PDHonline Course E504 (4 PDH)

Biomass Heating Project Analysis

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1. Biomass Heating Project Analysis

This course covers the analysis of potential biomass heating projects including a technology background and a detailed description of the calculation methods.

2. Biomass Heating Background

Biomass heating systems burn plant or other organic matter such as wood chips, agricultural residues or even municipal waste. This heat can be transported and used wherever it is needed—for the ventilation and space heating requirements of buildings or whole communities, or for industrial processes. Biomass heating systems differ from conventional wood-burning stoves and fireplaces in that they typically control the mix of air and fuel in order to maximize efficiency and minimize emissions, and they include a heat distribution system to transport heat from the site of combustion to the heat load. Many biomass heating systems incorporate a sophisticated automatic fuel handling system.

Biomass heating technology is not new. For many years people have used stoves and furnaces, fed with cut roundwood, for space heating. The development of automated biomass heating systems began in Scandinavia in the 1970s, when oil prices skyrocketed. Today, there are thousands of these systems in operation around the world, using a multitude of different types of biomass fuels, or "feedstock". The recent emphasis on renewable energy resources as replacements for conventional fuels, spurred by concerns about greenhouse gas (GHG) emissions, is causing a resurgence of interest in biomass heating, where the biomass is harvested in a sustainable manner.

Biomass heating offers a number of compelling advantages, both for the system owner and, in the case of district heating systems, for the local community. It can supplant expensive conventional energy sources such as fossil fuels and electricity with local biomass resources, which is often available at little or no cost as waste or low-value by-products from various industries (e.g. forestry and agriculture). In doing so, overall levels of pollution and greenhouse gases are reduced, the purchaser is insulated from fossil fuel price shocks, and local jobs are created in the collection, preparation, and delivery of the feedstock.

In addition, the heat distribution system of the biomass heating plant facilitates the use of waste heat from on-site power generation or thermal processes (i.e. waste heat recovery, or “WHR”) and can be extended to service clusters of buildings or even whole communities in a “district energy system”. Biomass heating systems tend to have higher initial costs than conventional fossil fuelburning systems. Furthermore, the quality of biomass feedstock is highly variable in comparison with the relatively standardized commercially available fossil fuels. Feedstock delivery, storage, and handling are more complex as a result, and often more physical space is required. All these factors require a high level of operator involvement and diligence.

Therefore, biomass heating systems are most attractive where conventional energy costs are high and biomass feedstock costs are low. This occurs when: electricity or some other costly form of energy is used for space and water heating; and biomass residues are available on-site or nearby at zero cost or, if there is a disposal fee for the biomass residues, at a discount.

Because of their size and complexity, the use of automated biomass combustion systems is largely limited to the industrial, commercial, institutional and community sectors. They tend to be located in rural and industrial areas, where restrictions on the types of pollutants they emit may be less severe, truck access for feedstock delivery may be in place, feedstock-handling equipment such as loaders may already be available, and the labour and expertise required to operate an industrial type boiler system may be easier to find.

Biomass combustion systems are often well suited to industrial process loads. Many industrial process loads have constant heat requirements and biomass heating systems operate most efficiently, and with the fewest operational challenges, when they supply a relatively constant quantity of heat, near their rated capacity, throughout the year. This also maximizes fuel savings by displacing a large amount of expensive conventional fuel, justifying the higher initial capital and on-going labour costs of the system.

This background section describes biomass heating systems, discusses the biomass heating markets including community energy systems, individual, institutional and commercial building, and process heat applications, and presents general biomass heating project considerations.

3. Description of Biomass Heating Systems

A biomass heating system consists of a heating plant, a heat distribution system, and a biomass fuel supply operation. These three parts are described in detail in the following section.

4. Heating plant

Biomass heating plants typically comprise a number of different heating units. This ensures that there will be sufficient heating capacity to meet the heating load (by turning on additional units when the load increases), reduces the risk that a fuel supply interruption will endanger the supply of heat (other units can compensate for the lack of fuel in the primary unit), and maximizes the use of the lowest-cost heat sources (by using the least expensive sources first, and activating more expensive sources only as needed). Four types of heat sources that may be found in a biomass heating plant are, in increasing order of typical cost per unit of heat produced:

- Waste heat recovery: The lowest-cost heat will typically be that provided by a waste heat recovery system. Some biomass heating plants can be situated near electricity generation equipment (e.g. a reciprocating engine driving a generator) or a thermal process that rejects heat to the environment. This heat, which would otherwise be wasted, can often be captured by a waste heat recovery system, at little or no additional cost.

- Biomass combustion system (BCS): The BCS is the unit that generates heat through combustion of biomass feedstock, and is thus by definition the heart of a biomass heating plant. If a low-cost feedstock is used, and the system is operated at a relatively constant loading near its rated capacity, the unit cost of heat produced by the BCS will be relatively low; the BCS will supply the portion of the heat load that is not met by waste heat recovery, up to the capacity of the BCS.

- Peak load heating system: Due to its operational characteristics and higher capital costs, the biomass combustion system may be sized to provide sufficient heat to meet typical heat loads, but too small to satisfy occasional peaks in the heating load. The peak load heating system will provide that small portion of the annual heating load that cannot be furnished by the BCS. Often it will rely on conventional energy sources, and be characterized by lower capital costs and higher fuel costs. In some cases the peak load heating system is also used during times of very low heat load; under such conditions, the biomass combustion system would be very inefficient or generate unacceptable levels of emissions (smoke).

- Backup heating system: Used in the case where one or more of the other heat sources are shutdown, either due to maintenance or an interruption in the fuel supply, the backup heating system will tend to share the peak load system's characteristics of lower capital costs and higher fuel costs. Often the peak load system serves as the backup to the biomass combustion system, and no additional backup heating system is included.

In the biomass combustion system (BCS), the principal interest in a heating plant, the biomass fuel or feedstock moves through the BCS in a number of stages, many of which are described here:

- Biomass Fuel (Feedstock) Delivery: if not available on site, the biomass fuel is delivered to a fuel receiving area, which must be large enough to accommodate the delivery vehicles.

- Biomass Fuel (Feedstock) Storage: the biomass fuel in the storage area must be sufficient to fire the plant over the longest interval between deliveries. The fuel can be stored in an outdoor pile, a protective shed, or inside a bin or silo. Outdoor storage, though inexpensive, permits precipitation and dirt to contaminate feedstock.

