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Performance of a Solar Greenhouse under Manitoba's Winter Weather Conditions

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Abstract The performance of a solar energy greenhouse, which has been efficiently used in China to grow vegetables and flowers during the wintertime, was investigated under cold Manitoba weather conditions. A 30 m by 7 m solar greenhouse was constructed in Elie, MB. The greenhouse was oriented due south to absorb maximum solar energy, and had a north wall to store solar energy at daytime and release thermal energy at nighttime. The preliminary data showed that the application of solar greenhouse under Manitoba's winter weather was promising. During the month of February the daytime temperature inside the greenhouse was above 15°C and the nighttime temperature stayed above 0°C when the outdoor temperature was as low as -30°C. Moreover, the comparison between the solar greenhouse and a conventional greenhouse showed that the solar greenhouse was 20°C warmer than the conventional one at night when the outdoor temperature was about -15°C. Without supplemental heating, vegetable seeds geminated well (95% in two weeks) in the solar greenhouse in February, and bedding plants (geraniums) grew well in March.

Keywords: greenhouse, solar energy, temperature.

Introduction

The commercial production of greenhouse plants is progressively gaining a satisfactory scientific achievement. Like all forms of agricultural production there is a rapid progress in achieving an increased plant production, better quality product and efficiency in the growing and handling of these plants. One of the primary elements that lead to these achievements is the provision of a suitable year round environment for the plants. To provide a suitable year round environment in cold climate, it is important to provide heating for winter months of the year. Greenhouses used for horticultural production have been mainly heated with fossil fuels such as oil, gas and coal. The ever-increasing price of fuel, especially, after the 1970s fuel crises, has limited the expansion of greenhouse production.

The heating energy consumption in greenhouses fluctuates in a wide range during summer and winter seasons as well as during day and night. Especially, in a cold climate a substantial amount of supplemental heating is required to run the greenhouse in wintertime. Hence, a reduced consumption of fuels for a greenhouse heating is a prerequisite for the existence of horticulture in the future (FAO, 1987). The problem of increasing cost of fuels and short supply of its energy resources makes greenhouse growers to look for all possible methods of energy conservation and to exploit alternative energy sources.

The best alternative energy source is solar energy. Solar energy greenhouses (SEG) have been used in some countries to minimize the cost associated with heating in cold weather. In the middle and northern China, a simple, inexpensive and energy conserving solar greenhouse has been used to produce vegetables in winter, late autumn and early spring since 1980s' (FAO, 1994). Manitoba, which has a substantial solar radiation during winter season, can make use of the technology on solar greenhouse. For example, In Winnipeg, the mean hourly global solar radiation is about 181 W/m^2 (on a horizontal surface) during daytime (9:00 am to 4:00 pm) in January, with a peak of 275 W/m^2 at noontime (Environment Canada weather data). This type of greenhouse provides opportunities for the Manitoba greenhouse growers to reduce or even eliminate supplemental heating for operating their greenhouses during winter months. Therefore, the use of solar energy for heating greenhouses may provide an economically viable solution to operating greenhouses in Manitoba during winter months.

The amount of solar energy indicated above is sufficient to maintain the desirable greenhouse temperature at daytime in Manitoba. However, the challenge is to maintain the greenhouse temperature after sunset with little or no supplemental heating. The objective of this study was to evaluate the performance of a solar energy greenhouse under Manitoba's winter weather conditions.

Materials and Method

Solar Greenhouse Construction

The main components of a solar energy greenhouse (SEG) were steel framing, a plastic cover, a solar energy collection (north) wall, and a thermal blanket (fig. 1). The greenhouse is constructed so that during the daytime the inside surface of the north wall is fully exposed to direct solar radiation. As the air in the greenhouse cools down at nighttimes, solar energy absorbed by the wall would be radiated back to the room. For the maximum collection of solar energy, the greenhouse was oriented in the east-west direction. The plastic cover forms the

