Biomass Heating Growth Assessment

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BIOMASS HEATING GROWTH ASSESSMENT

This course covers the assessment of potential biomass heating growths including a technology history and a detailed description of the computation processes.

Biomass Heating History

Biomass heating schemes burn plant or other organic material such as wood chips, agricultural residues or even municipal waste. This heat can be transported and applied wherever it is required—for the ventilation and space heating needs of buildings or whole communities, or for industrial processes. Biomass heating schemes 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 gas emissions, and they include a heat distribution system to transport heat from the area of combustion to the heat load. Many biomass heating schemes incorporate a sophisticated automatic fuel handling system.

Biomass heating technology is not new. For many years people have applied stoves and furnaces, fed with cut round wood, for space heating. The growth of automated biomass heating schemes began in Scandinavia in the 1970s, when oil prices skyrocketed. Today, there are thousands of these schemes in service around the world, using a multitude of different types of biomass fuels, or “feedstock”. The recent emphasis on alternative power 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.

Biomass heating offers a number of compelling advantages, both for the system owner and, in the case of district heating schemes, for the local community. It can supplant expensive conventional power sources such as fossil fuels and electricity with local biomass resources, which is usually 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 decreased, 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-area power production 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 power system”. Biomass heating schemes tend to have higher preliminary prices than conventional fossil fuel burning schemes. 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 usually more physical space is required. All these factors require a high level of operator involvement and diligence.

Therefore, biomass heating schemes are most appealing where conventional power prices are high and biomass feedstock prices are low. This happens when electricity or some other costly form of power is applied for space and water heating; and biomass residues are available on-area 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 schemes is 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 labor and expertise required to operate an industrial type boiler system may be easier to find.

Biomass combustion schemes are usually well suited to industrial process loads. Many industrial process loads have constant heat needs and therefore biomass heating schemes operate most efficiently, and with the fewest service 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 big amount of expensive conventional fuel, justifying the higher preliminary capital and on-going labour prices of the system.

This history section defines biomass heating schemes, discusses the biomass heating markets including community power schemes, individual, institutional and commercial building, and process heat applications, and delivers general biomass heating growth considerations.

Description of Biomass Heating Schemes

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

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 extra units when the load increases), reduces the danger 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 required). Four types of heat sources that may be found in a biomass heating plant are indicated below in increasing order of typical cost per unit of heat produced:

- Waste heat recovery: The lowest-cost heat will typically be that offered by a waste heat recovery system. Some biomass heating plants can be situated near electricity production 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 usually be captured by a waste heat recovery system, at little or no extra 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 applied, 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 part 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 features and higher capital prices, the biomass combustion system may be sized to offer sufficient heat to meet typical heat loads, but too small to satisfy occasional peaks in the heating load. The peak load heating system will offer that small part of the annual heating load that cannot be furnished by the BCS. Usually it will rely on conventional power sources, and be characterized by lower capital prices and higher fuel prices. In some cases the peak load heating system is also applied during times of very low heat load; under such conditions, the biomass combustion system would be very inefficient or generate unacceptable levels of gas emissions (smoke).

- Backup heating system: Applied 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 features of lower capital prices and higher fuel prices. Usually the peak load system serves as the backup to the biomass combustion system, and no extra 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 defined here:

- Biomass Fuel (Feedstock) Delivery: if not available on-area, the biomass fuel is provided to a fuel receiving area, which must be big 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 schemes 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 schemes, 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 schemes, 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. Bigger BCSs use boilers, with water, steam, or thermal oil as the heat transfer medium.

- Ash Removal and Storage: this calls for 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 schemes use the natural draft resulting from the buoyancy of the warm exhaust; bigger schemes 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 defined above, instrumentation and control schemes of varying sophistication oversee the service of a BCS, modulate the feed of air (and in automated BCSs, fuel in response to demand), and maintain safe operating conditions.

Biomass combustion schemes cover a wide range of equipment, distinguished by changes 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 big heating plants, BCS installations can usually be assorted within three broad feed system categories, based on their capacity:

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

- Small automatic feed schemes (50-500 kW): use particulate biomass fuel (feedstock), typically utilizing 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 schemes (400 kW and up): have fully automated feeding of particulate biomass fuel (feedstock), typically utilizing 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 schemes configured to meet specific fuel features or specific heating needs.

