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CLEAN ENERGY PROJECT ANALYSIS:
RETSCREEN® ENGINEERING & CASES TEXTBOOK

CANMET Energy Technology Centre - Varennes (CETC)

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BIOMASS HEATING PROJECT ANALYSIS

CHAPTER

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TABLE OF CONTENTS

BIOMASS HEATING PROJECT ANALYSIS CHAPTER

Clean Energy Project Analysis: RETScreen® Engineering & Cases is an electronic textbook for professionals and university students. This chapter covers the analysis of potential biomass heating projects using the RETScreen® International Clean Energy Project Analysis Software, including a technology background and a detailed description of the algorithms found in the RETScreen® Software. A collection of project case studies, with assignments, worked-out solutions and information about how the projects fared in the real world, is available at the RETScreen® International Clean Energy Decision Support Centre Website www.retscreen.net.

1 BIOMASS HEATING BACKGROUND[1]

Biomass heating systems burn plant or other organic matter—such as wood chips, agricultural residues or even municipal waste—to generate heat. 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. ***Figure 1*** shows a small commercial biomass heating system.

Figure 1:
Small Commercial Biomass Heating System.

Photo Credit:
Credit: Grove Wood Heat

1. Some of the text in this "Background" description comes from the following two Natural Resources Canada (NRCan) supported reports: ***Buyer's Guide To Small Commercial Biomass Combustion Systems***, NRCan, 2002, and, McCallum, B., ***Small-Scale Automated Biomass Energy Heating Systems: A Viable Option For Remote Canadian Communities?,*** NRCan/CFS's Great Lake Forestry Centre and NRCan's CEDRL, 1997.

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". Despite this, much of the general public and many heating professionals are unaware of the benefits of this cost-effective, proven, and reliable source of energy. 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 fuel-burning 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 ongoing 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.

1.1 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.

1.1.1 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). As described by Arkay and Blais (1996), the 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:

1) **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.

2) **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.

3) **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).

4) **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 illustrated in ***Figure 2*** and 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.

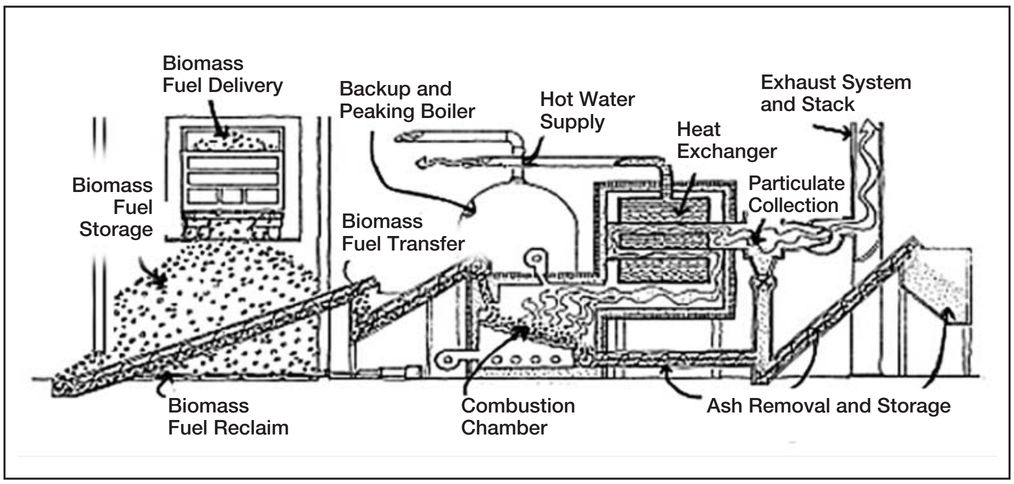


Figure 2:

Biomass Combustion System – General Layout

[adapted from NRCan's Buyer's Guide To Small Commercial Biomass Combustion Systems, 2002].

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.

1.1.2 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 90°C 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; and ▪ 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); and ▪ 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; and ▪ 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
[adapted from NRCan's Buyer's Guide To Small Commercial Biomass Combustion Systems, 2002].

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, as depicted in ***Figure 3***; it is not necessary to bury the pipes below the frost line since the pipes are insulated and circulate hot water.

Figure 3:
Water Pipes in District Heating System.

Photo Credit:
SweHeat

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.

1.1.3 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. ***Figures 4*** and ***5*** show two examples of low-cost biomass fuel. Whatever the biomass resource, it can be considered a renewable resource only if it is harvested in a sustainable manner.

Figure 4:
Walnut Shells for Biomass Combustion.

Photo Credit:
Warren Gretz/NREL Pix

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.

Figure 5:
Bagasse for Biomass Combustion.

Photo Credit:
Warren Gretz/NREL Pix

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. ***Figure 6*** shows a wood biomass fuel supply being harvested in a commercial operation.

Figure 6:
Wood Biomass Fuel Harvesting.

Photo Credit:
Bruce McCallum [1995]

The size of wood that can be chipped is limited by the size of the chipper selected. Large-diameter trees require a large chipper with a powerful engine. 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.

1.2 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.

1.2.1 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, as seen in ***Figure 7***. 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.

RETScreen® International Biomass Heating Project Model

The RETScreen® International Biomass Heating Project Model can be used world-wide 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. The model 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 (e.g. oil-fired boiler). The model is designed to analyse a wide range of systems with or without district heating.

Note that the RETScreen Combined Heat and Power Project Model can also be used to evaluate these and a large number of other project types.

1.2.2 Individual institutional and commercial buildings

Individual buildings can satisfy their heating requirements with biomass combustion systems, as seen in ***Figure 8***. 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.

Figure 7:
Biomass-Fired District Heating System at the Cree Community of Oujé-Bougamou in Northern Quebec, Canada.

Photo Credit:
NRCan

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 common in countries such as Sweden and Denmark, where they are found in institutional buildings and small industry, such as sawmill kilns.

Figure 8:
An Institutional Building Heated with Biomass.

Photo Credit:
ECOMatters Inc.

1.2.3 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. ***Figure 9*** depicts an industrial application of biomass heating. These applications benefit from having skilled labour on-site, loading and storage infrastructure, and free feedstock material.

Figure 9:
A Brazilian Mill that Makes Use of Bagasse, a Byproduct of Sugar Refining.

Photo Credit:
Ralph Overend/NREL Pix

Figure 10:
A Specialized Biomass Feedstock Handling System.

Photo Credit:
Ken Sheinkopf/Solstice CREST

1.3 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 (see ***Figure 10***). 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.

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.

2 RETSCREEN BIOMASS HEATING PROJECT MODEL

The RETScreen Biomass Heating Project Model can be used world-wide 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. The model 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 (e.g. oil-fired boiler). The model is designed to analyse a wide range of systems with or without district heating.