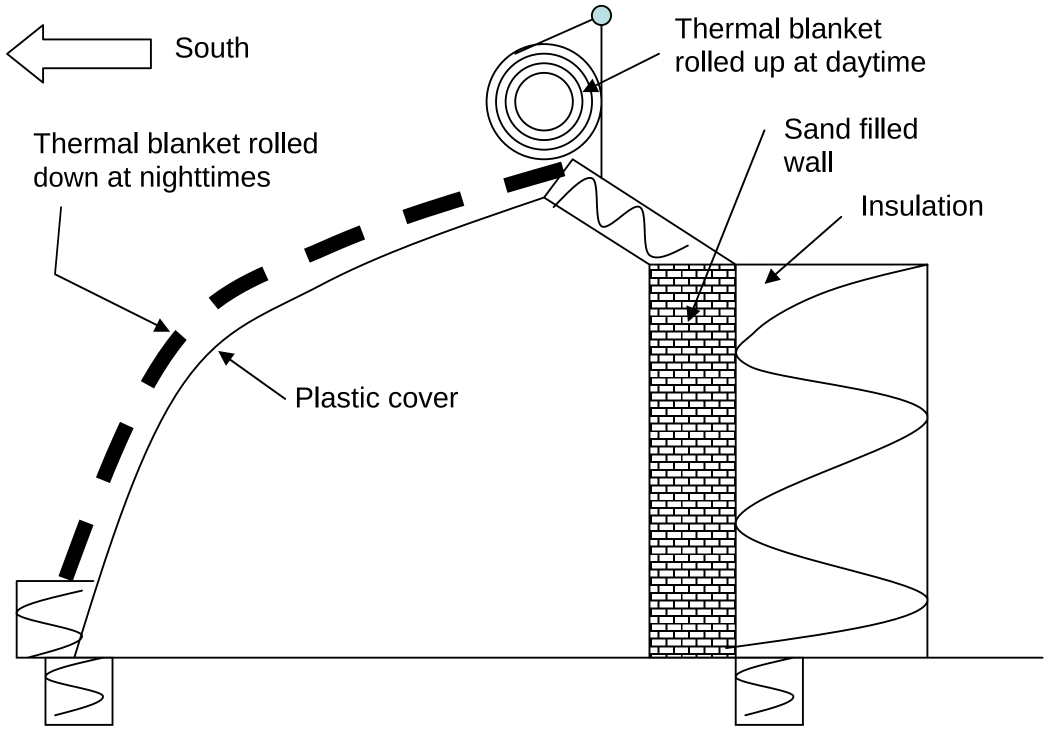

Figure 1. The side view of solar energy greenhouse.

greenhouse enclosure on the south side, while the wall and a small section of insulated roof forms the enclosure on the north side. The north wall, which is filled with sand acts as heat reservoir and it also, blocks the northern wind, reducing heat losses caused by infiltration. The thickness of the north wall was about 30 cm, of which the portion filled with sand was 15 cm and insulation 15 cm. The 15-cm fibreglass insulation on the north and sidewalls provided thermal resistance of about R-20.

The inside wall sheathing was made of galvanized sheet steel. A portion of the inside surface of the north wall was painted black to assess the advantage of having a darker colour for maximum absorption of solar energy.

The transparent plastic cover was a single layer of polyethylene, which has a solar radiation transmissivity τ, of 0.80 to 0.90 (Aldrich and Bartok, 1992). The thermal blanket used to minimize heat loss during the night was a cotton blanket with an approximate R-value of 5 (RSI 0.88). A winch system was used to operate the thermal blanket, i.e., roll it up at daytime and place it over the plastic cover at nighttimes. To maximize the heat gain, the blanket was rolled up at about 9:00 A.M. and rolled down at about 6:00 P.M. The blanket provided insulation at night.

Temperature Monitoring

The temperature of the greenhouse was monitored at different positions using K-type thermocouples. The room air temperature, outdoor air temperature, soil temperature, and the temperature profile across the wall were recorded every 10 minutes. The room temperatures were recorded at three different positions with approximately 1.5, 3, and 4 meters above the ground. The soil temperatures were monitored across the greenhouse at three positions and different depth in the soil. They were recorded near the north wall, south end and in the middle of the room at the depth of about 2, 15 and 30 cm. Temperature across the depth of wall was monitored for both painted and unpainted sections at three depths of 2, 6 and 10 cm from the inside surface of the wall. The temperature sensed by the thermocouples was recorded using a computer controlled data acquisition system (HP3852A, Hewlett-Packard, USA).

For comparison, temperature was also recorded in an unheated conventional greenhouse located near Landmark, Manitoba. A HOBO® H8 Pro series data logger (Onset Computer Corporation, Bourne, MA) was launched and positioned at three locations in the greenhouse for about a month in March, 2005. Temperature was recorded at a10 minute internal.

A portable WatchDog™ weather station (Model 550, Spectrum Technologies, Inc., Plainfield, IL) was placed at about 2 m above the ground near the solar greenhouse to collect on-site weather information. Global solar radiation, ambient temperature, relative humidity, and wind speed and direction were recorded every 5 minutes.

Plant Growth

To assess the practical applicability of the solar greenhouse, vegetable (Xianggang Qinygengyoucia 2000) was seeded in the greenhouse at the end of February, 2005. The medium used for the germination was Sunshine Mix 2 Mix Basic Professional growing mix soil. Bedding plants (geraniums) had also been grown in the greenhouse since March 15, 2005.