- Biomass Fuel (Feedstock) Reclaim: this refers to the movement of the biomass fuel from storage to the combustion chamber. It can be effected manually, as in the loading of outdoor furnaces with cut logs; fully automated, using augers or conveyors; or rely on both operator and machinery. Fully automatic systems can be vulnerable to biomass fuel variability and detritus, such as frozen or irregularly shaped clumps, wire, or gloves.

- Biomass Fuel (Feedstock) Transfer: this is the movement of the biomass fuel into the combustion chamber. In automated systems, a screw auger or similar device moves the biomass fuel and a metering bin measures the flow into the combustion chamber.

- Combustion Chamber: the biomass fuel is injected into an enclosed combustion chamber, where it burns under controlled conditions. To this end, a control system regulates the inflow of air in response to heat demand; in automated BCSs, biomass fuel flow is also regulated.

Refractory materials keep the heat of combustion inside the chamber. Many combustion chambers support the burning feedstock on a grate, enabling airflow up through and over the burning biomass fuel, facilitating complete combustion. In more sophisticated systems, the grate moves in order to evenly distribute the fire bed, convey the biomass fuel through zones of different under-fire airflow, and to push the ash to the end of the combustion chamber. Hot exhaust gases exit the combustion chamber and either pass through a heat exchanger, into a secondary combustion chamber containing a heat exchanger, or, if the heat exchanger is in or around the combustion chamber, directly into an exhaust system.

- Heat Exchanger: the heat from combustion is transferred to the heat distribution system via a heat exchanger. In simple outdoor furnaces, an insulated water jacket around the combustion chamber serves as the heat exchanger. Larger BCSs use boilers, with water, steam, or thermal oil as the heat transfer medium.

- Ash Removal and Storage: this involves voiding the BCS of bottom ash, which remains in the combustion chamber, and fly ash, which is transported by the exhaust gases. Bottom ash may be removed manually or automatically, depending on the system. Fly ash may deposit in the secondary combustion chamber or the heat exchanger (necessitating cleaning), escape out the flue, or be taken out of suspension by a particulate collection device (exhaust scrubber).

- Exhaust System and Stack: this vents the spent combustion gases to the atmosphere. Small systems use the natural draft resulting from the buoyancy of the warm exhaust; larger systems rely on the fans feeding air into the combustion chamber to push out the exhaust gases, or draw the exhaust gases out with a fan at the base of the chimney.

In addition to the equipment described above, instrumentation and control systems of varying sophistication oversee the operation of a BCS, modulate the feed of air and, in automated BCSs, fuel, in response to demand, and maintain safe operating conditions.

Biomass combustion systems cover a wide range of equipment, distinguished by variations in fuel and air delivery, design of combustion chamber and grate, type of heat exchanger, and handling of exhaust gas and ash. Other than very large heating plants, BCS installations can generally be classified within three broad feed system categories, based on their capacity:

- Small manual feed systems (50-280 kW): typically are outdoor furnaces burning blocks of wood and distributing heat with hot water.

- Small automatic feed systems (50-500 kW): use particulate biomass fuel (feedstock), typically utilising a two-stage combustor (i.e. with a secondary combustion chamber) and incorporating a fire-tube hot water boiler (i.e. a tube that carries hot combustion gases through the water that is to be heated).

- Moderate-sized feed systems (400 kW and up): have fully automated feeding of particulate biomass fuel (feedstock), typically utilising a moving or fixed grate combustor with integral or adjacent fire-tube boiler for hot water, steam or thermal oil.

In addition to these general types, there is a wide variety of specialty biomass combustion systems configured to meet specific fuel characteristics or specific heating requirements.

The sizing of the biomass combustion system relative to that of the peak load heating system is a crucial design decision. The overriding objective is to minimize the total life-cycle cost of the heat supply. There are two common approaches to BCS system sizing: base load design and peak load design. The choice of design method will depend on the variability of the load, the cost of biomass and conventional fuels, the availability of capital, and other factors specific to the application. Peak load sizing is more common in large installations with high continuous energy demands. Base load sizing is often applied to smaller installations serving exclusively space heating or variable loads. The two approaches to system design are compared in Table 1.

For applications exhibiting strong seasonal variation in the heat load, such as year round process loads augmented by space heating requirements in the winter, two BCSs may be used. A small unit operates in the summer, a larger unit sized for the typical winter load runs during wintertime, and both units operate simultaneously during periods of peak demand. This arrangement facilitates the operation of each BCS at a loading close to its rated capacity, raising efficiency and reducing emissions. Moreover, it is still possible to provide some heat when one system is shut down for maintenance.

5. Heat distribution system

The heat distribution system transports heat from the heating plant to the locations where it is required. This may be within the same building as the BCS, in a nearby building, or in a cluster of buildings located in the vicinity of the plant in the case of a district heating system. In most systems, a network of insulated piping conveys water at temperatures up to 90ºC away from the plant and returns the cooled water back to the plant for reheating; in some industrial systems, heat is distributed by steam or thermal oil.

Approaches To Biomass Combustion System Sizing	
Base Load Design	Peak Load Design
Description (Design philosophy)	
Maximise cost effectiveness by ‘undersizing’ the BCS to handle only the major (or base) portion of the heating load. Use a lower capital cost, smaller fossil fuel system to handle peaks.	Determine the peak (or maximum) heating load, then oversize the system by a contingency factor to ensure that unanticipated extreme loads can be satisfied.

Advantages	
BCS is running at or near its full (optimum) capacity most of the time, which will provide highest seasonal efficiency Capital costs significantly reduced Better system control for efficient performance and lower emissions.	Minimizes use of fossil fuel; Maximizes use of biomass; Provides the possibility for increased energy use at marginal cost (if biomass fuel cost is low) Provides a built-in capacity surplus for future load expansion.
Disadvantages	
A conventional system is required for peak heating loads Fossil fuel use will be increased; Future load expansion will affect base load Increased energy use must be supplemented by more expensive conventional fuels.	A larger system greatly increases capital cost (and labour operating costs) With variable loads (as in heating applications), the BCS must be operated at part load much of the time. This reduces operating efficiency, resulting in an increase in biomass fuel consumption; and When operated at low load, BCSs are prone to higher emissions (smoke) and often unstable combustion.

Table 1. Approaches to biomass combustion system sizing

Within a building, heat is typically distributed by baseboard hot water radiators, under-floor or in-floor hot water piping, or hot air ducting. Between buildings, a network of insulated underground piping transports heat. Small distribution networks utilize low cost coils of plastic pipe. In larger networks, a pipe-within-a-pipe arrangement is common: the inner carrier pipe is generally steel, the outer casing is polyethylene, and the cavity between the carrier pipe and the casing is filled with polyurethane foam.

