler and its basic parameters.

Figure 4. ATMOS DC 24 RS briquette boiler [20].

3.1.1.3 Biomass boilers fired by chips

Wood chips are most often defined as wood (although it can be other lignocellulosic biomass), chopped into small, irregular pieces that can be produced at relatively low economic costs [21], however, it depends on the chipper and the way it works. As a rule, the average size of the chips is in the range of 16 to 45 mm [22]. Some pieces can be up to 100 mm long, but chips should not exceed this length due to the potential for blockages and breakdowns in the chip supply system [23].

Wood chip boilers are fully automated devices, which are an alternative to oil or gas heating systems, as they are characterized by high efficiency, comfort in operation, stable heating, and flexible use [24]. These boilers are also called multi-fuel heating systems because they can burn not only wood chips - optionally, they can be powered with pellets, seeds or comminuted other energy plants [25].

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

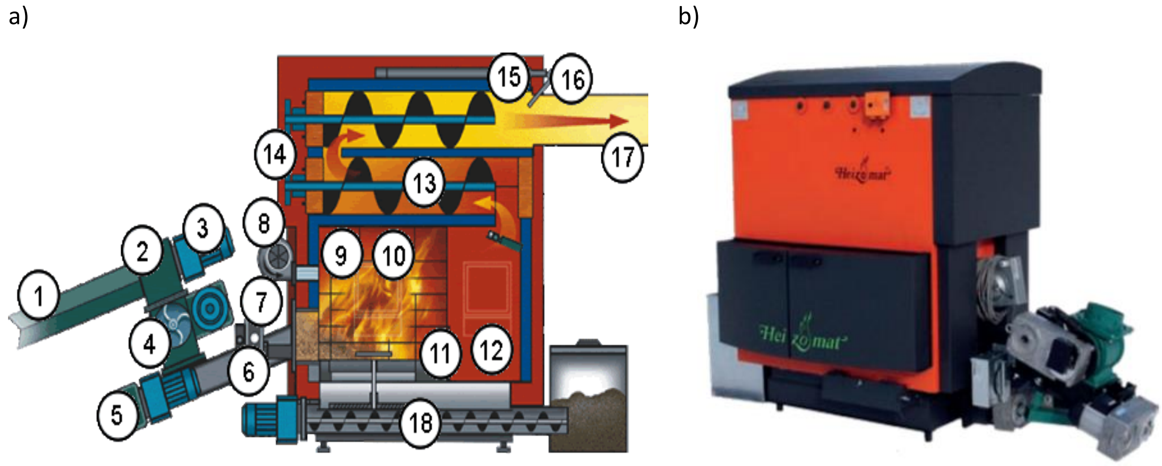

Figure 5. RH-AK 30-990 kW Wood Chip Boiler Cross Section [26]

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 [26]

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

Logs are usually pieces of wood that have been cut into typical lengths of 0.25 m, 0.33 m or 0.50 m [28]. The moisture content in this material should not exceed 20%, hence the logs should be seasonal for minimum two years under the appropriate conditions to meet this requirement [27]. Otherwise, the combustion process will be performed inefficiently, and potential problems with heat generation, heat exchange, the accumulation of soot and tar may occur [28]. It should be noted that the logs must be free of any chemicals (preservatives). The manual process of direct loading into the high-efficiency boiler is required, which is a significant disadvantage and considerable limitation compared to e.g., automated pellet boilers [28].