Six worksheets (*Energy Model*, *Heating Load Calculation & District Heating Network Design (Heating Load & Network)*, *Cost Analysis*, *Greenhouse Gas Emission Reduction Analysis (GHG Analysis)*, *Financial Summary*, and *Sensitivity and Risk Analysis (Sensitivity)*) are provided in the Biomass Heating Project Workbook file. The *Heating Load & Network* worksheet is used with the *Energy Model* worksheet to estimate the heating load and cost of the distribution system and energy transfer stations for the potential biomass and/or WHR heating system.

The ***Energy Model*** and ***Heating Load & Network*** worksheets are completed first. The ***Cost Analysis*** worksheet should then be completed, followed by the ***Financial Summary*** worksheet. The ***GHG Analysis*** and ***Sensitivity*** worksheet are optional analysis. The *GHG Analysis* worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project. The *Sensitivity* worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. In general, the user works from top-down for each of the worksheets. This process can be repeated several times in order to help optimize the design of the biomass heating project from an energy use and cost standpoint. In general, the user works from top-down for each of the worksheets.

This section describes the various algorithms used to calculate, on a month-by-month basis, the energy production of biomass heating systems in RETScreen. A flowchart of the algorithms is shown in ***Figure 11***. The calculation of the load and demand duration curves is presented in *Section 2.1* followed by the description of the peak heating load and total energy demand calculation in *Section 2.2*. The evaluation of the energy mix (energy delivered) that will meet the load, as well as fuel consumption (biomass or otherwise) are shown in *Section 2.3*. District heating network considerations are covered in *Section 2.4*. Finally a validation of the RETScreen Biomass Heating Project Model is presented in *Section 2.5*.

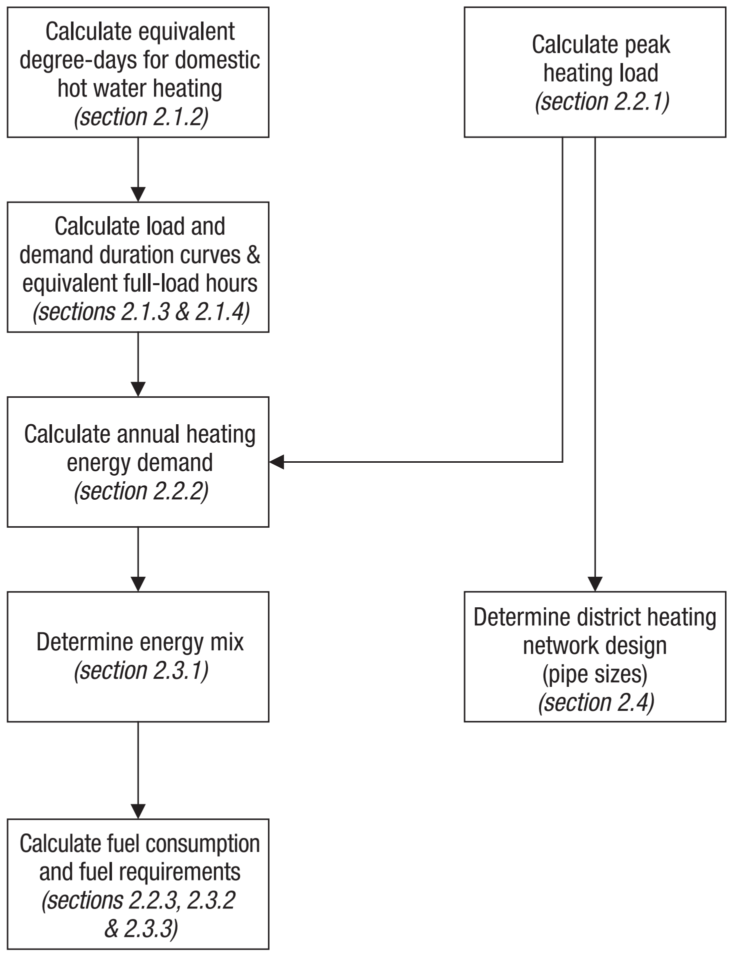
The Biomass Heating Project Model contains two sub-models. The first sub-model calculates the portion of the energy requirements that can be met by the various heating systems (waste heat recovery, biomass, peak load heating system) and establishes the corresponding energy use. The second sub-model guides the user through the design of a district heating network (if there is one); this sub-model is included 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.

The main limitation of the model is that it has not been validated for large-scale district energy systems. However, the model can be used with confidence for small commercial and commercial/industrial biomass systems (maximum of 2.5 MW peak capacity, with multiple biomass systems) on single building or district heating systems (1 to 100 buildings).

Note that the RETScreen Combined Heat and Power Project Model can also be used to evaluate these and a large number of other project types, including large-scale district energy systems.

Figure 11:

Biomass Heating Energy Model Flowchart.



2.1 Site Conditions

The model 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.

2.1.1 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 (1997) 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. In Sweden, it is defined as the coldest temperature that is expected once every 20 years. The design heating temperature is used to determine the *total peak heating load* (see *Section 2.2.1*) and to size the heating system.

Heating degree-days help determine the heating demand[2]. Heating degree-days are defined as the difference between a set temperature (usually 18°C) and the average daily temperature. Mathematically:

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

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 average daily temperature for day k of month i. The annual degree-days, DD, is calculated by adding the monthly degree days:

$$DD = \sum_{i=1}^{12} DD_i \tag{2}$$

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, as will be seen in the next *Section 2.1.2*.

2.1.2 Equivalent degree-days for domestic hot water heating

The RETScreen Biomass Heating Project Model allows the user to include domestic hot water as part of the energy demand met by the heating system[3]. 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 Q_H the part of the

2. It is assumed that the user is already familiar with the concepts of *load* and *demand*. Load refers to instantaneous values (power, expressed in W) whereas demand refers to integrated values (energy, expressed in J or in Wh).
3. The hot water demand can also be used to simulate non-weather dependent process demands.

demand corresponding to space heating, Q_{DHW}, the portion of the demand corresponding to domestic hot water (*DHW*) heating, is calculated as follows:

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

$$Q_{DHW} = d\,Q \tag{4}$$

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

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 (6) and is:

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

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):

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

It should be noted that the model takes into account domestic hot water demand in a rather coarse way. For example, the model 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.

2.1.3 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. An example of a load duration curve is shown in ***Figure 12***. 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.