Piping is usually buried 60 to 80 cm below ground surface. It is not necessary to bury the pipes below the frost line since the pipes are insulated and circulate hot water.

In a district heating system, a central biomass plant provides heat to a number of consumers located around the area near the central plant. The consumers will often be grouped in clusters of public, commercial, and residential buildings located within a few hundred meters of each other. District heating systems offer a number of advantages over the use of individual heating plants in each building. A single, large plant will have a level of sophistication, efficiency, and automation that would not be possible in the smaller plants.

In addition, individual consumers will not need the equipment or expertise needed to successfully operate their individual biomass combustion system, further encouraging the substitution of biomass over fossil fuels. Additionally, fuel consumption, labour requirements, and emissions will be reduced, waste heat may be used more effectively, and the system will be operated more safely, all because the plant is centralized.

Heat distribution systems can often be expanded to accommodate new loads if the main distribution piping has sufficient capacity. Additional buildings within a reasonable distance can be connected to the system until its capacity is reached. If sufficient space is allocated in the heating plant building, additional burners can be installed at a later date to increase capacity.

Since the initial costs of a district heating system are high, it is cheaper to be integrated into newly constructed areas. Finally, a biomass combustion and district heating system requires a high level of dedication and organization than simple fossil fuel-fired systems.

6. Biomass fuel supply operation

The biomass fuel supply operation is the sequence of activities that results in the delivery of biomass fuel (feedstock) to the heating plant. Since the proper functioning of the plant is intimately related to the timely supply of appropriate biomass fuel, and since this operation often entails local activity rather than decisions made at a distant refinery, the fuel supply operation is considered a “component” of the plant.

A reliable, low-cost, long-term supply of biomass fuel is essential to the successful operation of a biomass heating plant. Fossil fuel products are relatively standardized, generally available, and easy to transport and handle. In contrast, many biomass fuels are highly variable in terms of moisture content, ash content, heating value, bulk consistency, and geographical availability.

Biomass combustion systems—and especially their fuel handling sub-systems—may be designed to operate with only one type of biomass of a certain quality, and may require modification or operate poorly when used with a different biomass fuel. Thus, the installation of a biomass heating plant must be preceded by a thorough assessment of the quality and quantity of the biomass resource that is available, the reliability of the suppliers, the fuel handling requirements imposed by the characteristics of the available biomass fuel, and possible changes in the future demand for the targeted biomass resource.

For example, if an alternative use is discovered, that may increase the price of the biomass resource. Therefore, long-term supply contracts should be negotiated whenever possible.

A wide range of low-cost material can be used as biomass fuel such as wood and wood residues in chunk, sawdust, chip, or pellet form; agricultural residues such as straw, chaff, husks, animal litter, and manure; fast-growing energy crops planted specifically for biomass combustion, including willow, switchgrass, and hybrid poplar; and municipal solid waste. Whatever the biomass resource, it can be considered a renewable resource only if it is harvested in a sustainable manner. The price of the biomass fuel depends on the source. If the biomass fuel is a waste product that must be disposed of, it may have a negative cost since tipping fees are reduced.

Residuals, such as bark from a sawmill, which do not need to be disposed of but have no alternative use, are often available at no cost. By-products, such as shavings and sawdust, have a low-value alternative use and therefore will typically be available at a low cost.

Plant biomass, which is harvested or purpose grown specifically for use as a biomass fuel, will normally have higher costs, and prepared fuels, such as briquettes, may cost more than fossil fuels. These prepared fuels may have stable, uniform characteristics, however, making them convenient for use in small systems with simple fuel handling systems, where minimum operator involvement is a necessity.

For example, prepared wood pellets have achieved considerable success in Europe. In many countries that have embraced biomass heating, woodchips and other wood products are the principal biomass resource. The goal of every forestry operation should be to maximize the utilisation of harvested trees and to provide for the establishment of a new crop of productive trees. In the forestry industry, harvested trees should be sorted so that a range of products reflecting the quality of the trees can be produced: timber from the boles of spruce or pine and firewood or woodchips from small diameter, dead, diseased and otherwise unusable trees. A community logging operation can integrate woodchip fuel production into their product offering.

The size of wood that can be chipped is limited by the size of the chipper selected. Because of the high costs for large chippers, most small-scale chipping operations employ small-scale chippers, often powered by farm tractors that can chip trees up to about 23 cm (10 inches) in diameter. Larger, second-hand industrial chippers are sometimes available at a reasonable cost.

Chipping can take place at the logging site. However, in isolated areas where winter roads may be used for transport, a significant quantity of chipping material can be stockpiled near the heating plant and chipped as it is required. If there is no logging operation nearby, a stand-alone operation to supply wood and produce chips will need to be established. Woodchips must be of good quality, and free of dirt and oversized sticks, which are produced when chipping knives get dull. Sticks can cause jamming and shutdowns of the fuel-feed system; dirt causes excessive wear as well.

7. Biomass Heating Application Markets

Biomass heating markets can be classified by the end-use application of the technology. The three major markets are community energy systems, institutional and commercial buildings, and process heat applications.

8. Community energy systems

Community energy systems make use of a biomass heating plant and a district heating system to service clusters of buildings or even an entire community. Such community energy systems can provide space heating, heating of ventilation air, water heating, and process heat. These can be supplied to individual buildings, such as institutional (e.g. hospitals, schools, sports complexes), commercial (e.g.

offices, warehouses, stores), residential (e.g. apartments) and industrial buildings. They can also provide heat to individual homes, especially if the houses are newly constructed and in groups.

Small community energy systems employ fully automated, highly sophisticated, “small-industrial” biomass heating plants, usually with a capacity of 1 MW or higher. They have large fuel storage bins, computerized control systems, burners with automated de-ashing augers, and smoke venting systems that are usually equipped with particulate collectors and induced draft fans.

9. Individual institutional and commercial buildings

Individual buildings can satisfy their heating requirements with biomass combustion systems. Since substantial fuel savings must be achieved in order to offset the higher initial costs and annual labour operational requirements of the biomass system, it is rare that a building as small as an individual house would use a biomass heating plant as described in the previous sub-section. Rather, biomass heating is found in institutional buildings such as schools, hospitals, and municipal buildings; commercial buildings like stores, garages, factories, workshops, and hotels; and even agricultural buildings, such as greenhouses. The biomass heating plants in individual buildings tend to be of the “small-commercial” or “commercial” variety. For plants with capacity of 75 to 250 kW, small-commercial systems are common.