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

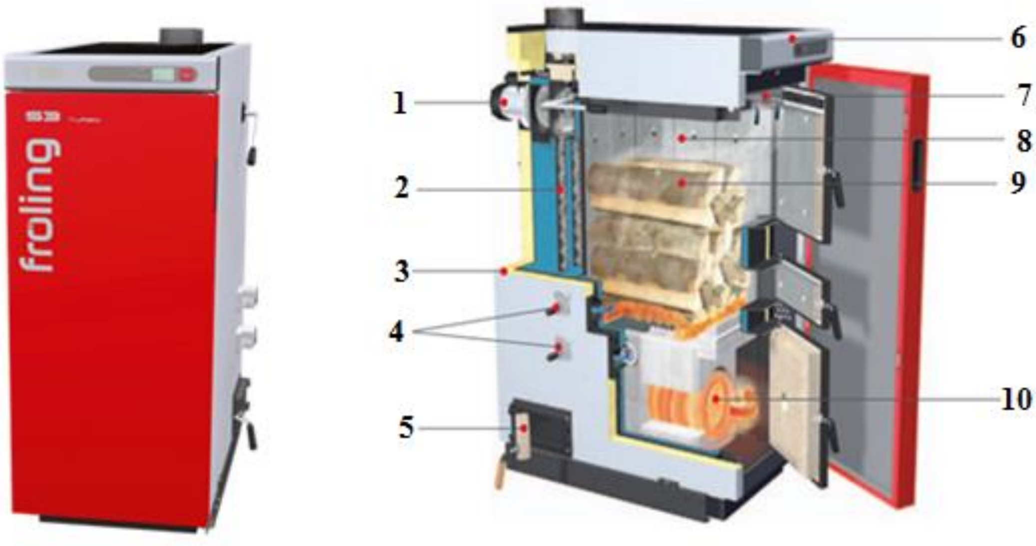

Figure 6. Construction of the wood logs fired boiler [29]:
1 – speed-regulated induced draught fan for maximum ease of use, 2 – EOS (efficiency optimisation system) for high efficiency and easy cleaning, 3 – top quality thermal insulation, 4 – manual adjusters (actuators with Lambdatronic) for primary 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) [30]. 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 [30]. Example of the cubes/bales fired boiler is presented in Figure 7.

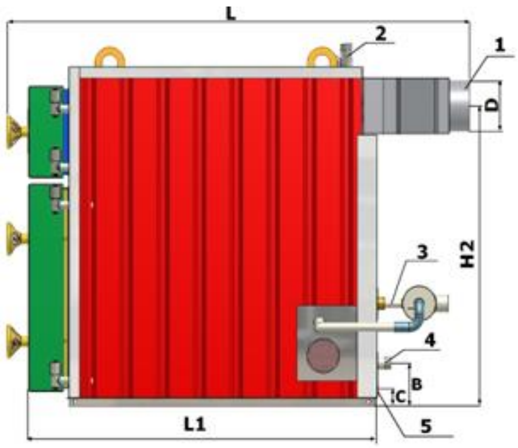

Figure 7. Construction of the straw bales fired boiler [30]:
1 – combustion flare, 2 – the outlet of water to the tank, 3 – air collector, 4 – the return pipe to the tank, 5 –drain plug, 6 –opening light.

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, and also 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) [4]. 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) [31].

3.1.2.1 Storage/Feeding systems for pellets

Optimization of the method of pellets storing depends on the available storage space. Pellets can be stored in bulk in a ventilated room next to the boiler, or in a sealed tank (when the room is exposed to moisture) [32]. Trucks can deliver the amount of pellets for a whole year (or heating season) unloading the biofuel by blowing them (Figure 8) into the warehouse. The pneumatic system is able to transport pellets for distance of 30 m [32].

Figure 8. Pellets delivery process with the use of a tanker [33]:
1 – tanker, 2 – delivery pipe, 3 – prefabricated silos.

Pellet supply systems for heating devices [34]:

a) dry storage room – could be directly adjacent or not adjacent to the heating room (pellets are stored on the ground, and the amount of fuel may be enough for a few months);
b) storage room with a sloping floor that could be directly adjacent or not adjacent to the heating room (the amount of fuel is enough depending on the size of the sloping floor, from a few to several days);
c) storage in separate tanks/big bags (the amount of fuel can be enough from several weeks to several months - depending on the size of the designed tank),
d) mixed option (the possibility of combining several methods of storing pellets, allowing to store the fuel for a whole year of operation).

