CONCRETE MASONRY WALL TO PROVIDE SOLAR HEAT TO A PIG BARN IN SASKATOON, CANADA

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A concrete masonry wall has been added to the south wall of a farrowing barn to capture the solar heat. The building is located near Saskatoon, Canada at 52° north latitude. The blocks, each measuring 200 x 200 x 400 mm, have a pair of offset holes to increase thermal storage as well as to facilitate air movement. The wall measures 18 m long, 2.2 m high, and 200 mm thick, providing 39 m² of effective solar absorbing area. The wall was painted black and covered with clear corrugated fiber-glass glazing. The wall was ventilated continuously with outside air which transferred the absorbed heat into the barn. Recorded data during the cold winter of 1982 showed that the wall collected 1.75 kWh/m² daily or about 70 kWh for the total collector area. The collected heat provided about 50% of the space heat demand of the farrow barn. The fresh ventilating air was tempered by an average of 11°C during the same period. The solar heat contribution increased to 63% during the milder winter of 1983.

SYSTEM DESCRIPTION

The main component of the solar heating system is a south-facing vertical wall made of concrete blocks. The face of the wall is painted black and then covered with corrugated fibreglass. The side view of the wall and its foundation are shown schematically in Fig. 1.

The sun’s heat passes through the corrugated fibreglass as short-wave radiation energy. Some of this energy is immediately absorbed by the wall, and some of it is reflected back from the black surface of the wall as long-wave radiation. The reflected energy is prevented from escaping by the fibreglass, which is not transparent to long-wave radiation. The energy-trapping process is called the “greenhouse effect.” It allows the wall to operate at maximum efficiency as a solar collector. The result is that the concrete wall absorbs a significant percentage of the sun’s available energy.

As shown in Fig. 1, cold outside air first enters the system through a gap (A) near the top of the concrete wall. The air passes down through the narrow space between the fibreglass and the wall. At the bottom of the wall (B), it enters a series of short horizontal channels cut through the concrete blocks along the bottom layer of the wall; the figure shows one such channel in side view. Then the air flows up through vertical channels in the blocks.

Maintaining livestock buildings in cold climates at a proper temperature represents one of the most energy-consuming operations in the agricultural production system. About 70–90% of the heat loss in these buildings is through ventilation. Ventilation is necessary to remove excess moisture, toxic gases and dust. Solar collectors that are capable of absorbing and storing low grade heat are effective in reducing heating requirements of livestock buildings.

In a well-insulated hog barn, about 75% of the heat lost in cold weather is in the ventilating air (Jordan et al. 1979). A continuous winter ventilation rate of 7 L/sec per sow is recommended by Turnbull and Bird (1979). This is a minimum rate to keep moisture, toxic gases and dust down to safe levels. Heat used to warm ventilating air in a swine building to 10–20°C can provide a high percent of the total heating requirement.

Air-type solar collector-storage systems are becoming both technically and economically feasible for use on livestock buildings. A Trombe wall was first utilized in a swine building in Kansas (Robbins and Spillman 1980). The plans and description of this unit are now available for use on hog barns located in the Midwest and North Central regions of the United States (MWPS-22, 1980). Winsfield and Munroe (1979) described several Trombe walls on swine buildings in southern Ontario. The results so far have been promising. No such collector-storage units have been tested or installed on prairie livestock housing.

This paper describes the construction and performance of a solar heating system which has been used successfully for two consecutive winters to provide supplementary heating for a hog barn located at the University’s Prairie Swine Centre near Saskatoon.
Figure 1. Solar collector/storage wall.

As shown in Fig. 1, the concrete-block wall is erected 700 mm away from the existing south face of the farrowing barn. The 200-mm-thick wall is 2.2 m high and 18 m long. Regular weight concrete blocks with nominal dimensions of $200 \times 200 \times 400$ mm were used in the construction of the wall. Figure 3 shows the form and the actual dimensions of the blocks used. The blocks were uncut half-bricks available from a local concrete plant. There were four holes in each block; two of the holes were filled for this application. Each block weighs 20 kg and is 87% solid, with two holes.

Solar Energy Available

Because the days are shorter, there are fewer sunshine hours during the cold season. From mid-October to mid-April, Saskatoon receives only about 34% of the total annual sunshine available (Table I). Yet during the same period, a vertical south-facing wall receives about as much of the sun’s energy as it gets during the rest of the year. As shown in the table, from mid-October to mid-April it receives 49% of the total solar energy available annually.

The most efficient heating of a flat surface is at a right-angle, or 90°, to the direction of radiation. In winter, the sun is low in relation to our location, and its radiation is therefore almost “head on” to the vertical, south-facing wall; in summer, however, with the sun high in the sky its radiation strikes the vertical surface at a sharp angle (Fig. 4). Although there are fewer hours of sunshine during the cold months, this is offset by the more efficient angle of the sun for heating the vertical wall. Table I shows that about 755 kWh of the sun’s energy fall on each square metre of a vertical south-facing wall at Saskatoon from mid-October to mid-April.