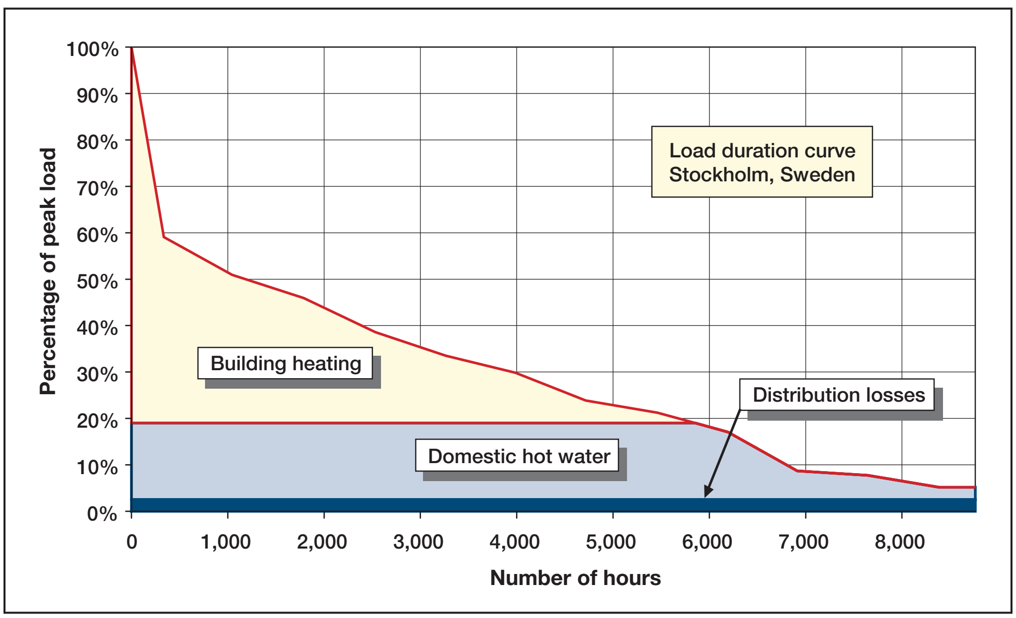


Figure 12:

Example of a Load Duration Curve for Stockholm, Sweden.

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 in Uppsala, Sweden. 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 2*** for $i' = 0, 1 \ldots 13$[4].

i'	0	1	2	3	4	5	6	7	8	9	10	11	12	13
$F_{i'}$	1.00	0.50	0.60	0.60	0.70	0.77	0.66	0.68	0.68	0.69	0.78	0.80	0.92	1.00

Table 2: Empirical Factors $F_{i'}$

The algorithm 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 for Stockholm (Sweden) 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) for Stockholm are given in ***Table 3***. 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.

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):

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

where DD_i is the degree-days for month i and N_i the number of days in that month. These values are calculated for the Stockholm example and are shown in ***Table 3***. 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.

4. $i' = 0$ is the start of the months sorted by degree-days in ascending order, $i' = 1$ is the month with the highest number of degree-days … $i' = 12$ is the month with the lowest number of degree-days, and $i' = 13$ is the end of the sorted months.

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	411.0	235.6	81.0	35.0	65.2	192.0	334.8	471.0	598.3
N_i	31	28	31	30	31	30	31	31	30	31	30	31
dd_i	23.8	24.0	20.9	16.4	10.3	5.4	3.8	4.8	9.1	13.5	18.4	22.0

Table 3: Degree-Days for Stockholm, Sweden.

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 $N_{i'}$ for the Stockholm example are shown in ***Table 4*** (note that February is listed last).

STEP 3:

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

$$C_{0'} = 8760 \; hours \tag{10-0}$$

$$C_{1'} = C_{0'} - N_{1'} \frac{24}{2} \tag{10-1}$$

$$C_{2'} = C_{1'} - \left(N_{1'} + N_{2'} \right) \frac{24}{2} \tag{10-2}$$

$$C_{3'} = C_{2'} - \left(N_{2'} + N_{3'} \right) \frac{24}{2} \tag{10-3}$$

...

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

$$C_{13'} = C_{12'} - N_{12'} \frac{24}{2} = 0 \tag{10-13}$$

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 4***.

STEP 4:

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

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

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

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

...

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

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

where $F_{0'}, F_{1'} \ \ldots \ F_{13'}$ are the empirical monthly factors, $F_{i'}$, mentioned earlier in ***Table 2***. ΔT_{des} is the difference between the set point temperature (T_{set} = 18°C) and the design heating temperature T_{des} for the specified location (see *Section 2.1.1*):

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

These fourteen points $(C_{i'}, D_{i'})$ define the load duration curve expressed as a percentage of the peak load. The $D_{i'}$ values calculated for the Stockholm example are shown in ***Table 4*** and the resulting load duration curve is shown in ***Figure 13***.

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.

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 $G_{0'}, G_{1'} \ldots G_{13'}$ that express the demand relative to the maximum power (as will be seen in *Section 2.1.4*, coefficient $G_{13'}$ is intimately related to number of equivalent full-load hours):

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

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

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

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

...

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

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

The coefficients $G_{i'}$ calculated for the Stockholm example are shown in ***Table 4***.

STEP 6:

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

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

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

...

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

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

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 4*** and the resulting demand duration curve is shown in ***Figure 14.***

i'	0	1	2	3	4	5	6	7	8	9	10	11	12	13
$dd_{i'}$ (°C-d/d)	--	3.8	4.8	5.4	9.1	10.3	13.5	16.4	18.4	20.9	22.0	23.8	24.0	--
$N_{i'}$ (days)	--	31	31	30	30	31	31	30	30	31	31	31	28	--
$C_{i'}$ (hours)	8,760	8,388	7,644	6,912	6,192	5,460	4,716	3,984	3,264	2,532	1,788	1,044	336	0
$D_{i'}$ (%)	5.1%	5.1%	7.7%	8.7%	17.0%	21.2%	23.8%	29.8%	33.5%	38.6%	45.9%	50.9%	59.0%	100.0%
$G_{i'}$ (hours)	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%	50.0%	59.6%	64.8%	75.1%	80.3%	86.1%	92.3%	95.1%	97.3%	100.0%

Table 4: Stockholm Example of Coefficients Calculation Sorted by the Ascending Order of the Monthly Degree-Days per Day ($dd_{i'}$).

The load duration curve and the demand duration curve are both expressed as a percentage of, respectively, the peak load and the annual demand. Absolute values of the peak heating load and the annual energy demand have yet to be calculated. This will be described in *Sections 2.2.1* and *2.2.2*.

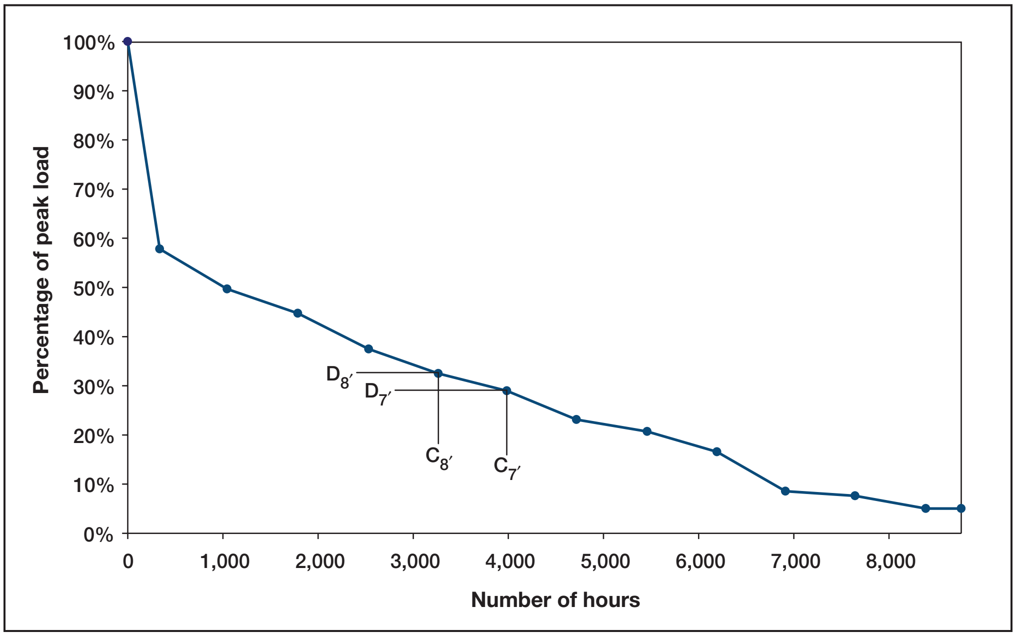


Figure 13:

Example of the Load Duration Curve Calculated for Stockholm.