Due to the need to provide a large amount of biomass fuel to the boiler throughout the heating season, a sufficiently large room or external tank (above ground or underground) for storing pellets or other forms of biomass should be provided. It is accepted to use the rule that every 1 kW of heat load requires 0.9 m3 of storage [32].

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 [35]:
a) conical; b) flat bottom; c) trough.

Depending on the shape and form, the tanks are characterized by different properties [31]:

a) 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.
b) 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.
c) 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 pellet tanks (Figure 10) are relatively rarely used, but they save the space in the heated building. It is worth emphasizing that due to the potential occurrence of a special assembly situation (ground water, water under pressure, watertight soil), these tanks must be reinforced and meet the technical requirements [36]. These systems are compatible with boilers, because the transport of fuel is carried out by suction [36].

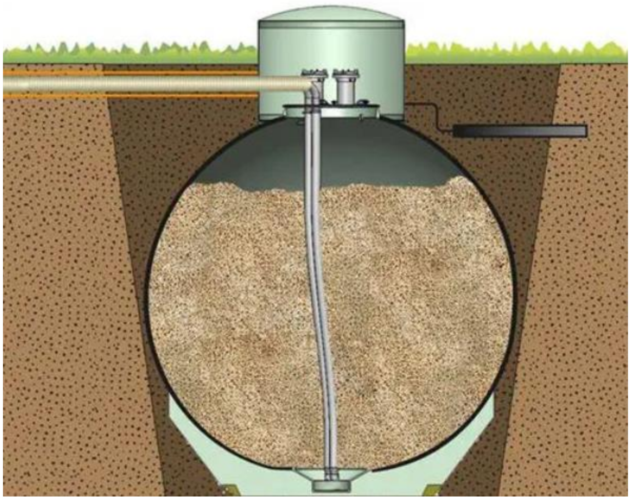

Figure 10. Underground pellet storage silo [37].

The room should meet several requirements when storing pellets in a storage room. According to DEPV [38,39], it is crucial that the warehouse is oblong or rectangular and provides good access to connections (so that the transport of pellets takes place without restrictions). Moreover, the storage room should not have an electrical installation and on the walls it is recommended to install a special mat to protect against abrasion and tearing.

A significant obstacle in the storage of pellets is their susceptibility to moisture absorption (absorption of water). Therefore, special conditions should be provided in a room dedicated to their storage. EPC (European Pellet Council) states that the warehouse should be dry all year round with air humidity close to 80% [31]. In addition, according to the recommendations, it is recommended to use a storage tank when there is a risk that the walls of the room may be damp - however, if there is no such risk, pellets can be stored on a slipping floor with a unique structure that facilitates loading the material into the boiler [31].

This structure is shown in Figure 11. According to the recommendations of [31], slipping floors should have a slope of 40 to 50 degrees (to insure falling) and be made of appropriate materials (wood with a smooth surface, 20-25 cm thick). The construction should also be equipped with stable supports to withstand the adequate load of pellets [31].

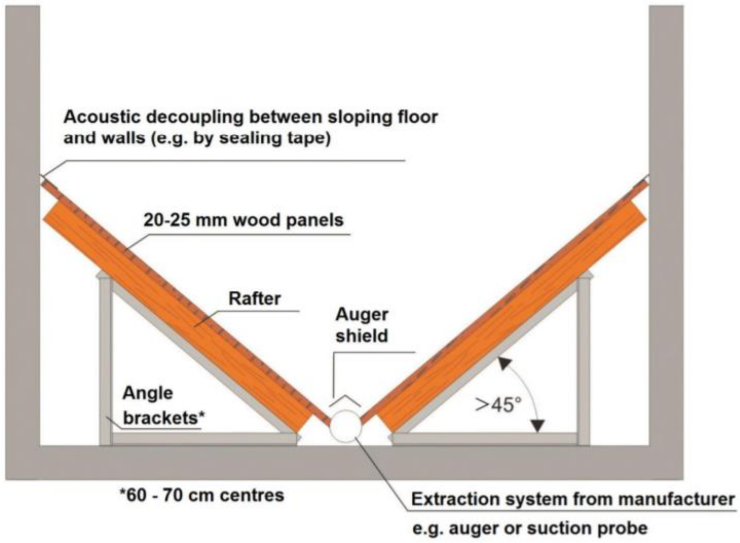

Figure 11. Sloping floor dedicated for pellets storage [31].

