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Biomass Energy for Supplemental Heating in a Solar Energy Greenhouse

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ABSTRACT A biomass boiler was tested for its suitability of providing supplement heat to a solar energy greenhouse. The greenhouse, located in southern Manitoba, measured 7 m wide and 30 m long and had an insulated concrete wall on the north side and double layer poly on the south side. The biomass boiler was rated 25 kW (85,000 Btu/h) for wood pellets and corn. Three biomass fuels (oat hull pellets, wood pellets, and sunflower hulls) were used in the boiler. Thermal energy was delivered from the boiler to the greenhouse through a hydronic system. Thermocouples were used to measure the greenhouse temperature and water temperature in the hydronic system. It was concluded that the biomass boiler was sufficient in providing supplemental heat to the solar energy greenhouse in February and March in southern Manitoba. The biomass consumption rate for oat hull pellets with a calorific value of 17 MJ/kg was determined to be 303 g/d-m^2 in February and 130 g/d-m^2 in March. When the biomass consumption rate was normalized against the Heating Degree Days (HDD), the biomass consumption rates were 9 and 8 g/HDD-m^2 for February and March, respectively.

Keywords: greenhouse, biomass energy, hydronic heating.

INTRODUCTION Cost of heating is a major expense in operating greenhouses in cold climate regions during winter months. According to the Commission of the European Communities (1986), more than 75% of thermal energy consumption in agriculture is devoted to greenhouse heating in cold climate regions. Alternative energy sources, such as solar energy and biomass energy, may provide an economically feasible solution. Solar energy greenhouses (SEG) have been widely used in northern China for producing vegetables in winter, late fall, and early spring since 1980s' (FAO 1994). Beshada et al. (2006) tested a solar energy greenhouse in southern Manitoba and found that the lowest nighttime temperature inside the greenhouse was 1.6°C when the outdoor temperature was -29.2°C. The solar energy greenhouse maintained the indoor temperature above 0, 5 and 10°C 82%, 35% and 19% of the time, respectively, while the outdoor temperature fluctuated between -29.2°C and 4.5°C. Although the SEG can maintain the greenhouse temperature much higher than conventional greenhouses without supplemental heating, the temperature is still not high enough for growing most crops. For example, many small greenhouse growers in Manitoba operate their greenhouses from February to June to grow bedding plants and the set temperature is typically 70°F (21.1°C) during the day and 60°F (15.6°C) at night. Therefore, supplemental heating may still be required to maintain the night temperature.

Natural gas has been traditionally used as the primary source of fuel to heat greenhouses in Canada. The increasing prices of fossil fuels have resulted in many growers switching to alternate fuels (OMAFAR, 2009). Biomass fuels, including woodchips, sawdust (from fresh-cut, wood mills, furniture factories, pallets, etc.), construction and demolition debris (wood-based), energy crops, farm-waste (plant materials, seeds), food processing waste, and pelletized agricultural-and wood-based products), are among the choices by the growers (OMAR, 2009). Based on case studies of various options of biomass heating in greenhouses, Sanford (2010) concluded that a payback period of 3.2-3.7 years is expected for a pellet boiler.

Although information exists in the literature for biomass heating in greenhouses, little is available on biomass heating in solar energy greenhouses. The objective of this study was to investigate the biomass energy as a source of supplemental heating in a solar energy greenhouse located in southern Manitoba.

MATERIALS AND METHOD

Solar Energy Greenhouse (SEG) The experiment was conducted in a solar energy greenhouse at Blue Lagoon Florascape farm in St. Francois Xavier, MB. The SEG was 30 m long, 7 m wide, and had a maximum height of 2.4 m along the north wall (figs. 1 and 2). The south facing arch of the SEG was covered with a double layer of 8-mm polyethylene (SunSaver4, Ginegar Plastic Products Ltd., Israel). A small fan was used to inflate the double layer poly, creating an airspace of about 4 - 6 inches between the two layers. The north wall consisted of 196-mm concrete and 50-mm foam insulation. The north portion of roof was also insulated with 50-mm foam insulation.