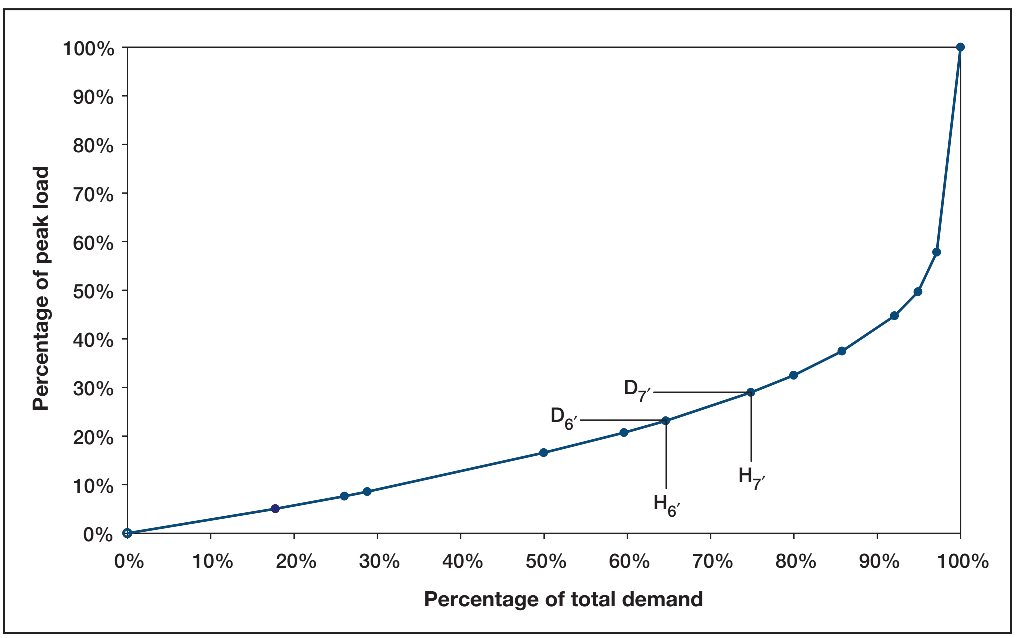


Figure 14:

Example of the Demand Duration Curve Calculated for Stockholm.

2.1.4 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%):

$$E_{flh} = \frac{G_{13'}}{100} \tag{15}$$

where $G_{13'}$ is given by equation (13-13). In the Stockholm example of *Section 2.1.3* the equivalent full load hours is 2545 hours.

2.2 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 inputs entered by the user in the RETScreen Biomass Heating Project Model.

2.2.1 Peak heating load

In the RETScreen Biomass Heating Project Model, the 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 (see *Section 2.1.1*) and on the building insulation efficiency, as shown in ***Figure 15*** (see Community Energy Technologies (CET), 1997). Typical values for residential building heating load range from 42 to 118 W/m². The total peak load P_j for the j^{th} cluster of buildings is therefore:

$$P_j = p_{H,j} A_j \tag{16}$$

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:

$$P = \sum_j P_j \tag{17}$$

where the summation is done for all clusters. Up to 14 different building clusters can be specified by the user in the RETScreen Biomass Heating Project Model.

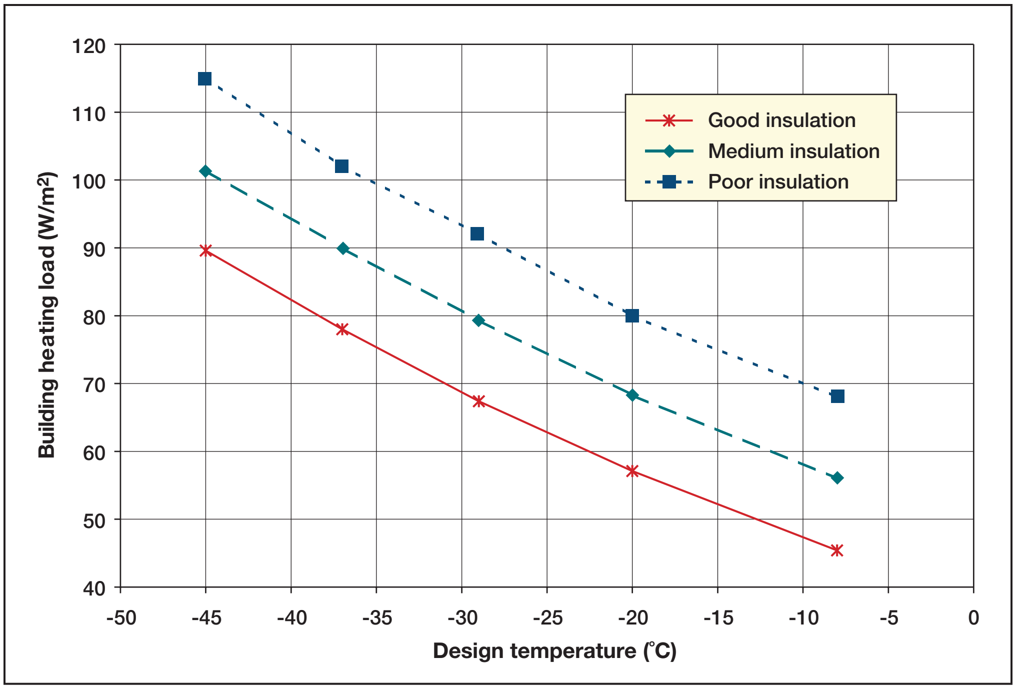


Figure 15:
Residential Building Heating Load (CET, 1997).

2.2.2 Annual heating energy demand

Annual heating energy demand Q is calculated as:

$$Q = P\,E_{flh} \tag{18}$$

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

2.2.3 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 5*** summarizes the units and calorific values for the different fuel types in the RETScreen Biomass Heating Project Model.

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 5: Units and Calorific Values of Various Fuels.