Depending on the technical possibilities and the space available to the end user, there are several options for optimal connection of the heating unit with the biomass storage. These systems can be located in the same room or in separate places (Figure 12), but it should be remembered that in order to maintain optimal functionality, it is necessary to distribute properly the pipes that make up the installation.

a) *b)*

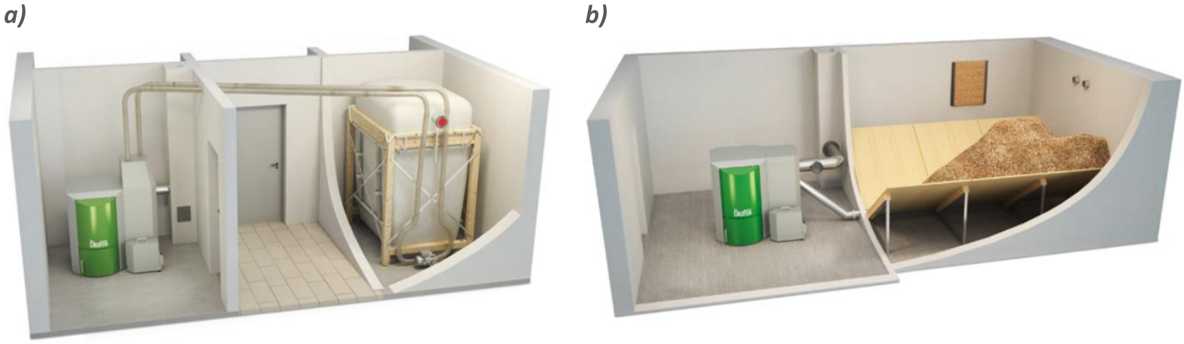

Figure 12. Examples of connecting a pellet boiler with a storage system [40].

3.1.2.1 Storage/Feeding systems for briquettes

Proper storage of briquettes is very important, because they are particularly susceptible to weather conditions - storing them in places not intended for this may reduce their mechanical strength. In order to keep the briquette in proper quality and ensure safe storage conditions, the following instructions should be followed [41]:

a) *only dry and cooled briquettes should be placed on the heap/warehouse - it is necessary to control their temperature;*
b) *the pallet is stable, if the briquettes are placed on a hard, checked surface - it is optimal to build a stepped/stepped pile;*
c) *do not exceed four pallets in a stack - this is important from the point of view of fire protection;*
d) *it is important to keep walkways for pallet trucks;*
e) *for safety, keep a distance of approx. 20 cm between rows of pallets;*
f) *in a row, the distance between pallets should be approx. 10 cm;*
g) *during storage of briquettes, air humidity should be higher than 60%, but briquettes should not be sprayed in any way;*
h) *the stack must be freely accessible from all sides;*
i) *there should be air circulation between the layers if horizontal liners are used;*
j) *if during the inspection, any pallet/stack of briquettes will have an inappropriate temperature or humidity, it should be separated and stored separately;*
k) *when the belts around the pallets are loosened, they should be tightened again using a device adapted for this purpose.*

Do store your briquettes in [42]: 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: [43,44]
a) foiled pallets inside the room; b) bags.

3.1.2.1 Storage/Feeding systems for chips

There are several options for storing chips, which depend on the available technical capabilities of the user and the required storage space. It is generally recommended that the stored chips are covered to prevent moisture absorption, but providing airflow is also important to dissipate water vapor, reduce the risk of composting and mold formation [23]. According to the recommendations [45], the care should be taken to ensure that the deduced chips warehouse is cleaned regularly, and the value of moisture content of the fuel should be provided during delivery (on the receipt or a separate document) to confirm its quality.