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 process 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 big installations with high continuous power demands. Base load sizing is usually 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 needs in the winter, two BCSs may be applied. A small unit operates in the summer, a bigger unit sized for the typical winter load runs during wintertime, and both units operate simultaneously during periods of peak demand. This arrangement facilitates the service of each BCS at a loading close to its rated capacity, raising efficiency and reducing gas emissions. Moreover, it is still possible to offer some heat when one system is shut down for maintenance.

Heat distribution system

The heat distribution system transports heat from the heating plant to the areas 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 schemes, 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 schemes, 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) part of the heating load. Use a lower capital cost, smaller fossil fuel system to handle peaks.	Check 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 offer highest seasonal efficiency - Capital prices significantly decreased - Better system control for efficient performance and lower gas emissions.	- Minimizes use of fossil fuel; - Maximizes use of biomass; - Offers the possibility for enhanced power use at marginal cost (if biomass fuel cost is low) - Offers a built-in capacity surplus for future load expansion.
Disadvantages	
- A conventional system is required for peak heating loads - Fossil fuel use will be enhanced; - Future load expansion will affect base load - Enhanced power use must be supplemented by more expensive conventional fuels.	- A bigger system greatly increases capital cost (and labour operating prices) - 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 gas emissions (smoke) and usually 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 bigger networks, a pipe-within-a-pipe arrangement is common: the inner carrier pipe is usually 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 offers heat to a number of consumers located around the area near the central plant. The consumers will usually be grouped in clusters of public, commercial, and residential buildings located within a few hundred meters of each other. District heating schemes offer a number of advantages over the use of individual heating plants in each building. A single, big 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 required to successfully operate their individual biomass combustion system, further encouraging the substitution of biomass over fossil fuels. Exchanger, fuel consumption, labor needs, and gas emissions will be decreased, waste heat may be applied more effectively, and the system will be operated more safely, all because the plant is centralized.

Heat distribution schemes can usually be expanded to accommodate new loads if the main distribution piping has sufficient capacity. Extra 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, extra burners can be installed at a later date to increase capacity.

Since the preliminary prices 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 schemes.

Biomass fuel supply service

The biomass fuel supply service 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 service usually entails local activity rather than decisions made at a distant refinery, the fuel supply service is considered a “component” of the plant.

A reliable, low-cost, long-term supply of biomass fuel is essential to the successful service of a biomass heating plant. Fossil fuel products are relatively standardized, usually 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 schemes—and especially their fuel handling sub-schemes—may be designed to operate with only one type of biomass of a certain quality, and may require modification or operate poorly when applied 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 needs imposed by the features 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 applied 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 power crops planted specifically for biomass combustion, including willow and hybrid poplar; and municipal solid waste. Whatever the biomass resource is, it can be considered an alternative resource only if it is harvested.

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 decreased.

Residuals, such as bark from a sawmill, which do not need to be disposed of but have no alternative use, are usually 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 prices, and prepared fuels, such as briquettes, may cost more than fossil fuels. These prepared fuels may have stable, uniform features, however, making them convenient for use in small schemes with simple fuel handling schemes, 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 service should be to maximize the utilization of harvested trees and to offer 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 or otherwise unusable trees. A community logging service 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 prices for big chippers, most small-scale chipping services employ small-scale chippers, usually powered by farm tractors that can chip trees up to about 23 cm (10 inches) in diameter. Second-hand industrial chippers are sometimes available at a reasonable cost.

Chipping can take place at the logging area. However, in isolated areas where winter roads may be applied 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 service nearby, a stand-alone service to supply wood and produce chips will need to be made. 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.

Biomass Heating Application Markets

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

Community power schemes

Community power schemes make use of a biomass heating plant and a district heating system to service clusters of buildings or even an entire community. Such community power schemes can offer 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 offer heat to individual homes, especially if the houses are newly constructed and in groups.