Results and Discussion

Temperature Variation

Typically, the highest temperature inside the greenhouse was recorded in the afternoon between 2:00 and 4:00 P.M. The temperature started to rise as soon as the thermal blanket was rolled up and started to decrease after 4:00 P.M. Figure 2 shows the average temperature recorded inside and outside the greenhouse on one of the coldest days in February. The daytime temperature inside the greenhouse reached 25°C and the nighttime remained above 0°C while the outdoor temperature was slightly above -20°C during the day and close to -30°C at night. In other words, the solar energy greenhouse could keep the inside temperature about 20 to 45°C above the outdoor temperature.

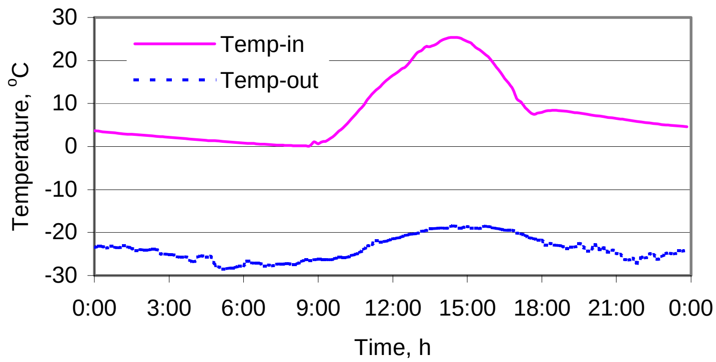

Figure 2. The room air temperature recorded inside and outside the greenhouse on February 7, 2005.

Temperature inside the greenhouse was highly influenced by the amount of global solar radiation that reached the surface of the greenhouse cover. Figure 3 shows the temperature profile in the greenhouse for two days in February, when the total available solar energy was 1.8 and 3.7 kWh, respectively. The maximum inside temperature for 3.7 kWh was about 18°C higher than that for 1.8 kWh. However, even with 1.8 kWh of global radiation, the temperature inside the greenhouse stayed above 0°C at night.

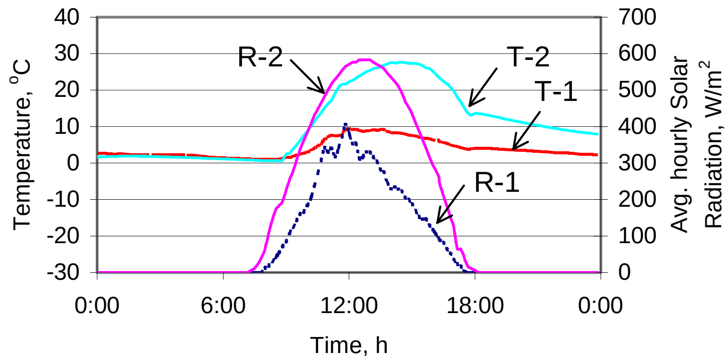

Figure 3. Effect of available solar radiation on temperature inside the greenhouse. T-1, T-2, R-1 and R-2 shows the temperature and global solar radiation recorded on February 13 and 28, respectively.

The temperature distribution inside the north (solar energy storage) wall was monitored. As shown in Figure 4, the temperature started to rise after the thermal blanket was opened and started to fall after 4:00 P.M. The graph also shows that temperature decreased with the distance from the wall surface in the daytime. However, at nighttime due to thermal radiation of the stored heat, the outer layer of the wall cooled faster than the inside.

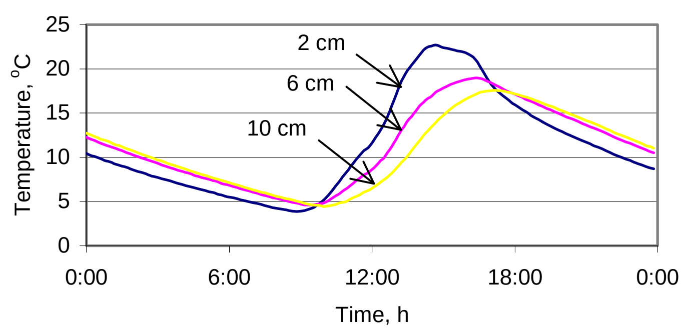

Figure 4. The temperature recorded across the painted portion of the north wall on Feb.19. On this day the night ambient temperature was < –20 ^{o}C.

The impact of surface colour on wall temperature was apparent. As shown in Figure 5, the black surface resulted in temperature about 5 to 6°C higher than the unpainted silver surface of galvanized steel. Higher temperature means more energy storage in the wall. The analysis showed if the inside surface was painted black, 17 % more energy could be stored in the north wall.