The technical capabilities and the fuel warehouse owned determine the form of chip delivery. There are several ways to deliver [46]:

a) Tipped Delivery into Bulk Store - often used, involving the delivery of biomass in bulk with a dump truck and loading the chip with a lift/telescopic loader to a warehouse (often a container), which is covered with a pad.
b) Ramped Delivery - delivery consisting in unloading biomass to the warehouse with a dump truck using a specially built ramp. However, due to significant financial outlays, it is recommended to build a ramp only for installations with a capacity of 100 kW or more. Often, in order to maintain safety, the ramp construction project should be consulted with appropriate specialists.
c) Blown Delivery - a similar delivery option as in the case of pellets, consisting in blowing chips into the target warehouse using a vacuum pipe driven by a hydraulic pump, which is part of the supply tanker equipment.
d) Fast Feed Auger Delivery - delivery dedicated to smaller installations, consisting in pouring the purchased biomass into the trough. Then, using a screw conveyor, the chips are transported to the final warehouse.

Fuel delivers options, depending on the storage scenarios, are shown in Figure 14.

a)

b)

c)

d)

Figure 14. Chips deliver options, depending on storage scenarios [46]:
a) tipped delivery into a bulk fuel store with tele handler chips moving; b) fast feed auger delivery; c) ramped delivery; d) blown delivery.

Chips can also be stored directly outside, but it is necessary to provide them with a roof, because, like other forms of biomass, they easily absorb moisture. There may also be a loss of chips dry matter during outside storage [47]. Various types of buildings can be used to store chips outside - sheds, arched halls and others.

The choice of storage and delivery options depends mainly on four components - the scale of the project, the technical capabilities of the end user, financial outlays, and location conditions. 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 [48] dedicated to smaller installations (Figure 15).

a)

b)

Figure 15. Outdoor chips storages for larger installation [48,49]:
a) arched hall; b) shed.

The distance and potential difference in levels between the biomass storage site and the boiler is the main factor determining the choice of the feeder system, so that the transport of the wood chips is as effective as possible. As a rule, installations are equipped with blade reels (reel biomass) and screw conveyors or other feeders (the role of which is to transport biomass to the boiler) [4,50]. Examples of storage and loading solutions for wood chips are shown in Figure 16.