The greenhouse was fully cropped using trays on benches and pots on the ground. The first section of the greenhouse had three benches, each covered with a series of six to eight 130 W heat pads (Alternative Heating Systems Inc., Winnipeg, MB) for providing heat directly to the root zone of the plants. Heat pads on each bench were equipped with a master thermostat which controlled the surface temperatures of all the heat pads on that bench. This section of the greenhouse also had a lighting system consisted of a single 1000 W high pressure sodium bulb, a reflective shade, necessary hardware, and ballast. A 5-kW electrical heater was installed in the middle section of the greenhouse to provide additional supplemental heat when needed. The thermostat on the heater was set at 13°C.

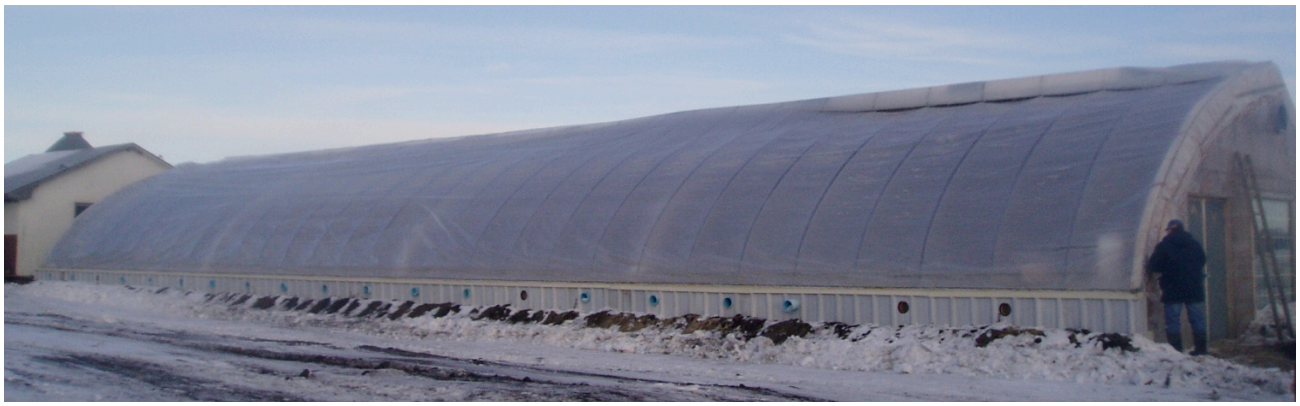


Figure 1. Solar energy greenhouse located in St. Francois Xavier, MB.

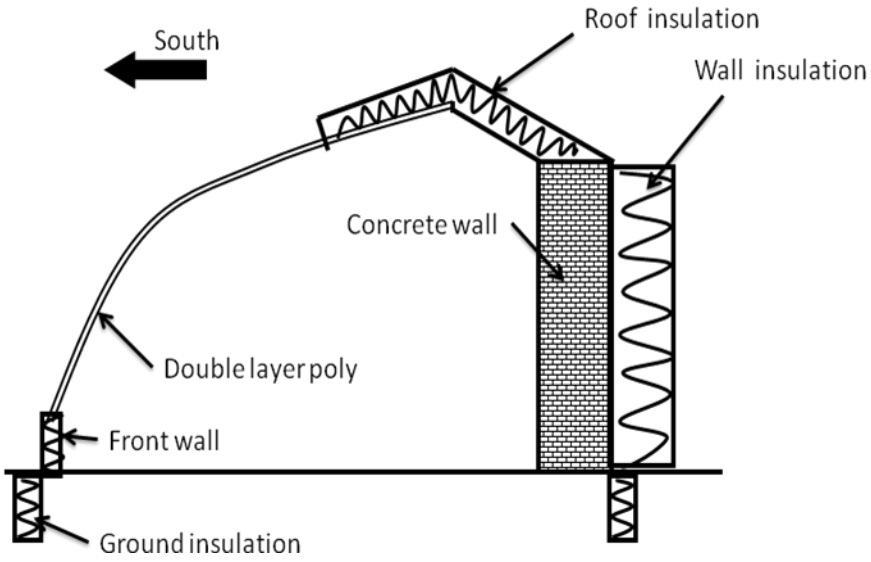


Figure 2. Schematics of solar energy greenhouse used in experiment.