The alternative fuel consumption is calculated as:

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

where M_{AFC} is the alternative fuel consumption[5], $\eta_{hs,se}$ is the heating system seasonal efficiency (expressed without units) entered by the user, C_f is the calorific value for the selected fuel type[6], and Q is the energy demand of the building or cluster of buildings (expressed in kWh).

2.3 Energy Delivered and Fuel Consumption

2.3.1 Energy mix determination

The load and demand duration curves (as shown in ***Figure 13*** and ***Figure 14***) 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; it is used first. 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, as will be illustrated using the Stockholm example previously presented.

Suppose that the heating system designed to meet the energy needs of ***Figure 14*** consists of a WHR system sized for 10% of peak heating load. A biomass heating system is engaged when the WHR cannot meet the load and is sized for 40% of peak heating load. Finally,

5. Unit: m^3, L or MWh, as per ***Table 5***.
6. Unit: kWh/unit, as per ***Table 5***.

a peaking boiler with 50% of peak capacity is installed. Then, as shown in ***Figure 16***, the WHR system will meet 31% of annual heating energy demand; the biomass heating system will produce 64% (95% - 31%) of the annual demand. The remaining part will be met by the peaking boiler, which will deliver a total of 5% of the annual heating energy demand.

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.

In the RETScreen Biomass Heating Project Model, the user enters the WHR system capacity P_{WHR} and the biomass heating system capacity P_{bio} in kW. The percentages of peak load (as in ***Figure 16***) are $p_{WHR,\%}$ and $p_{bio,\%}$, given simply by:

$$p_{WHR,\%} = \frac{P_{WHR}}{P} 100 \tag{20}$$

$$p_{bio,\%} = \frac{P_{bio}}{P} 100 \tag{21}$$

where P is the peak load for heating calculated from equation (17). Similarly, if $q_{WHR,\%}$, $q_{bio,\%}$, and $q_{PLHS,\%}$ are the percentages of annual heating energy demand met respectively by the WHR, the biomass, and the peak load heating systems, as obtained by ***Figure 16***, then the heating energy delivered by the WHR system, Q_{WHR}, by the biomass system, Q_{bio}, and by the peak load heating system, Q_{PLHS}, are given by:

$$Q_{WHR} = \frac{q_{WHR,\%}}{100} Q \tag{22}$$

$$Q_{bio} = \frac{q_{bio,\%}}{100} Q \tag{23}$$

$$Q_{PLHS} = \frac{q_{PLHS,\%}}{100} Q \tag{24}$$

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

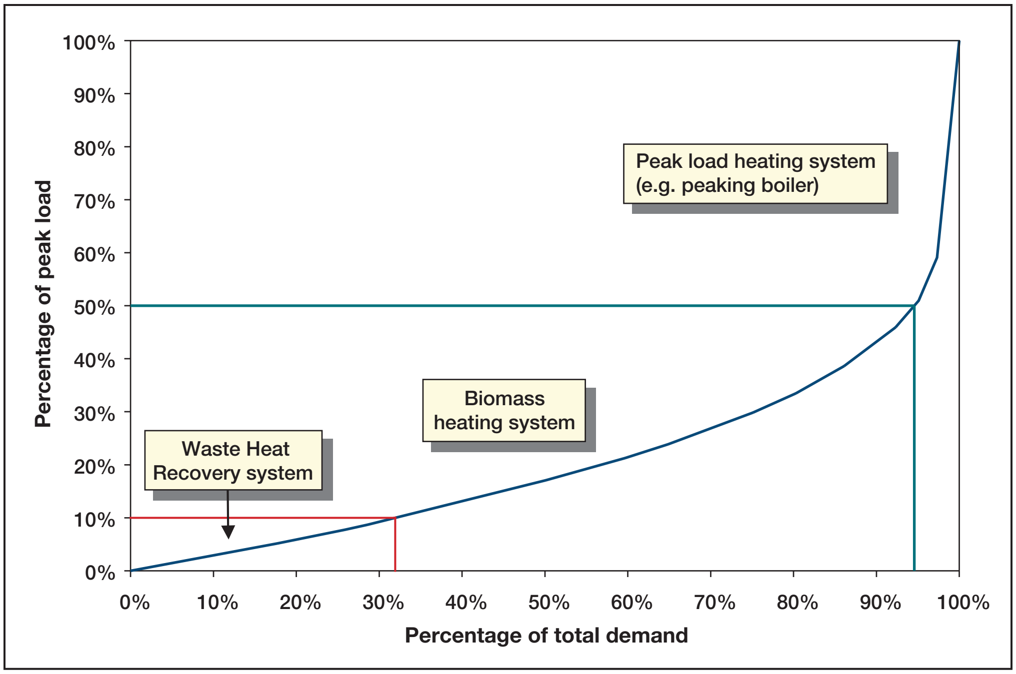


Figure 16:

Percentage of Total (Energy) Demand Met by the Various Heating Systems (Stockholm Example).

2.3.2 Heating fuel requirements

Heating fuel requirements for the peak load heating system are determined through a method similar that of *Section* 2.2.3, 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).

2.3.3 Biomass annual fuel requirements

Energy recovery from biomass is achieved by direct combustion or indirectly by thermomechanical 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 RETScreen Biomass Heating Project Model only considers direct combustion.

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

$$M_{bio} = \frac{Q_{bio}}{NHV\ \eta_{bio,se}} \tag{25}$$

where Q_{bio} is the energy demand met by the biomass heating system (calculated 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 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. In the RETScreen Biomass Heating Project Model, the user selects the type of biomass fuel from a list, and specifies the moisture content. 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. In the RETScreen Biomass Heating Project Model, $MCWB$ is entered by the user.

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 6*** shows the analysis of various biomass fuel types used in the RETScreen Biomass Heating Project Model.

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, and is used in the RETScreen Biomass Heating Project Model:

$$HHV = 34.1\,C + 123.9\,H - 9.85\,O + 6.3\,N + 19.1\,S \tag{27}$$

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:

$$NHV = \left(HHV - 21.92\,H\right)\left(1 - MCWB/100\right) - 0.02452\,MCWB \tag{28}$$

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 6: Biomass Fuel Type.

2.4 District Heating Network Design

District heating network design is included in the RETScreen Biomass Heating Project Model so that the user can perform a preliminary sizing of the pipes and costing of the installation. Its results have no influence on the energy calculation.

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 *second-*

ary 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. In RETScreen Biomass Heating Project Model the oversizing factor is specified by the user.

For preliminary sizing of the network pipes, a simplified method has been used in the RETScreen Biomass Heating Project Model. 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 used. Standard formulae (Avallone, 1987) 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 7***.

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 7: 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:

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

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:

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

The actual formula used in the RETScreen Biomass Heating Project Model includes a factor for pipe oversizing; if κ is the main pipe oversizing factor, expressed in %, entered by the user, equation (30) becomes:

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

Table 7 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 P_j' given by:

$$P_j' = \frac{P_j\left(1 + \kappa'/100\right)}{N_j} \tag{32}$$

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

2.5 Validation

Numerous experts have contributed to the development, testing and validation of the RETScreen Biomass Heating Project Model. They include biomass heating modelling experts, cost engineering experts, greenhouse gas modelling specialists, financial analysis professionals, and ground station and satellite weather database scientists.