Instrumentation

The solar wall was instrumented with type T thermocouples to sense temperatures at various locations. The air velocity passing through a 2.5-m-long, 350-mm-diameter duct was measured by a vane anemometer. A Honey-comb flow straightening structure was installed at the entrance of the duct to provide a uniform airflow to the vane anemometer. A star-type pyranometer was installed directly on the wall to measure total radiation on the vertical surface.

The voltage output of the pyranometer, the flow meter and thermocouples were scanned by a data logger. Incoming data lines were scanned every minute, averaged over 30 min and the results were recorded on floppy disks for further analysis.

Table I. Solar Energy Available in Saskatoon (Ten Years Average)

<table>
<thead>
<tr>
<th></th>
<th>Mid-October</th>
<th></th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual</td>
<td>mid-April</td>
<td></td>
</tr>
<tr>
<td>Sunshine hours</td>
<td>2453</td>
<td>827</td>
<td>34</td>
</tr>
<tr>
<td>Solar heat on vertical south-facing wall (kWh/m²)</td>
<td>1530</td>
<td>755</td>
<td>49</td>
</tr>
</tbody>
</table>
Total supplemental heat was calculated by adding the collected solar energy to the power consumption by the electric space heaters. The contribution of the solar wall in heating the barn was calculated as the ratio of the solar heat gain to the total supplemental heat.

**PERFORMANCE**

We measured the efficiency of the solar wall during the three coldest months of 1982—January, February, and March (Table II). For example, as shown in Table II, 2898 kWh were available in January. The wall collected 1990 kWh during the

<table>
<thead>
<tr>
<th>Period</th>
<th>Available solar energy (kWh)</th>
<th>Collected solar energy (kWh)</th>
<th>Collection efficiency (%)</th>
<th>Supplemental heat (total) (kWh)</th>
<th>Solar collector contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan.</td>
<td>2898</td>
<td>1990</td>
<td>69</td>
<td>7892</td>
<td>20</td>
</tr>
<tr>
<td>Feb.</td>
<td>4113</td>
<td>2064</td>
<td>50</td>
<td>2319</td>
<td>47</td>
</tr>
<tr>
<td>Mar.</td>
<td>4146</td>
<td>1908</td>
<td>46</td>
<td>942</td>
<td>67</td>
</tr>
<tr>
<td>Total</td>
<td>11 162</td>
<td>5962</td>
<td>55</td>
<td>11 153</td>
<td>45</td>
</tr>
</tbody>
</table>

Figure 4. The sun's angle in relation to a vertical south-facing wall at Saskatoon in winter and summer.

**CALCULATIONS**

The heat gained by the solar wall was obtained by applying the following formula

\[ Q = V d C TD \]

where

- \( Q \) = heat gained (lost) every 30 min. (J/h)
- \( V \) = air volume flow rate (m³/h)
- \( d \) = averaged air density (kg/m³)
- \( C \) = air specific heat (J/kg·°C)
- \( TD \) = temperature rise; temperature of the tempered air entering the mixing room minus the outdoor temperature (°C)

Monthly solar heat gain was calculated by cumulating the \( Q \) values for the period. The collector efficiency was calculated as the ratio of the heat gained over the total solar radiation available on the vertical solar wall.
same period, or about 69% of the solar heat available. Thus, the efficiency of the solar wall during January 1982 was about 69%. As the weather warmed up, the wall’s efficiency decreased to 50% in February and dropped to 46% in March. Data in Table III show a similar trend for 1983.

The Wall’s Contribution

The wall provided on average about half the total heating requirements of the barn (Tables II and III). For January to March of 1982, its first period of operation, the wall contributed about 45% of the barn’s heating requirement (Table II); for the fall of 1982 (October to December) and the winter of 1983 (January to April) it contributed on average about 63% of the heat required (Table III). In January of 1982, a record cold month, when the heating requirements were higher than in any other month, the solar wall contributed about 20% of the heat, with the remaining 80% supplied by electric heaters. In February, when heating requirements were lower, the wall provided about 47% of the heat; and in March it provided about 67%. Tables II and III show that the wall contributes a greater percentage of the total heat requirement for the barn when the weather is less severe. In October of 1982, for example, it contributed almost all the heat required for the barn (99%).

Another way of looking at the performance of the wall is to consider warming up the outside air. As shown in Table IV, the wall warmed the air by an average of 11°C.

COSTS AND BENEFITS

The “payback period” is the amount of time it takes for the solar heating system in effect to pay for itself. A “simple payback period” is calculated as follows:

Simple payback period = the cost of the solar system/annual savings

The total cost of the retrofit, including materials and labor, was approximately $4013. We calculated that the solar collection system at the Prairie Swine Centre barn saved about 9000 kWh during the entire 1982 heating season. This amounted to about $338, with electricity at 3.75 cents per kWh (Table V). Therefore, the retrofitted solar system would take roughly 12 yr to pay for itself.

The simple payback period is a simplification. The rate of increase in the price of energy is generally more than the rate of increase in overall inflation and interest rates, the system might take less time to pay for itself than the simple payback period would indicate.

CONCLUSIONS

The overall contribution of the solar wall was about 9000 kWh for the entire, 1982 heating season. The solar contribution was 58% of the total supplemental heat required for the 18-sow farrow barn. The wall was able to temper the cold ventilating air by an average of 11°C.

ACKNOWLEDGMENT

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REFERENCES