These automated, relatively simple plants have low initial costs compared to larger, more sophisticated systems. Fuel hoppers are typically quite small, and the operator must fill them about twice a day. The ash must also be raked off the grate once a day; larger systems use automatic ash handling systems. Electronic controls regulate airflow and fuel feed.

Commercial (also called “intermediate-scale”) biomass heating systems, sized from 200 to 400 kW, have characteristics of both small-commercial and industrial biomass heating systems. They employ larger fuel storage bins and have more elaborate fuel feeding mechanisms than small-commercial systems, but they have simple low cost control panels—some have fixed burner grates that require manual de-ashing. Usually they do not have dust collectors or induced draft fans. They are found in institutional buildings and small industry, such as sawmill kilns.

10.Process heat

Small industrial biomass heating plants are also used to provide process heat to industry, especially in those sectors where biomass waste is produced. These include sawmills, sugar plants, alcohol plants, furniture manufacturing sites, and drying sites for agricultural processes.

Industrial processes will usually require substantial quantities of heat year round, thus justifying the higher capital costs of biomass heating through substantial savings in fuel costs. These applications benefit from having skilled labour on-site, loading and storage infrastructure, and free feedstock material.

11.Biomass Heating Project Considerations

Selecting a conventional gas or oil heating system is relatively straightforward. Bids from different suppliers are comparable because fuel quality is standardised, systems are simple and designs are similar.

Different bids often offer the same quality of heat service and the same level of operating convenience, leaving price as the sole deciding factor. Biomass combustion systems, on the other hand, are more complex than conventional systems and offer wide variations in design, leading to different feedstock and operating requirements.

Comparing BCSs to conventional plants requires a careful evaluation of life-cycle costs and savings; even comparing bids from different biomass heating system suppliers calls for diligence.

In such comparisons, the following particularities associated with biomass heating systems should be considered:

Physical size	Biomass fuel systems are much larger than conventional heating systems. They often require access for direct truck delivery of fuel, space for fuel storage, and a larger boiler room to house the mechanical fuel delivery and ash removal systems.
Fuel	Unlike gas and oil, biomass fuels are generally not standardised, homogeneous fuels backed by large national suppliers. As a result, fuel quality, consistency and supply reliability are concerns.

	Energy content varies significantly depending on the type of biomass used for fuel.
Operation	Biomass combustion systems typically require more frequent maintenance and greater operator attention than conventional systems. As a result, operator dedication is critical.
Mechanical Complexity	Biomass combustion systems are more complex than conventional heating systems, especially when it comes to fuel storage, fuel handling and combustion. The complexity arises due to the different characteristics of biomass fuel compared to fossil fuels. The increased complexity means capital costs that are both higher and more difficult to estimate.
Local pollution	Biomass combustion generates emissions that can affect local air quality and that may be subject to regulation. These include particulates, also known as soot, gaseous pollutants such as carbon monoxide, sulphur oxides, nitrogen oxides, and hydrocarbons, and low levels of carcinogens. The emissions generated by the system will depend on the type of fuel as well as the size and nature of the combustion system. Local emission regulations may be different depending on the fuel type and combustion system. In addition, ash must be discarded according to local regulations.
Combustion Hazards	Biomass combustion systems often require additional fire insurance premiums and special attention to general safety issues.

Table 2. Biomass heating system particularities

These special considerations must be weighed against the many advantages of biomass heating systems. In addition to those already described, such as reduced life-cycle costs, the following may be important:

Local economic benefits	Biomass fuel (feedstock) is often harvested, collected, and delivered by local operators; in contrast, fossil fuels are generally imported from outside the community. Furthermore, the preparation and delivery of biomass fuel is more labour intensive than is the case with fossil fuels. As a result, expenditures on biomass have a stronger “multiplier effect” for the local economy: money tends to stay within the community rather than leave, creating local jobs and improving the local tax base.

Heating Comfort	Low-cost biomass fuels make raising thermostats a more welcome proposition than with more expensive fossil fuels, resulting in warmer, more comfortable buildings.
Flexibility	Biomass combustion systems are highly flexible. Solid-fuel systems can be easily converted to burn almost any conceivable fuel (solid, liquid or gaseous) thus providing the user with great flexibility for the future.
Environment	Plant material that is harvested in a sustainable manner is considered a renewable energy resource since it will last indefinitely. Since growing biomass removes the same amount of carbon from the atmosphere as is released during combustion, so there is no net increase in the greenhouse gases that cause climate change. Most biomass fuels have negligible sulphur content and thus do not contribute to acid rain.
Price stability	Biomass fuel prices tend to be relatively stable and locally controlled; this is in marked contrast to the price for fossil fuels, which fluctuates widely and unpredictably in response to worldwide supply and demand.

Table 3. Biomass heating system particularities

12.Biomass Heating Modelling

Presented biomass heating modelling can be used to easily evaluate the energy production (or savings), life-cycle costs and greenhouse gas emissions reduction for biomass and/or waste heat recovery (WHR) heating projects, ranging in size from large scale developments for clusters of buildings to individual building applications. Calculation methods can be used to evaluate three basic heating systems using: waste heat recovery; biomass; and biomass and waste heat recovery combined. It also allows for a “peak load heating system” to be included. Presented calculation methodology is designed to analyse a wide range of systems with or without district heating.

This section describes the various calculation methods used to calculate, on a month-by-month basis, the energy production of biomass heating systems. A flowchart of the calculation method is shown in Figure 1.

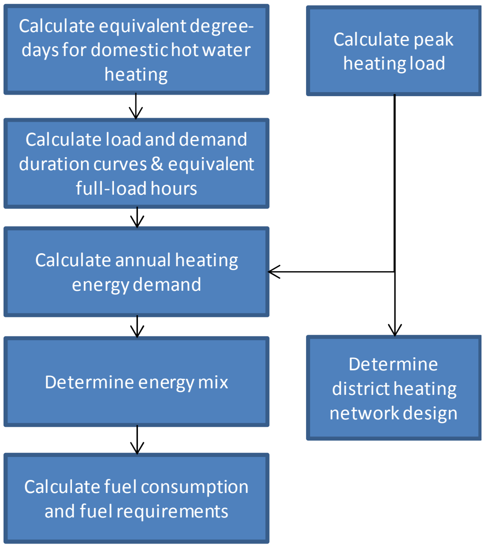

Figure 1. Biomass heating energy model

The calculation of the load and demand duration curves is presented in following sections followed by the description of the peak heating load and total energy demand calculation. The evaluation of the energy mix (energy delivered) that will meet the load, as well as fuel consumption (biomass or otherwise) are also shown following sections.