Biomass Energy Heating System A biomass boiler (Model PB150, Pinnacle Stove Sales Inc., Quesnel, BC) was installed to provide supplemental heating to the greenhouse (fig. 3). The boiler may be wood pellet or corn fired, and is rated at 85,000 - 130,000 BTU/hr input and 80% efficiency. Pellets are fed to the burner through a hopper with a capacity of 160 lbs. The boiler has a control system that prevents water circulation if the water temperature is below a predetermined level and shuts off the burner if the water temperature reaches a predetermined upper limit. The temperature of water inside the boiler was maintained at 100 – 120°F (38 – 49°C) during the experiment.

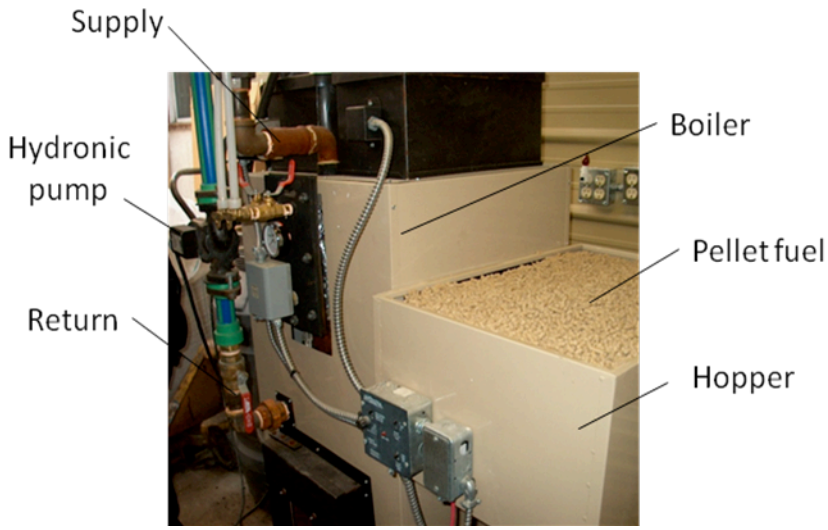


Figure 3. Photograph of biomass boiler system.

A hydronic water pump (Model 007, Taco Inc., Cranston, RI) was used to circulate hot water through a radiator in the greenhouse as well as a network of PVC pipes in the concrete wall of the greenhouse (fig. 4). The pump was rated 0 – 23 GPM at 0 – 10 ft head. The radiator was placed at the west end of the greenhouse, about 8 ft above the ground. A fan was installed behind the radiator to force the air to flow though the radiator. The pipes in the concrete wall kept the wall warm, and the wall in term released the thermal energy to the greenhouse at night.

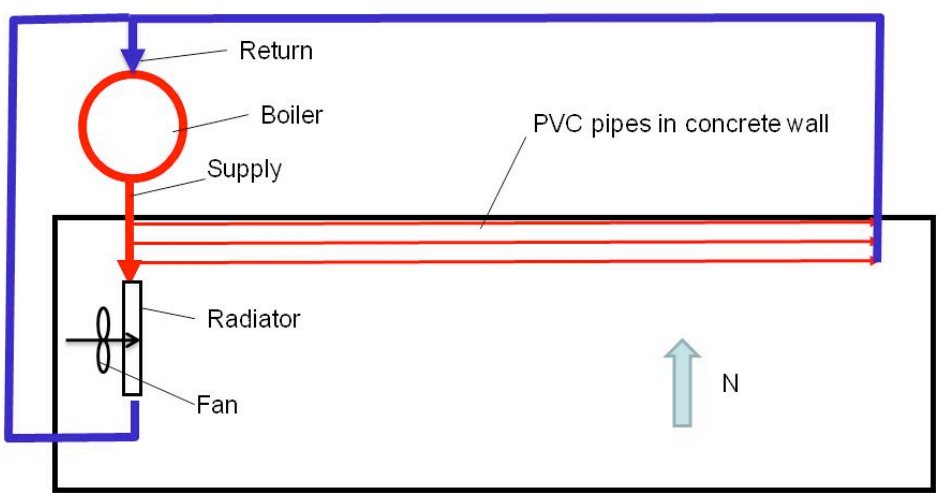


Figure 4. Schematics of heating loops of the biomass energy heating system.

Biomass Fuels Oat hull pellets (Can-Oat Milling, Portage la Prairie, MB), wood pellets (Winnipeg Forest Products, Winnipeg, MB), and sunflower hulls were used as fuels in the boiler. The calorific values for the materials are summarized in Table 1. Oat hull pellets were used most time during

Figure 5. Installation of thermocouples for measuring water temperature in the hydronic system.