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

Individual institutional and commercial buildings

Individual buildings can satisfy their heating needs with biomass combustion schemes. Since substantial fuel savings must be achieved in order to offset the higher preliminary prices and annual labor service needs of the biomass system, it is rare that a building as small as an individual house would use a biomass heating plant as defined 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 schemes are common. These automated, relatively simple plants have low preliminary prices compared to bigger, more sophisticated schemes. 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; bigger schemes use automatic ash handling schemes. Electronic controls regulate airflow and fuel feed.

Commercial (also called “intermediate-scale”) biomass heating schemes, sized from 200 to 400 kW, have features of both small-commercial and industrial biomass heating schemes. They employ bigger fuel storage bins and have more elaborate fuel feeding mechanisms than small-commercial schemes, 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.

Process heat

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

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

Biomass Heating Growth Considerations

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

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

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

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

Physical size	Biomass fuel schemes are much bigger than conventional heating schemes. They usually require access for direct truck delivery of fuel, space for fuel storage, and a bigger boiler room to house the mechanical fuel delivery and ash removal schemes.
Fuel	Unlike gas and oil, biomass fuels are usually not standardised, homogeneous fuels backed by big national suppliers. As a result, fuel quality, consistency and supply reliability are concerns. Power content varies depending on the type of biomass applied for fuel.
Service	Biomass combustion schemes typically require more frequent maintenance and greater operator attention than conventional schemes. As a result, operator dedication is critical.
Mechanical Complexity	Biomass combustion schemes are more complex than conventional heating schemes, especially when it comes to fuel storage, fuel handling and combustion. The complexity arises due to the different features of biomass fuel compared to fossil fuels. The enhanced complexity means capital prices that are both higher and more difficult to estimate.
Local pollution	Biomass combustion generates gas 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 gas 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 schemes usually require extra 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 schemes. In addition to those already defined, such as decreased life-cycle prices, the following may be important:

Local economic advantages	Biomass fuel (feedstock) is usually harvested, collected, and provided by local operators; in contrast, fossil fuels are usually 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 schemes are highly flexible. Solid-fuel schemes 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 is considered an alternative power 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 vary. 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

Biomass Heating Modelling

Biomass heating modelling can be applied to easily evaluate the power production (or savings), life-cycle prices and greenhouse gas emissions reduction for biomass and/or waste heat recovery (WHR) heating growths, ranging in size from big scale growths for clusters of buildings to individual building applications. Computation processes can be applied to evaluate three basic heating schemes using: waste heat recovery; biomass; and biomass and waste heat recovery combined. It also allows for a “peak load heating system” to be included. Computation processes are designed to analyze a wide range of schemes with or without district heating.

This section defines the various computation processes applied to compute, on a month-by-month basis, the power production of biomass heating schemes. A flowchart of the computation process is displayed in Figure 1.

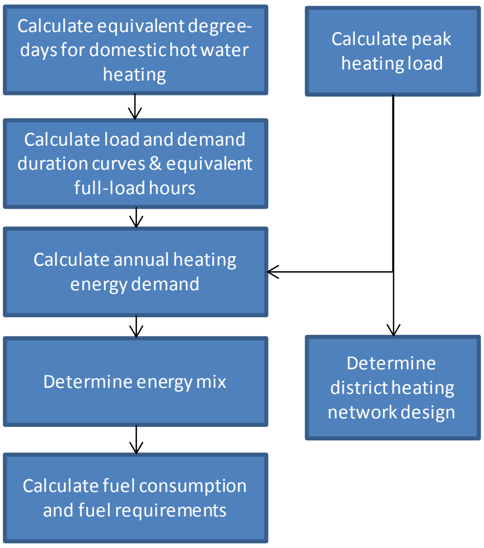

Figure 1. Biomass heating power model

The computation of the load and demand duration curves is given in following sections followed by the description of the peak heating load and total power demand computation. The evaluation of the power mix (power provided) that will meet the load, as well as fuel consumption (biomass or otherwise) are also displayed in the following sections.

The biomass heating computation contains two sub-models. The first sub-model computes the part of the power needs that can be met by the various heating schemes (waste heat recovery, biomass, and peak load heating system) and establishes the corresponding power use. The second sub-model is applied so that the user can perform a preliminary sizing of the pipes and costing of the installation, but has no influence on the annual power production computations, at least at the pre-feasibility stage of a growth.