The biomass heating calculation methodology contains two sub-models. The first sub-model calculates the portion of the energy requirements that can be met by the various heating systems (waste heat recovery, biomass, peak load heating system) and establishes the corresponding energy use. The second sub-model is used so that the user can perform a preliminary sizing of the pipes and costing of the installation, but has no influence on the annual energy production calculations, at least at the pre-feasibility stage of a project.

13. Site Conditions

Calculation methodology makes use of heating degree-days to calculate the building (or buildings) heating requirements. This section reviews the concept of degree-days, shows how it can be extended to include domestic hot water heating and explains how degree-days can be used to derive load and demand duration curves.

14.Design temperature and degree-days

Site conditions are defined through two user-entered parameters: the heating design temperature, and the monthly heating degree-days. The former corresponds to the temperature of an exceptionally cold day in the area. It is often specified by the local building code. For example, ASHRAE code defines it as the minimum temperature that has been measured for a frequency level of at least 1% over the year for the specified location. The design heating temperature is used to determine the total peak heating load and to size the heating system. Heating degree-days help determine the heating demand. Heating degree-days are defined as the difference between a set temperature (usually 18°C) and the average daily temperature.

Mathematically:

$$\mathrm{DD_i} = \sum_{k=1}^{N_i} (\mathrm{T_{set}} - \mathrm{T_{a,k}}) \qquad (1)$$

where $\mathrm{DD_i}$ is the monthly degree-days for month i , $\mathrm{N_i}$ is the number of days in month i, $\mathrm{T_{set}}$ is the set temperature, and $\mathrm{T_{a,k}}$ is the average daily temperature for day k of month i . The annual degree-days, DD, is calculated by adding the monthly degree days:

$$\mathrm{DD} = \sum_{i=1}^{12} \mathrm{DD_i} \qquad (2)$$

The main advantage of using degree-days is that, as a first approximation, the heating demand of a building can be assumed to be proportional to the number of heating degree-days. Degree-days can also be used to describe hot water consumption.

15.Equivalent degree-days for domestic hot water heating

Biomass heating project calculation methodology includes domestic hot water as part of the energy demand met by the heating system. The hot water demand is supposed constant throughout the year and is expressed by the user as a fraction d of the annual total demand. Thus if Q is the annual total energy demand and $\mathrm{Q_H}$ the part of the demand corresponding to space heating, $\mathrm{Q_{DHW}}$, the portion of the demand corresponding to domestic hot water (DHW) heating, is calculated as follows:

$$Q = Q_H + Q_{DHW} \quad (3)$$

$$Q_{DHW} = dQ \quad (4)$$

$$Q_H = (1 - d)Q \quad (5)$$

and therefore:

$$Q_{DHW} = \frac{d}{(1-d)} Q_H \quad (6)$$

Since the space heating demand is assumed to be proportional to the number of degree-days, the model defines an equivalent number of degree-days corresponding to the hot water demand. If DD is the number of degree-days for heating from equation (2), the equivalent degree-days for domestic hot water demand DD_{DHW} follows the same relationship as (6) and is:

$$DD_{DHW} = \frac{d}{(1-d)} DD \quad (7)$$

The equivalent degree-days for domestic hot water is often expressed as an average daily value by dividing equation (7) by the number of days in a year. This leads to a value dd_{DHW} which is expressed in degree-days per day (°C-d/d):

$$dd_{DHW} = \frac{1}{365} \frac{d}{(1-d)} DD \quad (8)$$

It should be noted that presented calculation methodology takes into account domestic hot water demand in a rather coarse way. For example, the calculation method assumes that the hot water demand is the same for every day of the year. This may be a reasonable approximation for a large district energy system, but may be inappropriate for, say, a school where there will be no domestic hot water load during the night and weekends. Similarly, the hot water load varies over the course of the year, both because input water is colder during the winter months and because hot water consumption is generally reduced during the summer months.

16.Load and demand duration curves

Now that the design conditions and the number of degree-days (including a degree-day equivalent for domestic hot water heating) have been estimated, the calculation of the load duration curve can proceed. The load duration curve shows the cumulative duration for different heat loads in the system over a full year. The load for a district heating system consists of three main contributions, namely: distribution losses, domestic hot water, and building heating. The building heating is the dominant load for most of the year. Distribution losses correspond to loss of heat from the buried pipes to their environment and stay fairly constant over the year (slightly higher in the winter as the supply and return temperatures are higher and the ground temperature is lower). Finally, the domestic hot water load is also fairly constant over the year compared to the heating load. Nevertheless, there is a load reduction during the night and during summer months.

In principle, the load duration curve should be derived from hourly loads to show all possible variations to the system. However, this information is rarely available for a system in the design or pre-feasibility stage. For this reason, a method has been developed to derive the load duration curve from monthly degree-days. The data used to develop the method is taken from very detailed studies of a relatively large biomass heating system. It includes empirical monthly factors, $F_{i'}$, which represent the influence of solar gains, wind, and occupants' habits on the energy requirements of the building. This monthly empirical factor is presented in Table 4 for $i' = 0,1 \dots 13$.

i'	0	1	2	3	4	5	6	7	8	9	10	11	12	13
$F_{i'}$	1.0	0.5	0.6	0.7	0.77	0.66	0.68	0.68	0.68	0.69	0.78	0.8	0.92	1

Table 4. Empirical factors $F_{i'}$

The process to determine the load and demand duration curves is described below and is illustrated with a step-by-step example. The example used is a heating system with a heating design temperature (T_{des}) of –19.4°C and with a fraction (d) of the domestic hot water demand equal to 19% of the annual energy demand.

The monthly heating degree-days (DD_i) are given in Table 5. According to equation (2), the annual degree-days (DD) is therefore equal to 4,238.6, and based on equation (8), the equivalent number of degree-days per day for domestic hot water heating (dd_{DHW}) is 2.72°C-d/d.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
i	1	2	3	4	5	6	7	8	9	10	11	12
DD_i	654.1	596.4	564.2	411	235.6	81	35	65.2	192	334.8	471	598.3
N_i	31	28	31	30	31	30	31	31	30	31	30	31
dd_i	23.8	24	20.9	16.4	10.3	5.4	3.8	4.8	9.1	13.5	18.4	22

Table 5. Degree-days at studied location

17.Step 1

Calculate the monthly degree-days per day dd_i (this is to eliminate the effect of months having different number of days), including in this quantity the equivalent degree-days for domestic hot water heating (calculated through equation 8):

$$dd_i = \frac{DD_i}{N_i} + dd_{DHW} \qquad (9)$$

where DD_i is the degree-days for month i and N_i the number of days in that month. These values are calculated and are shown in Table 5. It should be noted that January has the highest degree-days values, followed by December and February. However, due to the influence of the fewer number of days, N_i , in the calculation of equation (9), February has the highest degree-days per day, dd_i , than both January and December.