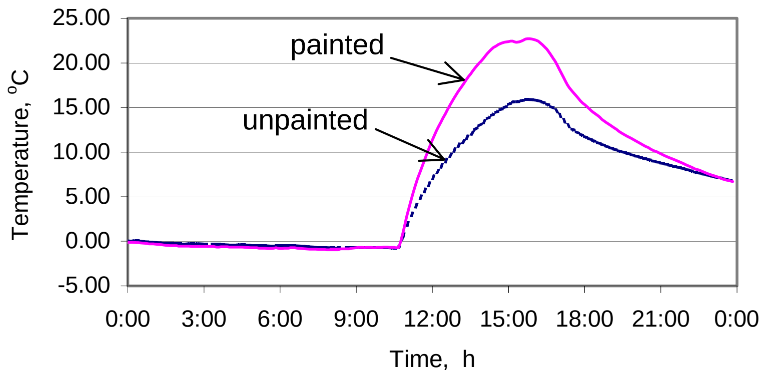

Figure 5. Temperature recorded at a depth of 2 cm for the painted and unpainted surfaces of the north wall.

The distribution of soil temperature across the greenhouse at a depth of 5 cm was also recorded. Figure 6 shows that the soil near the plastic heated and cooled faster than the others. The result also showed that during the night time the soil at the middle of the greenhouse stayed by about 2 to 4 ^{o}C warmer than the soil near the perimeter of the greenhouse.

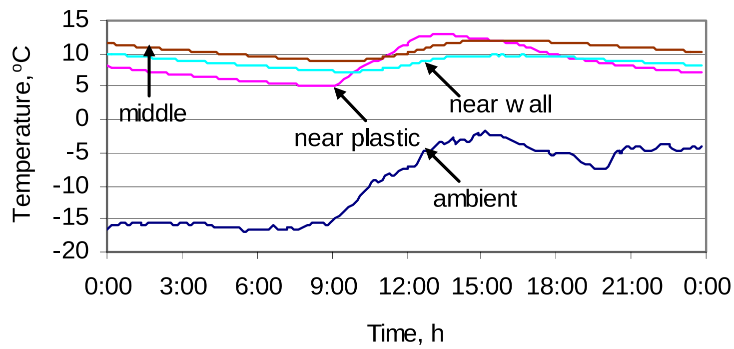

Figure 6. The temperature measured across the greenhouse at a soil depth of 5 cm.

Comparison between Solar and Conventional Greenhouses

Temperature recorded inside the solar greenhouses was compared with that in an unheated conventional greenhouse in March, 2005. Figure 7 depicts measured temperatures on one of the coldest days in March. The solar greenhouse was about 20°C warmer than the conventional greenhouse at nighttime, and the difference in the daytime maximum temperature between the two greenhouses was about 5°C. The solar energy greenhouse stayed at about 10°C at night while the outdoor temperature was -15°C.

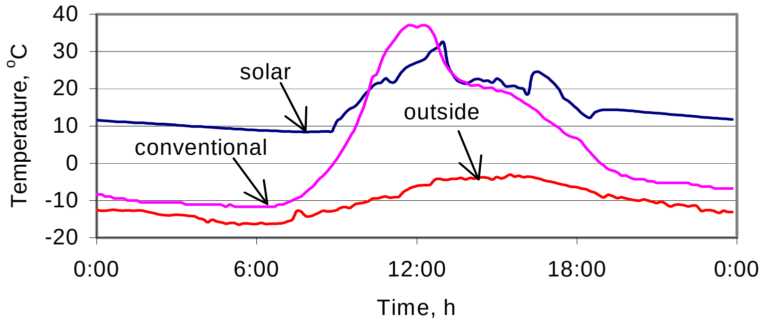

Figure 7. Temperature comparison between conventional and solar greenhouse based on the data obtained on March 20, 2005.

Plant Performance

About 80% to 90 % of the vegetable seeds germinated a week after seeding. The germination reached almost 95% two weeks after seeding (fig. 8).

Figure 8. Photos after the 1st (left) and the 3rd (right) weeks of seeding.

Planted in March, geraniums grew well in the solar energy greenhouse without any supplemental heat (fig. 9). On the day of transplanting there were only 2 plants flowered out of 160. However, the percentage of flowered geraniums increased to more than 8, 28, 55 and 70 % after 2, 3, 4 and 5 weeks of transplantation. The result also showed that almost 95 % of the geranium buds observed on the second week had flowered. Moreover, the number of buds on a single geranium plant varied between 2 to 12.

Figure 9. Geraniums at time of planting (left), three weeks (middle), and 5 weeks (right) after planting.

Conclusions

1. The solar greenhouse stayed above 0°C without supplemental heating in February and March when the outdoor temperature was as low as -30°C at night.

2. Temperature inside the solar greenhouse was significantly (20°C) higher than that in an unheated conventional greenhouse at night in March.

3. The solar greenhouse could potentially be used to grow vegetables and flowers during the winter season under Manitoba's winter conditions.

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