Validation of the RETScreen Biomass Heating Project Model was done against other models used in the industry. The validation focused on three areas: calculation of the load duration curve (*Section 2.5.1*), calculation of the as-fired calorific value (e.g. heating value) of biomass (*Section 2.5.2*), and district heating network design (*Section 2.5.3*).

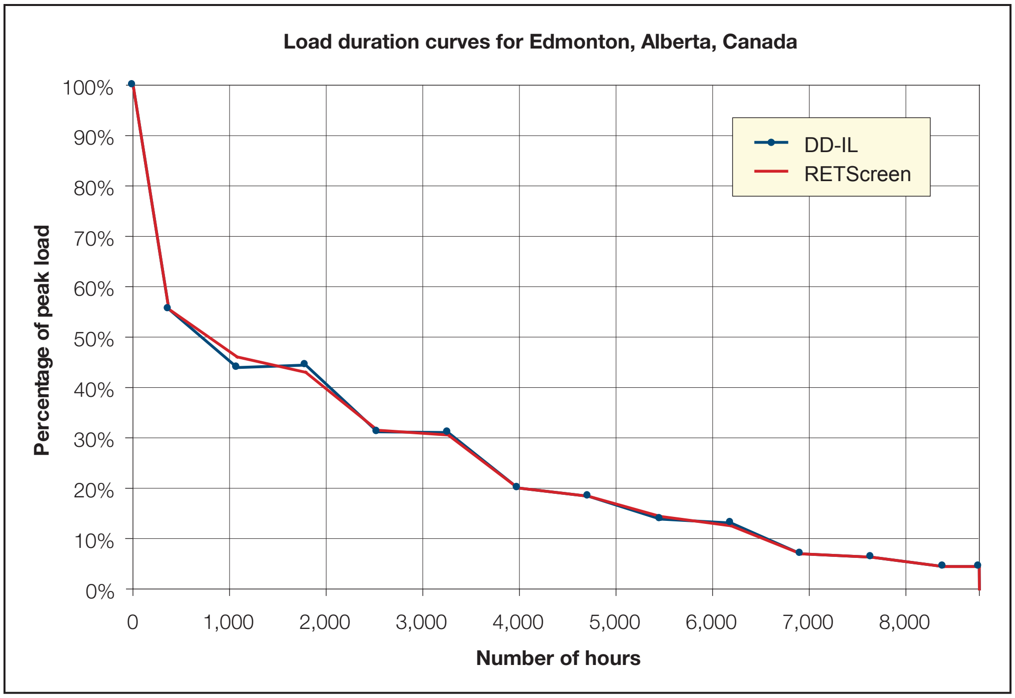
2.5.1 Validation of load duration curve

To validate the load duration curve generated by RETScreen (see *Sections 2.1.3* and *2.1.4*), a comparison was made with a computer model developed by Mr. Ingvar Larsson at FVB District Energy Consultants in Sweden. Mr. Larsson's model, hereafter named "DD-IL", was developed using extensive records from two large and closely monitored district heating systems, (St. Paul, Minnesota (USA) and Uppsala, Sweden). The RETScreen Biomass Heating Project Model was tested against DD-IL with data for four different cities: Edmonton (Alberta, Canada), Toronto (Ontario, Canada), St. Paul (Minnesota, USA), and Stockholm (Sweden). For all cities, degree-days data from DD-IL was used in RETScreen (rather than degree-days from the RETScreen on-line weather database) to eliminate artificial differences that could result from using weather data from different sources in the two programs. The only exception is for Edmonton where data from the on-line weather database of RETScreen was used in DD-IL. Load duration curves were generated for the four cities using a 2.74 °C-d/d (1,000 degree-days annually) equivalent degree-days for domestic hot water heating, except for Uppsala where a value of 2.88 °C-d/d (1,050 degree-days annually) was used.

Table 8 compares the equivalent full load durations calculated by the two programs for the four locations. The results are very similar (less than 1% difference). ***Figure 17*** shows the load duration curves calculated by the two programs. Again, the differences are minute. For Toronto and Uppsala the two programs generate exactly the same curves. For Edmonton and St. Paul, the generated curves are very close.

Location	DD-IL Equivalent Full Load Hours (h)	RETScreen Equivalent Full Load Hours (h)	Diff.
A. Edmonton, Alberta, Canada (RETScreen weather data)	2,173	2,188	0.7%
B. Toronto, Ontario, Canada (DD-IL weather data)	2,112	2,123	0.5%
C. St. Paul, Minnesota, USA (DD-IL weather data)	2,186	2,194	0.4%
D. Uppsala, Sweden (DD-IL weather data)	2,492	2,492	0.0%

Table 8: Comparison of Equivalent Full Load Duration Hours for Different Cities.