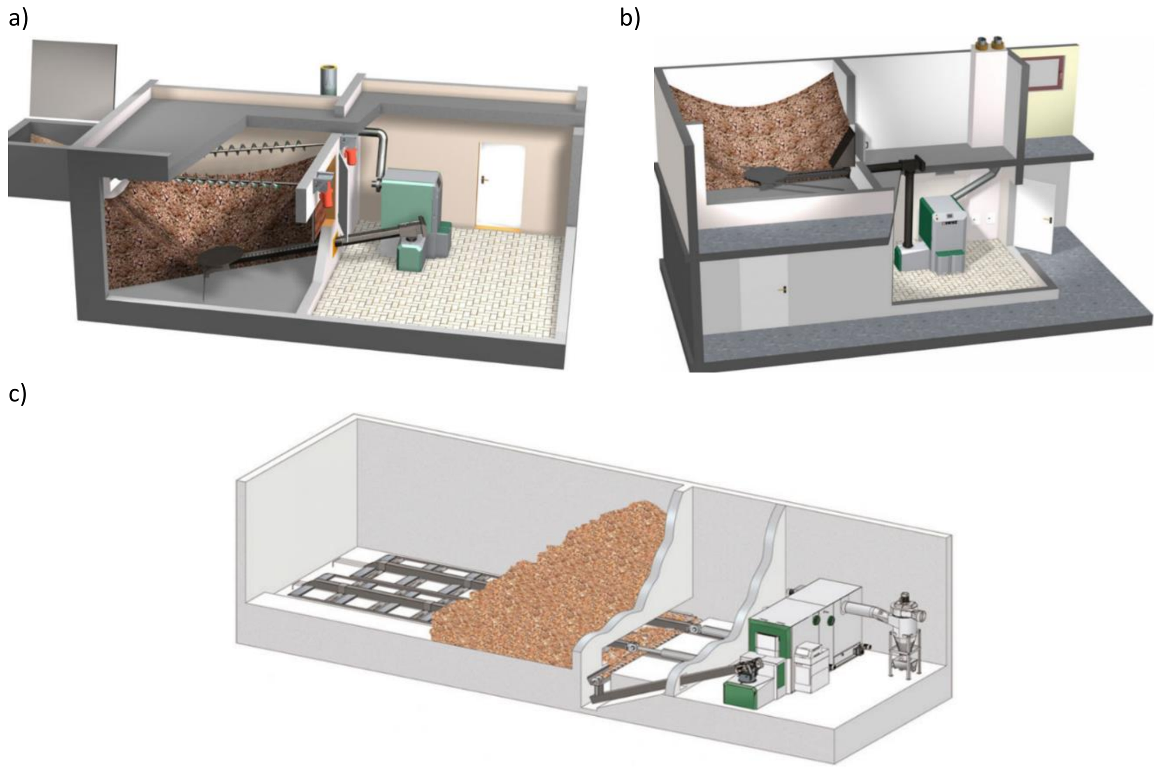

Figure 16. Examples of storage and loading solutions for chips [50]:
a) chips store and the boiler room are on the same level (leaf reel and 2 feeders); b) chips storage and boiler at different levels: horizontal leaf reel, feeder, slope system; c) hydraulic floor systems.

3.1.2.1 Storage/feeding systems for logs

During the heating season, it is important to prepare enough logs to ensure continuous heating in the specified building. To ensure dry and high-quality logs for burning in the boiler, the following instructions should be followed [51]:

a) *stack logs neatly* - arranging the logs in precise stack can reduce the risk of soaking the entire biomass during rain (only top layer of logs will get wet),
b) *consider location carefully* - a hard and stable surface is crucial; additionally, the risk of unfavorable weather conditions should be taken into account,
c) *avoid tree cover* - water running down trees or dripping from leaves/branches can cause that logs will absorb moisture*,*
d) *don't leave logs in a heap* - free scattering of logs is ineffective due to the risk of getting wet.

e) *use pallets where possible* - in the case of using warehouse, pallets or other construction, the risk of getting wet is much lower; however, it is worth remembering that the height of the stack in the warehouse should not be too high, because the whole structure may collapse,

f) *provide good circulation* - a gap should be provided between the logs storage area and other obstacles need to be removed to enhance air circulation – this is also important from the point of view of fire risk and fire safety.

It is possible to store logs in different systems - open space, closed space, covered with tarpaulin (Figure 17). However, it is important, as recommended by [51], not to completely cover the logs with a tarpaulin and to leave the sides of the stack uncovered, as otherwise it may significantly reduce a required air circulation.

a) b) c)

Figure 17. Examples of storage solutions for logs [51,52]
a) wooden log store; b) tarpaulin cover; c) metal log store.

3.1.2.1 Storage/Feeding systems for bales/cubes

Straw that is harvested from the field should be stored immediately after baling to avoid absorbing moisture from the air and getting wet [53]. Straw should be stored close to the field, covered with thatch, a tarpaulin or placed under a roofed place (shed/hall) [53]. Straw-burning boilers are able to burn material with a moisture content of less than 20% - the front of the boiler is equipped with an opening/gate enabling easy manual loading of a straw bale into the combustion chamber [54].

In order to minimize the risk of straw fire, the following instructions should be followed to ensure an appropriate degree of straw dryness [55]:

a) when storing straw in a roofed place (Figure 18b), special attention should be paid to ensure that water does not get inside and that the place remains dry,

b) when storing straw outdoors (Figure 18a), cover it with a tarpaulin/plastic or other waterproof material. It is important to arrange the bales in such a way that air can circulate freely. In addition, bales can be stored on gravel, tires or pallets instead of on the ground, which also allows protection from moisture.

a) b)

Figure 18. Examples of storage solutions for logs [56]:
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 [57,58]:
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 [59] 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 [60-62]

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:

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

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.