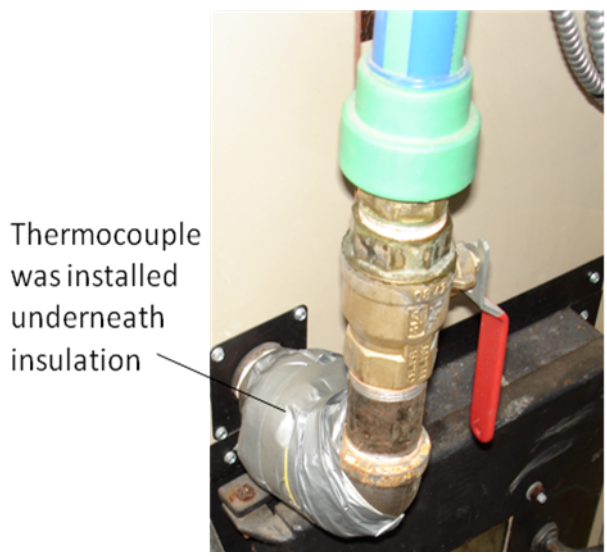
experiment, whereas the other two products were used only occasionally. Ash samples from oat hull pellets were also collected and analyzed for calorific value (2.1 MJ/kg, SGS Canada Inc., Delta, BC). Fuel loading was done on an as-needed basis, but mostly twice a day at 63 kg/day on average.

Table 1. Calorific values of biomass fuels used in experiment

	Oat hull pellets	Wood pellets	Sunflower hulls
Btu/lb	7,332*	8,700**	7,709 – 8,484***
MJ/kg	17.0	20.2	17.9 – 19.7

* analyzed by SGS Canada Inc., Delta, BC
** as per product specification
***Prairie Practitioners Group (2009)

Temperature and Flow Measurements T-type thermocouples were installed at nine locations throughout the greenhouse to monitor air temperature. Measurements were taken at ten minute intervals and recorded by a data acquisition system (CR1000, Campbell Scientific (Canada) Corp., Edmonton, AB). Water temperature in the hydronic heating system was measured at critical points, including the supply and return ports in the boiler. Because the hydronic loop was a closed loop, direct measurement of water temperature was difficult. Thermocouples were fixed onto the surfaces of metal pipes and then wrapped with fiberglass insulation and duct tape to indirectly measure water temperature (fig. 5).



A flow meter was installed in the supply line to measure water flow rate through the heating system. The meter was calibrated for the range of 0 - 90 GPM. The output voltage from the flow meter was fed to the Campbell Scientific data acquisition system and recorded along with the temperature every 10 minutes.

The experiment was conducted in the winters of 2010 and 2011. In 2010, the heating system was operated in February, March, and part of April, whereas the greenhouse was not operated until March in 2011.

RESULTS AND DISCUSSION The data for February 2010 is used as a sample in the following discussion because the highest energy demand among the three months when the experiment was conducted. The temperature profile for February 2010 is shown in figure 6. The lowest temperature was -31.4°C and the average daily mean -14.3°C. The total Heating Degree Days (HDD) was 905.6 °C-d.

The minimum (night) temperature in the greenhouse stayed above the setpoint 13°C most of time throughout the month of February, whereas the daytime temperature went over 20°C on most days (fig. 7). The average greenhouse temperature over the month was 16.1°C, and the minimum and

maximum temperatures were 7.4 and 40.7°C, respectively. The results indicates that the supplemental heating system was sufficient in maintaining the desirable temperature in the solar energy greenhouse.