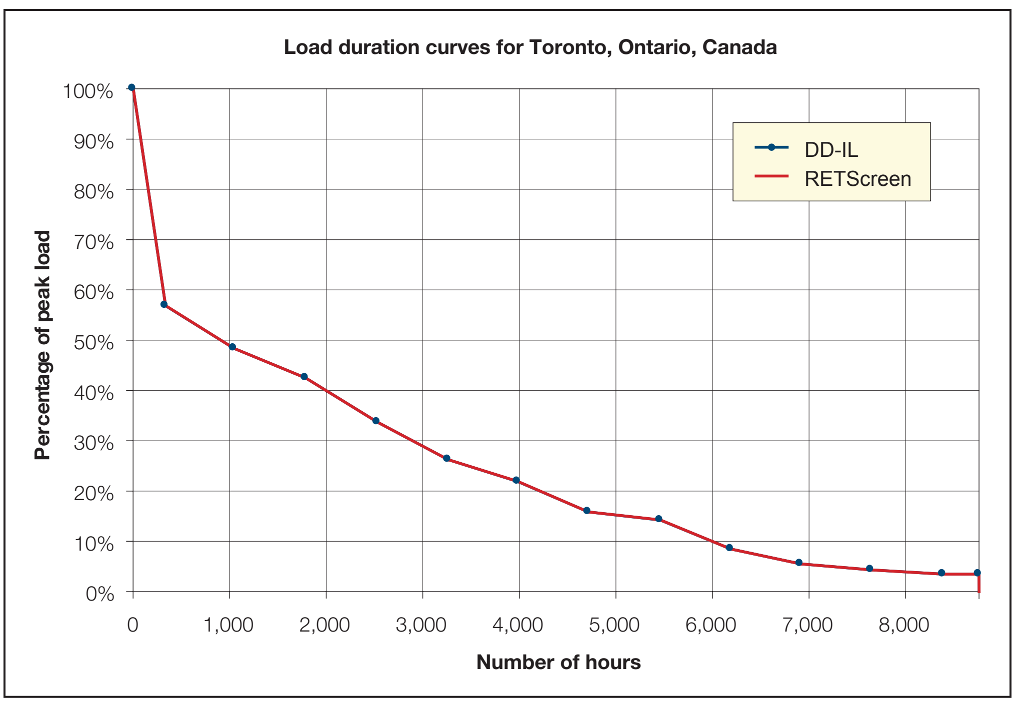
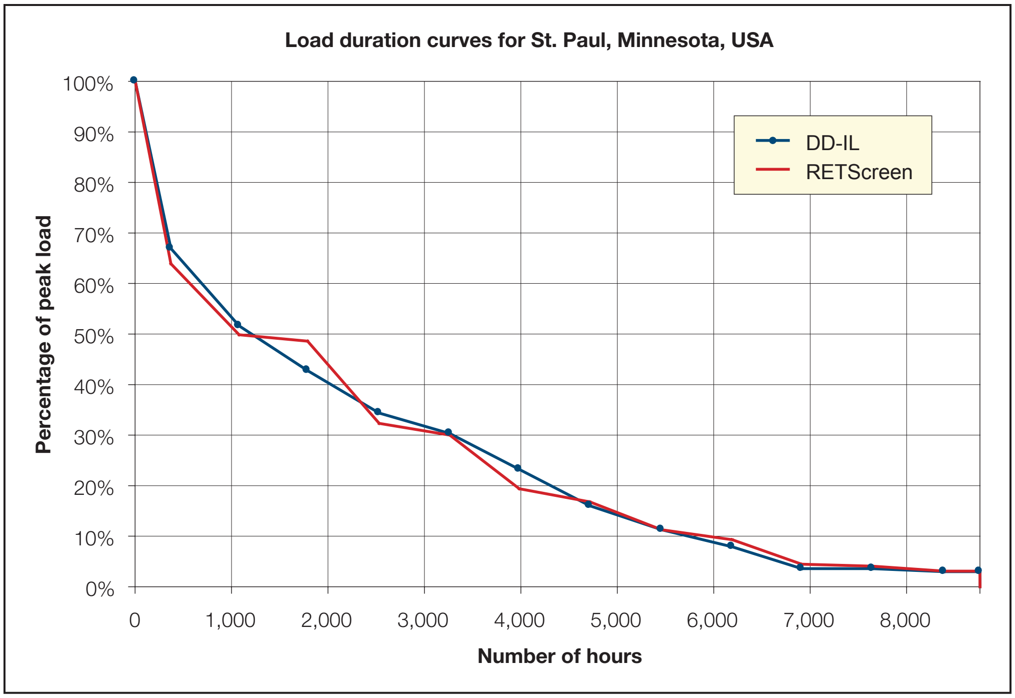


Figure 17a and 17b:

Comparison of Load Duration Curves Calculated with DD-IL and RETScreen for Four Different Cities.



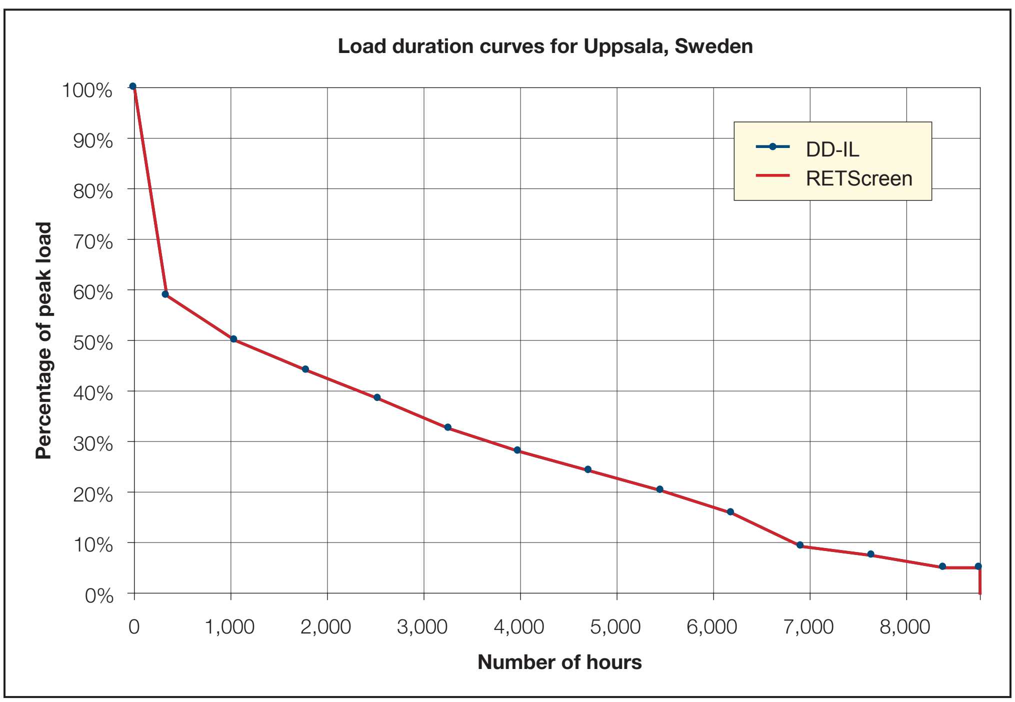


Figure 17c and 17d:

Comparison of Load Duration Curves Calculated with DD-IL and RETScreen for Four Different Cities.

2.5.2 Validation of as-fired calorific value (heating value) algorithm

To validate the as-fired calorific value (heating value) algorithm used by the RETScreen Biomass Heating Project Model (see *Section 2.3.3*), its predictions were compared to findings reported in the Summer Meeting of the Technical Section, Canadian Pulp and Paper Association, Quebec, Quebec, Canada, June 6 to 8, 1955. In the paper, entitled *Determination of Bark Volumes and Fuel Properties*, data was collected from thirty mills by the Forest Products Laboratories of Canada and the Federal Department of Mines and Technical Surveys. The chemical analyses (proximate and ultimate) from the samples were performed by the same laboratory. The heating values were statistically analyzed by the Forest Products Laboratories with the following results:

- **Age:** no correlation between heating value and the age of the tree was noticeable.
- **Geographical origin:** analyses of tests did not reveal any significant differences among heating values due to origin.
- **Species:** the tests show a significant difference in the heating value among various species in the following order (highest first): 1) Balsam, 2) Jack Pine, 3) Poplar, 4) Spruce.

Table 9 summarizes the heating values measured in the test. These values should be compared to those proposed by the RETScreen Biomass Heating Project Model for the heating value of wood waste, which range from a low of 17,723 MJ/t to a high of 19,760 MJ/t with an average of 18,673 MJ/t. The variation according to this test is +/- 3% for Jack Pine and up to –5% for Black Spruce. The estimate given by RETScreen Biomass Heating Project Model is amply sufficient at the pre-feasibility stage of a project.