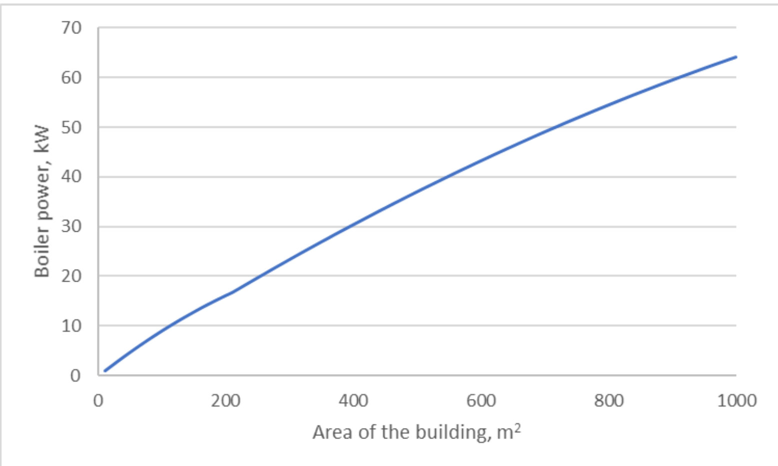

Figure 20. Thermal power of the boiler vs. Heated surface area of the building (in a temperate climate)[1].

[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:

a) burning instability,
b) increased pollutant emission,
c) low combustion efficiency and increased fuel consumption,
d) joking of conveyors,
e) corrosion,
f) 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:

a) 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.
b) 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.
c) 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:

a) the safe operation of the system.
b) minimized breakdowns (failures).
c) maximization of the operation lifetime of the boiler.

To plan the exploitation properly:

a) the boiler's overhauls should be made minimum once a year,
b) only high quality biomass should be used,
c) 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:

$$SPBT = \frac{I_o}{AC_a} \quad (5)$$

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

The formula of annual avoided costs is as follows:

$$AC_a = (HP_2 - HP_1) \cdot EC_a \quad (6)$$

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) [63]

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.

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[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 [64,65]

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 [64,65]

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:

a) 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.

b) 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.

c) 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.

d) 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.

e) 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.

f) 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.

g) 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.

h) 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.

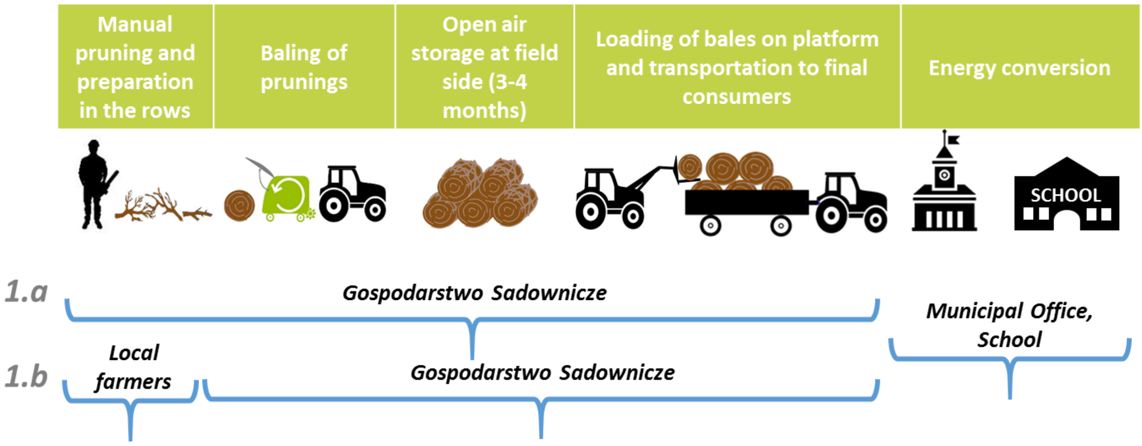

Figure 21.The logistics value chain of biomass utilization for energy purposes in rural area [66].

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 [66]

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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