Area Conditions

The computation process makes use of heating degree-days to compute the building (or buildings) heating needs. 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 applied to derive load and demand duration curves.

Design temperature and degree-days

Area conditions are defined through two user-entered parameters: the heating design temperature, and the monthly heating degree-days. The former matches to the temperature of an exceptionally cold day in the area. It is usually specified by the local building code. For example, the 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 area. The design heating temperature is applied to check the total peak heating load and to size the heating system. Heating degree-days help check the heating demand. Heating degree-days are defined as the difference between a set temperature (usually 18°C) and the mean daily temperature.

Mathematically:

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

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

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

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 applied to define hot water consumption.

Equivalent degree-days for domestic hot water heating

The biomass heating growth computation process includes domestic hot water as part of the power demand met by the heating system. The hot water demand is assumed 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 power demand and Q_H the part of the demand corresponding to space heating, Q_{DHW} , the part of the demand corresponding to domestic hot water (DHW) heating, is computed as follows:

$$Q = Q_H + Q_{DHW} \tag{3}$$

$$Q_{DHW} = dQ \tag{4}$$

$$Q_H = (1 - d)Q \tag{5}$$

and therefore:

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

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 Equation (6) and is:

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

The equivalent degree-days for domestic hot water is usually expressed as the mean 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):

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

It should be noted that the given computation process takes into account domestic hot water demand in a rather coarse way. For example, the computation process assumes that the hot water demand is the same for every day of the year. This may be a reasonable approximation for a big district power 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 usually decreased during the summer months.

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 computation of the load duration curve can continue. 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 the summer months.

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

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 check the load and demand duration curves is defined below and is explained with a step-by-step example. The example applied 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 power 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 area

Step 1

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

$$dd_i = \frac{DD_i}{N_i} + dd_{DHW} \tag{9}$$

where DD_i is the degree-days for month i and N_i the number of days in that month. These values are computed and are displayed 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 computation of Equation (9), February has the highest degree-days per day, dd_i , than both January and December.

Step 2

Sort the monthly degree-days per day ($dd_{i'}$) in ascending order for $i' = 0,1 \dots 13$ as previously defined. The sorted values of $dd_{i'}$ and $N_{i'}$ are displayed 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 computation sorted by ascending order of the monthly degree-days per day

Step 3

Check the coefficient $C_{i'}$ for fourteen cumulative durations, $C_{0'}$, $C_{1'}$, …$C_{13'}$ defined as:

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

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

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

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

…..

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

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

where $C_{0'}$ matches 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 computed for the example are displayed in Table 6.

Step 4

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

$$D_{0'} = \frac{dd_{1'}}{\Delta T_{des}} F_{1'} \tag{11-0}$$

$$D_{1'} = \frac{dd_{1'}}{\Delta T_{des}} F_{1'} \tag{11-1}$$

$$D_{2'} = \frac{dd_{2'}}{\Delta T_{des}} F_{2'} \tag{11-2}$$

…..

$$D_{12'} = \frac{dd_{12'}}{\Delta T_{des}} F_{12'} \tag{11-12}$$

$$D_{13'} = 100\% \tag{11-13}$$

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 (T_{set} = 18°C) and the design heating temperature T_{des} for the specified area:

$$\Delta T_{des} = T_{set} - T_{des} \tag{12}$$

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 computation of the demand duration curve, which redelivers the amount of power required as a function of the level of power over a full year. The computation of this curve is obtained by integrating the load duration curve with respect to time (i.e. check 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.

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 the 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 $G_{i'}$ computed for the example given in previous sections are displayed in Table 6.

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 power demand. The computation of coefficients $H_{i'}$ for the example is displayed in Table 6. The load duration curve and the demand duration curve are both expressed as a percentage of the peak load and the annual demand, respectively.

Equivalent full-load hours

Equivalent full load hours E_{flh} can be defined as the amount of hours a system is designed exactly for the peak heating load to 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).

Heating Load

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

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 area 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 j^{th} 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.