Eastern Canadian Bark	No. of Samples	Heating Value (MJ/t)		
		Average	Probable minimum	Probable maximum
Balsam All Varieties	28	21,167	20,911	21,422
Black Spruce	15	20,027	18,957	20,259
White Spruce	11	19,841	19,399	20,073
Red Spruce	3	20,073		
Jack Pine	12	20,771	20,213	21,329
Poplar	6	20,492	20,004	20,981
White Birch	3	23,981		
Yellow Birch	2	21,399		
Hard Maple	2	19,143		
Soft Maple	1	18,841		
Elm soft	1	17,678		
Beech	1	17,771		
Tamarack	1	20,957		
Hemlock Eastern	1	20,678		

Table 9: Measured Heating Values of Eastern Canadian Bark.

The higher heating value algorithm of the RETScreen Biomass Heating Project Model (equation 27) was also tested against 55 samples measured by the US National Renewable Energy Laboratory (NREL) under Subcontract TZ-2-11226-1 in February 1996. ***Figure 18*** compares measured values against values predicted by RETScreen. The average difference between the laboratory tests and the RETScreen Biomass Heating Project Model is 3.41% with a standard deviation of 3.75%. The difference between the results is again quite acceptable, keeping in mind that the typical variation in moisture content over a year for a biomass fuel can be more than 15%.

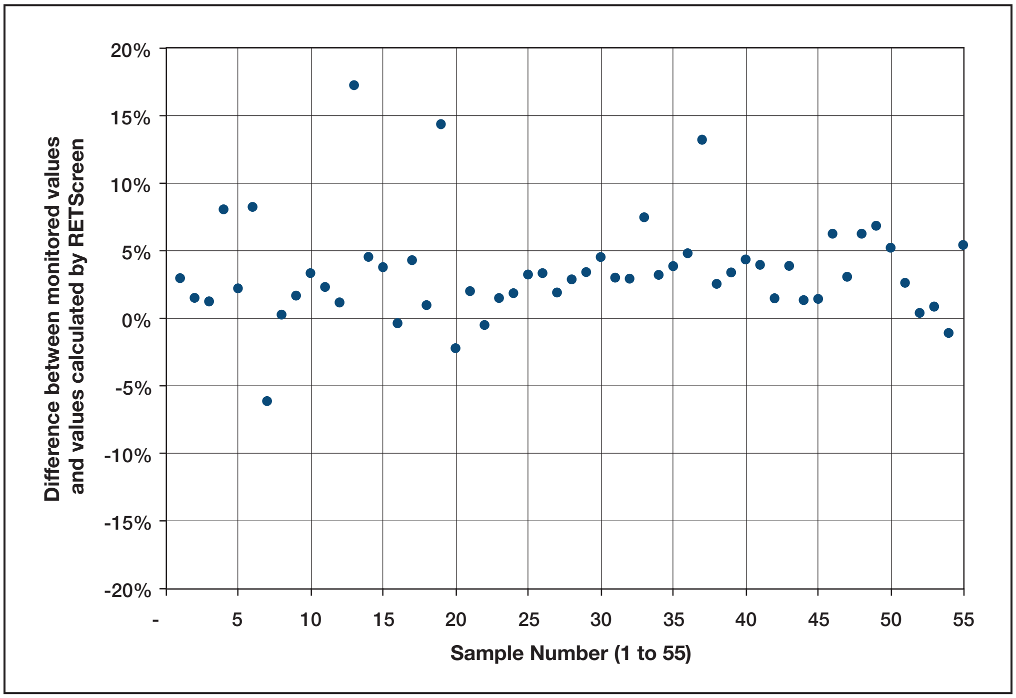


Figure 18:

Differences Between Measured Higher Heating Value and Values Predicted by RETScreen for 55 Wood Samples.

2.5.3 Validation of district heating network design

The district heating network design algorithms of the RETScreen Biomass Heating Project Model (see *Section 2.4*) were validated with the help of ABB's R22 computer program. The R22 computer program developed by ABB atomic division for sizing pipe distribution systems has been used extensively in Scandinavian countries for the design of district heating networks.

Table 10 shows pipe sizes calculated by the RETScreen Biomass Heating Project Model and values calculated by the R22 program. The values calculated by both RETScreen and R22 compare well to each other. RETScreen tends to be more conservative than R22. This is intentional, as the R22 program is a tool for detailed design, whereas the RETScreen Model is a feasibility tool. The selected pipe size is also a function of how much money can be spent on the project. If available money is restricted, the designer typically allows for higher friction losses. The sizing is still very safe with respect to sound and erosion problems.

Theoretically, the main distribution pipes should be sized with low friction losses and allow higher losses in the secondary distribution pipes to minimize required pumping load and investment costs. However, in practice space is often limited and capital costs need to be controlled resulting in a small main line. As for the secondary line, it is typically over-sized, since the customers' heating load is not well defined and to avoid noise problems.

Input				RETScreen Calculation	ABB-R22 Calculation	ABB-R22 Calculation
Supply (°C)	Return (°C)	Delta T (°C)	Load (kW)	Pipe Size DN	Pipe Size DN	Friction Losses[7] mmwc/m
95	65	30	25	32	25	4.9
95	65	30	50	32	32	5.3
95	65	30	75	40	32	11.5
95	65	30	100	50	40	9.4
95	65	30	200	50	50	10.8
95	65	30	250	65	65	4.5
95	65	30	400	65	65	11.2
95	65	30	420	80	65	12.3
95	65	30	720	80	80	15.4
95	65	30	740	100	100	4.3
95	65	30	1,250	100	100	11.8
95	65	30	1,260	125	100	12.0
95	65	30	2,260	125	125	12.6
95	65	30	2,270	150	125	12.7
95	65	30	3,830	150	150	13.3
95	65	30	4,250	N/A	200	4.0
120	75	45	50	32	25	8.4
120	75	45	90	32	32	7.4
120	75	45	100	40	32	9.1
120	75	45	140	40	40	8.1
120	75	45	150	50	40	9.3
120	75	45	300	50	50	10.7
120	75	45	310	65	50	11.4
120	75	45	620	65	65	11.8
120	75	45	630	80	65	12.2
120	75	45	1,090	80	80	15.6
120	75	45	1,100	100	100	4.2
120	75	45	1,880	100	100	11.8
120	75	45	1,900	125	100	12.1
120	75	45	3,400	125	125	12.6
120	75	45	3,450	150	125	13.0
120	75	45	5,750	150	150	13.3
120	75	45	6,400	N/A	200	4.1

Table 10: Comparison of the RETScreen District Heating Network Design (Pipe Sizing) Algorithm with ABB's R22 Computer Program.

7. mmwc/m: millimeters water column per meter of pipe.

2.6 Summary

In this section, the algorithms used by the RETScreen Biomass Heating Project Model have been shown in detail. This model uses 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 entered 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 specified by the 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 algorithm is used to provide a preliminary sizing of the distribution network. Various parts of the model have been validated against other programs or against values published in the literature. Despite the relative simplicity of the model, its accuracy proves acceptable, at least at the pre-feasibility or feasibility stage, when compared with other software tools or with experimental data.

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