18.Step 2

Sort the monthly degree-days per day ($dd_{i'}$) in ascending order for $i' = 0,1 \ldots 13$ as previously defined. The sorted values of $dd_{i'}$ and $N_{i'}$ are shown in Table 6 (note that February is listed last).

i'	0	1	2	3	4	5	6	7	8	9	10	11	12	13
$dd_{i'}$	-	3.8	4.8	5.4	9.1	10.3	13.5	16.4	18.4	20.9	22	23.8	24	-
$N_{i'}$(days)	-	31	31	30	30	31	31	30	30	31	31	31	28	-
$C_{i'}$ (hour)	8,76	8,38	7,64	6,91	6,19	5,46	4,71	3,98	3,26	2,53	1,78	1,044	336	0
$D_{i'}$ (%)	5.1	5.1	7.7	8.7	17	21.2	23.8	29.8	33.5	38.6	45.9	50.9	59	100
$G_{i'}$ (hour)	445	445	655	725	1,273	1,517	1,650	1,911	2,042	2,190	2,348	2,420	2,476	2,545
$H_{i'}$(%)	17.5	17.5	25.7	28.5	50	59.6	64.8	75.1	80.3	86.1	92.3	95.1	97.3	100

Table 6. Coefficients calculation sorted by ascending order of the monthly degree-days per day

19.Step 3

Determine the coefficient $C_{i'}$ for fourteen cumulative durations, $C_{0'}, C_{1'}, \ldots C_{13'}$ defined as:

$$C_{0'} = 8760 \text{ hours} \qquad (10\text{-}1)$$

$$C_{1'} = C_{0'} - N_{1'}\frac{24}{2} \qquad (10\text{-}2)$$

$$C_{2'} = C_{1'} - (N_{1'} + (N_{2'})\frac{24}{2} \qquad (10\text{-}3)$$

$$C_{3'} = C_{2'} - (N_{2'} + (N_{3'})\frac{24}{2} \qquad (10\text{-}4)$$

$$\ldots..$$

$$C_{12'} = C_{11'} - (N_{11'} + (N_{12'})\frac{24}{2}(10\text{-}12)$$

$$C_{13'} = C_{12'} - N_{12'}\frac{24}{2} = 0 \qquad (10\text{-}13)$$

where $C_{0'}$ corresponds to the number of hours in a full year and $C_{1'}$ to $C_{12'}$ correspond to the number of hours from the beginning of the year to the middle of the sorted months. The $C_{i'}$ values calculated for the example are shown in Table 6.

20.Step 4

Calculate the fractions of peak load $D_{i'}$ corresponding to the fourteen cumulative durations $C_{i'}$:

$$D_{0'} = \frac{dd_{1'}}{\Delta T_{des}} F_{1'} \qquad (11\text{-}0)$$

$$D_{1'} = \frac{dd_{1'}}{\Delta T_{des}} F_{1'} \qquad (11\text{-}1)$$

$$D_{2'} = \frac{dd_{2'}}{\Delta T_{des}} F_{2'} \qquad (11\text{-}2)$$

…..

$$D_{12'} = \frac{dd_{12'}}{\Delta T_{des}} F_{12'} \qquad (11\text{-}12)$$

$$D_{13'} = 100\% \qquad (11\text{-}13)$$

where $F_{0'}$, $F_{1'}$ …$F_{13'}$ are the empirical monthly factors, $F_{i'}$, mentioned earlier in Table 4. ΔT_{des} is the difference between the set point temperature (Tset = 18°C) and the design heating temperature T_{des} for the specified location:

$$\Delta T_{des} = T_{set} - T_{des} \qquad (12)$$

These fourteen points ($C_{i'}$, $D_{i'}$) define the load duration curve expressed as a percentage of the peak load.

The next two steps enable the calculation of the demand duration curve, which represents the amount of energy required as a function of the level of power over a full year. The calculation of this curve is obtained by integrating the load duration curve with respect to time (i.e. determine the area under the load duration curve) followed by normalizing the values since it is more convenient to express the demand duration curve relative to the total yearly demand.

21.Step 5

Integrate the load duration curve with respect to time by calculating fourteen coefficients $G_{i'}$ with a simple trapezoidal rule leading to fourteen coefficients $G_{0'}$, $G_{1'}$,…$G_{13'}$ that express the demand relative to the maximum power (coefficient $G_{13'}$ is intimately related to number of equivalent full-load hours):

$$G_{0'} = C_{0'}D_{0'} \tag{13}$$

$$G_{1'} = G_{0'} \tag{13-1}$$

$$G_{2'} = \frac{(C_{1'}+C_{2'})}{2}(D_{2'} - D_{1'}) + G_{1'} \tag{13-2}$$

$$G_{3'} = \frac{(C_{2'}+C_{3'})}{2}(D_{3'} - D_{2'}) + G_{2'} \tag{13-3}$$

……

$$G_{12'} = \frac{(C_{11'}+C_{12'})}{2}(D_{12'} - D_{11'}) + G_{11'} \tag{13-12}$$

$$G_{13'} = \frac{C_{12'}}{2}(D_{13'} - D_{12'}) + G_{12'} \tag{13-13}$$

The coefficients $G_{i'}$ calculated for the example presented in previous sections are shown in Table 6.

22.Step 6

Normalize the value $G_{i'}$ by determining fourteen coefficients $H_{i'}$, defined as:

$$H_{0'} = \frac{G_{0'}}{G_{13'}} \tag{14}$$

$$H_{1'} = \frac{G_{1'}}{G_{13'}} \tag{14-1}$$

….

$$H_{12'} = \frac{G_{12'}}{G_{13'}} \tag{14-12}$$

$$H_{13'} = \frac{G_{13'}}{G_{13'}} = 100\% \tag{14-13}$$

These fourteen points ($H_{i'}$, $D_{i'}$) together with the origin (0,0) define the demand duration curve expressed as a fraction relative to the total energy demand. The calculation of coefficients $H_{i'}$ for the example is shown in Table 6. The load duration curve and the demand duration curve are both expressed as a percentage of, respectively, the peak load and the annual demand.