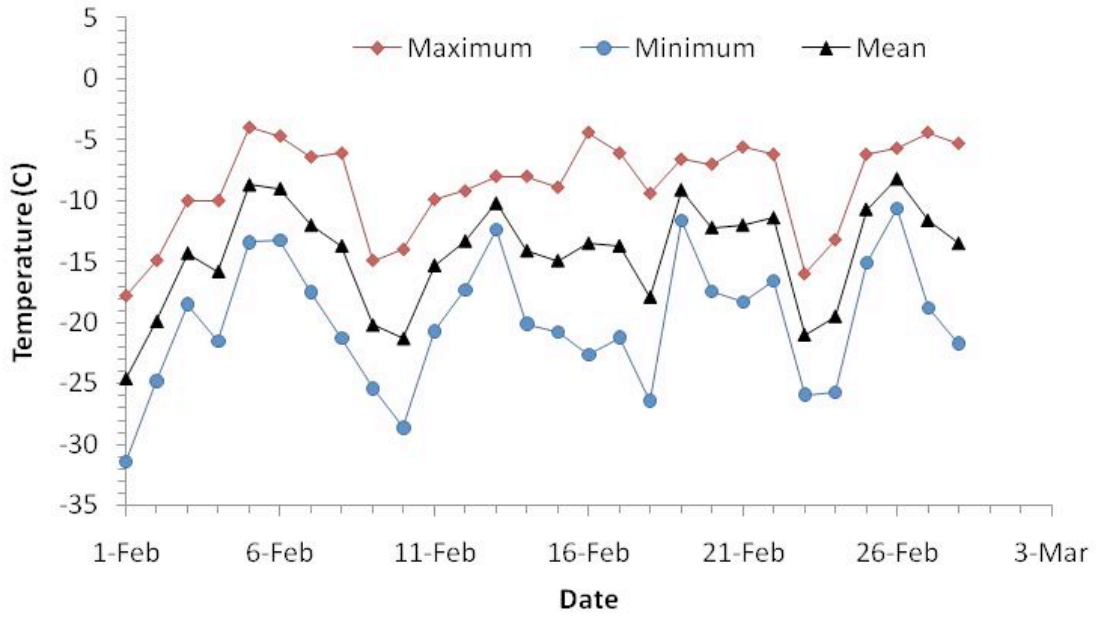


Figure 6. Outdoor temperature recorded at Winnipeg Airport by Environment Canada for the month of February 2010.

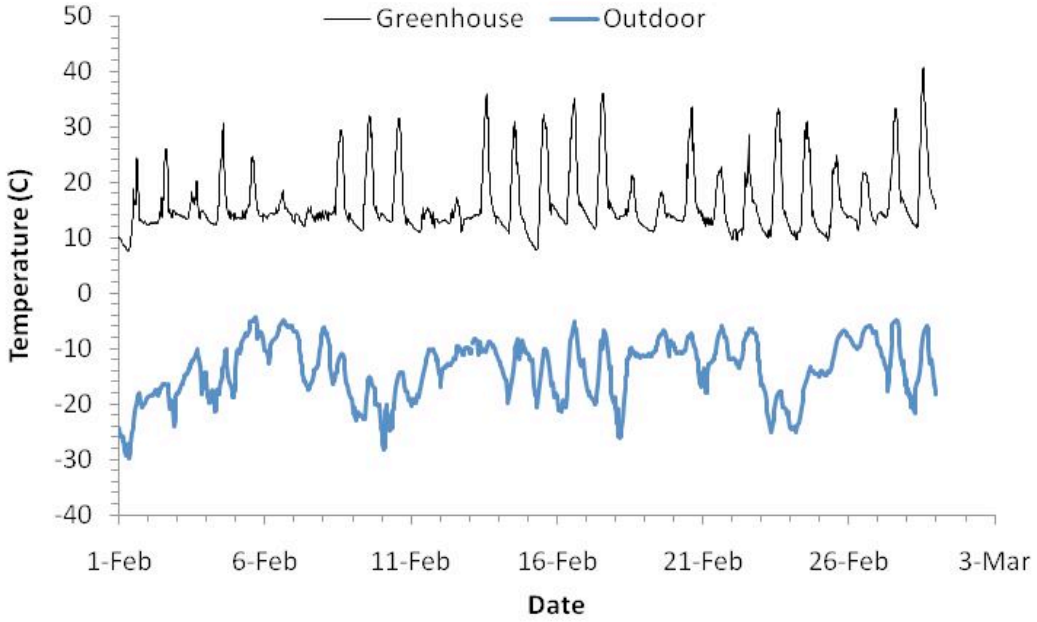


Figure 7. Greenhouse temperature and hourly outdoor temperature recorded at Winnipeg Airport by Environment Canada for the month of February 2010.

A total of 1753 kg of biomass (oat hull pellets) was used in the month of February 2010. This translates to 29,801 MJ of gross energy. The rate of biomass consumption (amount added to the boiler) was pretty consistent throughout the month (fig. 8). From the regression analysis, the biomass consumption rate was determined to be 63.7 kg/day, which results in 303 g/day per m^2 of greenhouse floor area.