Annual heating power demand

Annual heating power demand Q is computed as:

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

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

Fuel consumption (base case system)

To evaluate the financial viability of a biomass heating growth, the quantity of fuel that would be applied if the biomass system were not installed should be computed. This is the alternative fuel consumption, or what is referred to as the base case system. Units applied to measure fuel consumption and calorific values depend on the type of fuel applied. Table 7 summarizes the units and calorific values for the different fuel types.

Fuel	Unit	Calorific Value
Natural gas	m^3	10.33 kWh/m^3
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 computed as:

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

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 power demand of the building or cluster of buildings (expressed in kWh).

Power Provided and Fuel Consumption

Power mix determination

The load and demand duration curves are applied to check 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 offers free or low cost power recovered from a process or electricity production system. Then, the biomass combustion system meets the bulk of the annual heating power demand. Finally, the peak load heating system meets only a small part of the annual power demand during peak heating periods. The fraction of the total power heating demand met by each heating system depends on their peak load heating size.

The use of this process requires that the WHR system capacity and biomass heating system capacity be shown as a percentage of the peak heating load, and the power provided is computed 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 power provided is straightforward.

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

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

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

where P is the peak load for heating computed from Equation (17). Similarly, if $q_{WHR,\%}$, $q_{bio,\%}$, and $q_{PLHS,\%}$ are the percentages of annual heating power demand met by the WHR, the biomass and the peak load heating schemes, respectively, then the heating power provided by the WHR system, q_{WHR}, by the biomass system, Q_{bio}, and by the peak load heating system, Q_{PLHS} , are given by:

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

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

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

where Q is the total demand as computed in Equation (18).

Heating fuel needs

Heating fuel needs for the peak load heating system are checked through a process similar to that of previous sections, except that the power demand taken into consideration is the heating power provided by the peak load heating system, Q_{PLHS}, computed through Equation (24).

Biomass annual fuel needs

Power recovery from biomass is achieved by direct combustion or indirectly by thermo-mechanical conversion. Direct combustion entails burning the solid biomass. The indirect process converts 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, M_{bio}, expressed in kg, is computed through a formula very similar to Equation (19):

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

where Q_{bio} is the power demand met by the biomass heating system (computed through Equation 23), $\eta_{bio,se}$ 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 power 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 power in the water vapor produced from the water in the fuel and in the water vapor 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 schemes, this power, 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:

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

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

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

Analytical calculations have been developed to predict the higher heating value of coal and other fossil fuels. Exact computations 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:

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

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:

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

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 applied in Equation (25) to compute the annual biomass needs 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

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 power 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 process is applied. It has been assumed that the head loss is not to exceed 20 mm H_2O 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 applied. Standard calculations for pressure head loss in pipes as a function of water velocity and pipe diameter have been applied to compute maximum flow values as displayed in Table 9.

Pipe Size	Maximum Flow (m^3/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 computed 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, given the peak heating load of the building cluster (quantity P_j from Equation 17), to find the volumetric flow of water that the pipe will be required to carry:

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

The actual formula includes a factor for pipe oversizing. If k is the main pipe oversizing factor, expressed in % and entered by the user, then Equation (30) becomes:

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

Table 9 offers the desirable pipe sizes 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 the secondary distribution piping lines. The denominator of Equation (31) is then replaced with a load P_j' given by:

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

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

Summary

In this course, the computation process for biomass heating growth model has been displayed in detail. The computations given use a combination of algorithms to predict the power provided 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 the domestic hot water is included in the load by defining equivalent degree-days for hot water heating.

The peak load heating system is checked from the design temperature by the end user and from heating loads specified for each cluster of buildings. The demand duration curve is then applied to predict what fraction of the demand is met by each of the three heating schemes (waste heat recovery system, biomass heating system, and peak load heating system), given their respective capacities. The computation of heating power and biomass needs follow; biomass consumption depends on the type of wood fuel considered. Finally, a separate computation process is applied to offer a preliminary sizing of the distribution network.

References:

Clean Power Growth Assessment RETScreen® Engineering & Cases Textbook, Third Edition, © Minister of Natural Resources Canada 2001-2005, September 2005