23.Equivalent full-load hours

Equivalent full load hours E_{flh} can be described as the amount of hours a system designed exactly for the peak heating load will operate at full load during one year. It is equal to the area under the load duration curve divided by the maximum of the curve (100%):

$$E_{flh} = \frac{G_{13'}}{100} \qquad (15)$$

where $G_{13'}$ is given by equation (13-13).

24.Heating Load

Up to this point the load has been expressed (through the load duration curve) as a percentage of the peak load. Similarly, the demand has been expressed (through the demand duration curve) as a percentage of the total annual energy demand. This section will now describe the calculation of the peak load and the total annual energy demand from the user defined inputs.

25.Peak heating load

Peak heating load for a building (or a cluster of buildings with assumed similar thermal properties) is a value $p_{H,j}$ expressed in Watts per square meter of floor area. This value is entered by the user and depends on the design heating temperature for the specific location and on the building insulation efficiency. Typical values for residential building heating load range from 42 to 118 W/m². The total peak load P_j for the jth cluster of buildings is therefore:

$$P_j = p_{H,j} A_j \qquad (16)$$

where A_j is the total heated area of the jth cluster of buildings. The total peak heating load P seen by the system is:

$$P = \sum_j P_j \qquad (17)$$

where the summation is done for all clusters.

26.Annual heating energy demand

Annual heating energy demand Q is calculated as:

$$Q = PE_{flh} \qquad (18)$$

where P is the peak heating load (equation 17) and E_{flh} the equivalent full load hours (equation 15).

27.Fuel consumption (base case system)

To evaluate the financial viability of a biomass heating project, the quantity of fuel that would be used if the biomass system were not installed should be calculated. This is the alternative fuel consumption, or what is referred to as the base case system.

Units used to measure fuel consumption and calorific values depend on the type of fuel used. Table 7 summarizes the units and calorific values for the different fuel types.

Fuel	Unit	Calorific Value
Natural gas	m3	10.33 kWh/m3
Propane	L	7.39 kWh/L
Diesel (#2 oil)	L	10.74 kWh/L
#6 oil	L	11.25 kWh/L
Electricity	MWh	1,000 kWh/MWh
Other	MWh	1,000 kWh/MWh

Table 7. Units and calorific values of various fuels

The alternative fuel consumption is calculated as:

$$\mathrm{M_{AFC}} = \frac{\mathrm{Q}}{\eta_{\mathrm{hs,se}}\mathrm{C_f}} \qquad (19)$$

where M_{AFC} is the alternative fuel consumption, $\eta_{hs,se}$ is the heating system seasonal efficiency (expressed without units) entered by the user, C_f is the calorific value for the selected fuel type, and Q is the energy demand of the building or cluster of buildings (expressed in kWh).

28.Energy mix determination

The load and demand duration curves are used to determine the fraction of the demand met by the waste heat recovery system, the biomass heating system, and/or the peak load heating system. Typically, the waste heat recovery (WHR) system provides free or low cost energy recovered from a process or electricity generation system. Then, the biomass combustion system meets the bulk of the annual heating energy demand. Finally, the peak load heating system meets only a small portion of the annual energy demand during peak heating periods. The fraction of the total energy heating demand met by each heating system depends on their peak load heating size.

The use of this method requires that the WHR system capacity and biomass heating system capacity be expressed as a percentage of the peak heating load, and calculate the energy delivered as a fraction of the total demand. To convert from actual system capacities to percentage of peak load, and from percentage of annual demand to actual energy delivered is straightforward.

WHR system capacity PWHR and the biomass heating system capacity $\mathrm{p_{bio}}$ in kW need to be specified. The percentages of peak load are $\mathrm{p_{WHR,\%}}$ and $\mathrm{p_{bio,\%}}$, given simply by:

$$\mathrm{p_{WHR,\%}} = \frac{\mathrm{P_{WHR}}}{\mathrm{P}}100 \qquad (20)$$

$$\mathrm{p_{bio,\%}} = \frac{\mathrm{P_{bio}}}{\mathrm{P}}100 \qquad (21)$$

where P is the peak load for heating calculated from equation (17). Similarly, if $\mathrm{q_{WHR,\%}}$, $\mathrm{q_{bio,\%}}$, and $\mathrm{q_{PLHS,\%}}$ are the percentages of annual heating energy demand met respectively by the WHR, the biomass, and the peak load heating systems then the heating energy delivered by the WHR system, $\mathrm{q_{WHR}}$, by the biomass system, $\mathrm{Q_{bio}}$, and by the peak load heating system, $\mathrm{Q_{PLHS}}$, are given by:

$$\mathrm{Q_{WHR}} = \frac{\mathrm{q_{WHR,\%}}}{100}\mathrm{Q} \qquad (22)$$

$$\mathrm{Q_{bio}} = \frac{\mathrm{q_{bio,\%}}}{100}\mathrm{Q} \qquad (23)$$

$$\mathrm{Q_{PLHS}} = \frac{\mathrm{q_{PLHS,\%}}}{100}\mathrm{Q} \qquad (24)$$

where Q is the total demand as calculated in equation (18).

29.Heating fuel requirements

Heating fuel requirements for the peak load heating system are determined through a method similar that of previous sections, except that the energy demand taken into consideration is the heating energy delivered by the peak load heating system, Q_{PLHS}, calculated through equation (24).

30.Biomass annual fuel requirements

Energy recovery from biomass is achieved by direct combustion or indirectly by thermo-mechanical conversion. Direct combustion entails burning the solid biomass. Indirect methods convert the biomass to a liquid or gas. The wood-derived liquid or gaseous fuel is then burned to yield heat and combustion by-products.

The amount of biomass that will be burnt as fuel during one year, $\mathrm{M_{bio}}$, expressed in kg, is calculated through a formula very similar to equation (19):

$$\mathrm{M_{bio}} = \frac{\mathrm{Q_{bio}}}{\mathrm{NHV}\eta_{\mathrm{bio,se}}} \qquad (25)$$

where $\mathrm{Q_{bio}}$ is the energy demand met by the biomass heating system (calculated through equation 23), $\eta_{\mathrm{bio,se}}$ is the seasonal efficiency of the biomass heating system specified by the user, and NHV is the as-fired calorific value of biomass.

The as-fired calorific value, or heating value, of fuel is the measure of heat released, per unit weight of fuel, during the complete combustion of the fuel. The higher heating value refers to the maximum energy that can be released, per unit weight of dry fuel, from burning dry fuel. The net heating value (also referred to the calorific value as fired) of the fuel subtracts the energy in the water vapour produced from the water in the fuel and in the water vapour produced from the hydrogen in the fuel; it is expressed per unit weight of wet fuel.
High moisture content biomass fuel reduces system efficiency because the vaporization of water to steam requires heat. As flue gases are rarely condensed in small biomass heating systems, this energy, which otherwise would be useful in heat production, is diverted to drying the biomass in the combustion system prior to actually burning it. Higher moisture content in the fuel means a lower net heating value of the fuel. Typical as-fired calorific values for biomass range from 10,800 to 15,900 MJ/tonne.