The total biomass consumption in March dropped to 909 kg and the consumption rate was 27.2 kg/day (130 g/day-m^2). The lower biomass consumption in March than February was obviously due to the higher outdoor temperature. When the consumption rate was normalized against the Heating Degree Days (HDD), the rates of the two months were close: 9 g/HDD-m^2 for February and 8 g/HDD-m^2 for March.

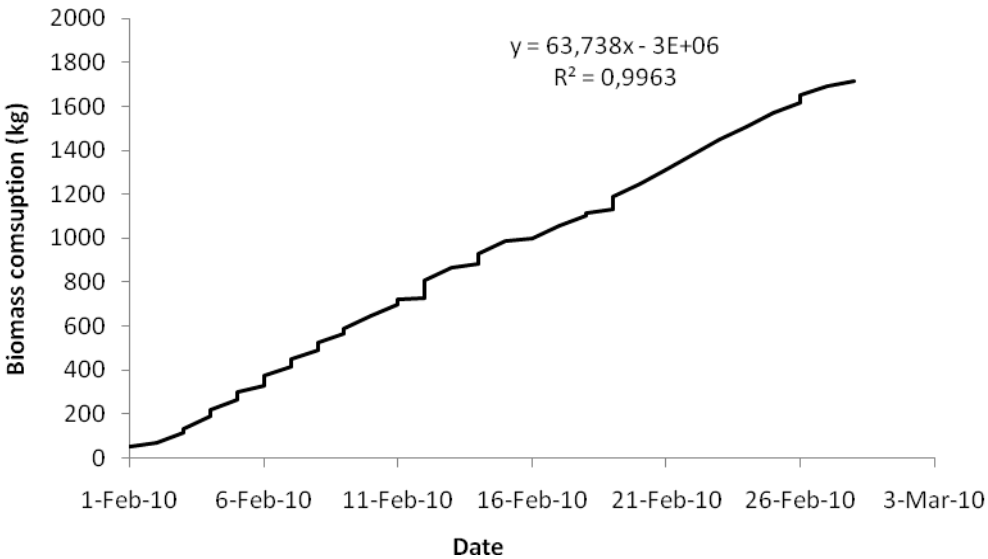


Figure 8. Biomass consumed in the month of February 2010.

Based on the measured rate of water flow and the measured temperature difference in water between the supply and return lines, the energy output from the boiler was calculated as follows:

$$E = \Delta t C_p \rho F \quad (1)$$

where E = energy output from boiler, W

Δt = temperature difference in water between the supply and return lines, °C

C_p = specific heat of water, J/kg-°C

ρ = density of water, kg/m^3

F = water flow rate, m^3/s

The flow meter was installed for the 2011 experiment to measure the rate of water flow though the boiler. Unfortunately, the data acquisition system stopped working one week after installing the flow meter. Therefore, data was only available for the period from March 14 to 22. Over this period, the average flow rate was measured to be 2.8 x 10^{-4} m^3/s (4.4 GPM).

Energy output from the boiler generally followed the biomass input (fig. 9). The highest output was 596 MJ/day. The total energy output for this 8-day period was 3310 MJ, while the gross energy input (285 kg of biomass) was 4851 MJ. The overall boiler efficiency was calculated to be 68% (3310 ÷ 4851). It is interesting to note that if the calorific value of ash was subtracted from the calorific value of biomass in calculating the boiler efficiency, the efficiency would be 78%.

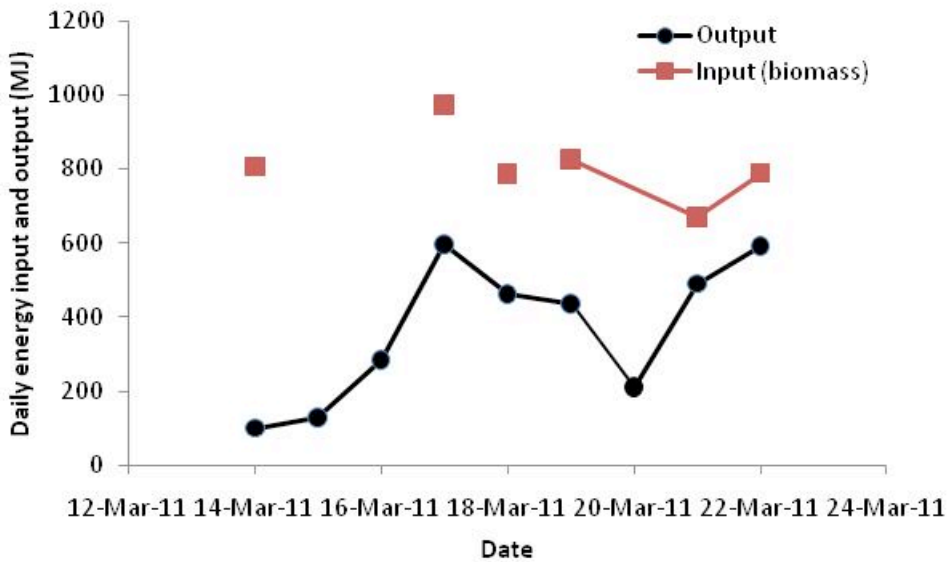


Figure 9. Energy input and output from the biomass boiler in February 2011.

The rate of energy output varied drastically from 0.2 to 12.9 kW, with an average of 4.4 kW (fig. 10). This indicates that the boiler control system was effective in regulating the energy output to meet the energy demand by the greenhouse.

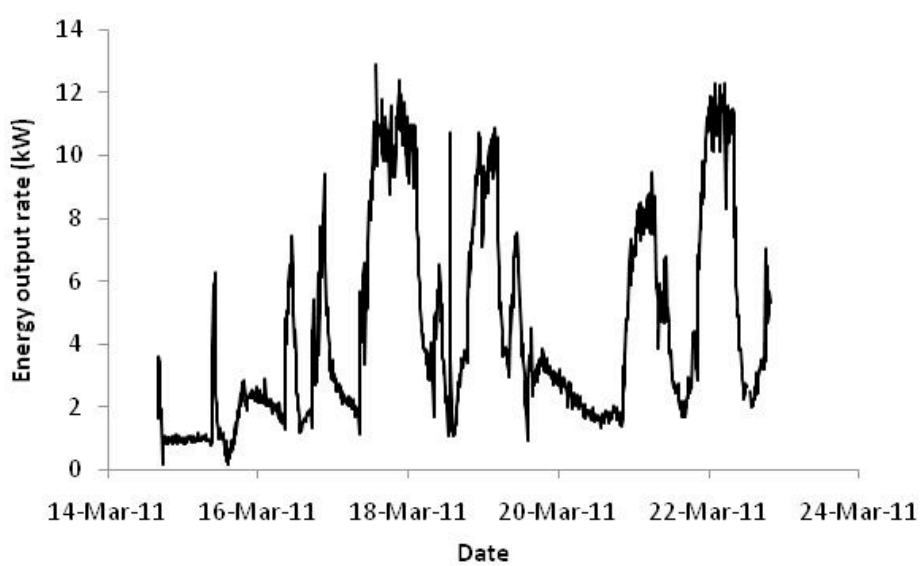


Figure 10. Energy output rate from the biomass boiler in February 2011.

The measured energy output was much lower than the rated boiler capacity (85,000 Btu/h, or 25 kW). This low output was primarily due to the fact that the experiment was conducted in a period when the outdoor temperature was relatively warm and the greenhouse did not require much supplemental heat. According to the weather record by Environment Canada, the average daily mean temperature was -2.7°C for this 8-day test period. The daily average biomass consumption was 25.9 kg/day, which is close to what was recorded in March 2010 (27.2 kg/day). Based on the biomass consumption, the daily average energy input rate was calculated to be 6.2 kW, from which an efficiency of 71% was estimated (4.4/6.2).

CONCLUSION Using oat hull pellets, wood pellets, and sunflower hulls, a biomass boiler rated 25 kW (85,000 Btu/h) was sufficient in providing supplemental heat to a 210 m^2 solar energy greenhouse in southern Manitoba. The biomass consumption rate for oat hull pellets was determined to be 303 g/d-m^2 in February and 130 g/d-m^2 in March. When the biomass consumption rate was normalized against the Heating Degree Days (HDD), the biomass consumption rates were 9 and 8 g/HDD-m^2 for February and March, respectively. The boiler control system was effective in regulating the energy output to meet the energy demand by the greenhouse.

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