The heating value of biomass fuels depends on the nature of the fuel considered. The moisture content on a wet basis of biomass fuel is the weight of water in a biomass sample divided by the total weight of the sample:

$$\mathrm{MCWB} = \frac{\mathrm{W_{water}}}{\mathrm{W_{water}} + \mathrm{W_{drywood}}} 100 \qquad (26)$$

where MCWB is the moisture content on a wet basis, expressed in %, $\mathrm{W_{water}}$ is the weight of water, and $\mathrm{W_{drywood}}$ is the weight of dry biomass.

The ultimate analysis of a fuel describes its elemental composition as a percentage of its dry weight. Typically, the ultimate analysis tests for hydrogen, carbon, oxygen, nitrogen, sulphur (the amount of sulphur in biomass fuels is typically very low or non existent) and ash. Table 8 shows the analysis of various biomass fuel types.

Analytical formulae have been developed to predict the higher heating value of coal and other fossil fuels. Exact calculations are available for all components of biomass fuel, which will oxidize. However, it is very difficult to quantify the contribution of volatiles to the heating value. From experience, the following formula has proven to be reliable for biomass:

$$\mathrm{HHV} = 34.1\mathrm{C} + 123.9\mathrm{H} - 9.85\mathrm{O} + 6.3\mathrm{N} + 19.1\mathrm{S} \qquad (27)$$

where HHV is the higher heating value in MJ/kg, and C, H, O, N and S are the percentage weight for carbon, hydrogen, oxygen, nitrogen, and sulphur respectively. The corresponding net heating value (as-fired) NHV, in MJ/kg, is given by:

$$\mathrm{NHV} = (\mathrm{HHV} - 21.92\ \mathrm{H})(1 - \mathrm{MCWB}/100) - 0.02452\ \mathrm{MCWB} \qquad (28)$$

where MCWB is the moisture content on a wet basis of biomass entered by the user, and expressed in %. The value from equation (28) is used in equation (25) to calculate the annual biomass requirements of the heating system.

Type	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Bagasse	48.64%	5.87%	42.85%	0.16%	0.04%	2.44%
Peat	51.20%	5.70%	33.20%	1.40%	0.30%	8.20%
Rice husks	38.83%	4.75%	35.59%	0.52%	0.05%	20.26%
Switchgrass	47.45%	5.75%	42.37%	0.74%	0.08%	3.61%
Wheat straw	46.96%	5.69%	42.41%	0.43%	0.19%	4.32%
Wood high HV	52.10%	5.70%	38.90%	0.20%	0.00%	3.10%
Wood low HV	52.00%	4.00%	41.70%	0.30%	0.00%	2.00%
Wood medium HV	48.85%	6.04%	42.64%	0.71%	0.06%	1.70%

Table 8. Biomass fuel type

31. District Heating Network Design

A district heating piping distribution system consists of an underground hot water distribution network with supply and return pipelines in a closed circuit. Each building is connected to the network via a building heat transfer station that regulates and measures the energy taken from the distribution system. The network consists of a main distribution line which connects several buildings, or clusters of buildings, to the heating plan, and secondary distribution lines which connect individual buildings to the main distribution line. The pipe network is usually oversized to allow a future expansion of the system. For preliminary sizing of the network pipes, a simplified method is used. It has been assumed that the head loss is not to exceed 20 mm H2O or 200 Pa per meter of pipe, and for pipe dimensions larger than 400 mm, a maximum velocity of 3 m/s is to be used. Standard formulae for pressure head loss in pipes as a function of water velocity and pipe diameter have been used to calculate maximum flow values as shown in Table 9.

Pipe Size	Maximum Flow (m3/h)
DN32	1.8
DN40	2.7
DN50	5.8
DN65	12.0
DN80	21.0
DN100	36.0
DN125	65.0
DN150	110.0

Table 9. Maximum allowable flow in selected pipe sizes for a maximum friction loss of 200 Pa/m

The total heating load carried in a pipe in the main distribution line, P_{pipe}, can be calculated as:

$$P_{pipe} = \rho V C_p \Delta T_{s-r} \qquad (29)$$

where ρ is the density of water, V the volumetric flow of water, C_p its specific heat (set to its value at 78°C, 4,195 J/(kg °C)), and ΔT_{s-r} is the differential temperature between supply and return, specified by the user. This relationship can be inversed to find, given the peak heating load of the building cluster (quantity P_j from equation 17), the volumetric flow of water that the pipe will be required to carry:

$$V = \frac{\rho C_p \Delta T_{s-r}}{P_j} \qquad (30)$$

Actual formula includes a factor for pipe oversizing; if k is the main pipe oversizing factor, expressed in %, entered by the user, equation (30) becomes:

$$V = \frac{\rho C_p \Delta T_{s-r}}{(1+k/100)P_j} \qquad (31)$$

Table 9 provides the desirable pipe size given the flow. In the case where several clusters of buildings are served by the same main distribution line pipe, the load in equation (31) should naturally be replaced by the sum of the relevant loads. Finally, a similar relationship holds for secondary distribution lines piping. The denominator of (31) is then replaced with a load $\mathrm{P_j'}$ given by:

$$\mathrm{P_j'} = \frac{\mathrm{P_j(1+k'/100)}}{\mathrm{N_j}} \qquad (32)$$

where $\mathrm{k'}$ is the secondary pipe network oversizing factor specified by the user, and $\mathrm{N_j}$ is the number of buildings in the cluster.

32.Summary

In this course, calculation methods for biomass heating project model have been shown in detail. Presented calculations use a combination of algorithms to predict the energy delivered, on a yearly basis, by a biomass heating system. The load and demand duration curves are derived from monthly degree-days data specified by the user; and domestic hot water is included in the load by defining equivalent degree-days for hot water heating.

The peak load heating system is determined from the design temperature determined by the end user and from heating loads specified for each cluster of buildings. The demand duration curve is then used to predict what fraction of the demand is met by each of the three heating systems (waste heat recovery system, biomass heating system, and peak load heating system) given their respective capacities. Calculation of heating energy and biomass requirements follow; biomass consumption depends on the type of wood fuel considered. Finally, a separate calculation method is used to provide a preliminary sizing of the distribution network.