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 × 200 × 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 m^2 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/m^2 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.

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). Winfield 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.

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.

As the air passes down through the space between the fibreglass and the surface of the wall and then up through the wall itself via channels in the concrete, it is warmed or "tempered" by the heat energy stored in the wall. The tempered air leaves the wall through a series of channels near the roof of the barn (C). It then enters the space between the retrofitted concrete wall and the original wall of the barn. From this space, which serves as a duct, the air flows into the mixing room through a pipe (D).

The mixing room is shown in the plan view (right side) of the farrowing barn shown in Fig. 2. The solar-heated air which enters the mixing room may require additional heat to maintain the barn at an adequate temperature. This additional heat is provided by two thermostatically controlled 5-kW space heaters in the mixing room; the heaters bring the temperature of the air up to about 18°C.

A fan then forces the heated air out of the mixing room through two plastic pipes. These pipes extend along the length of the farrowing room as shown in Fig. 2. The heated air passes through the perforations in the pipes to warm the room. A portion of the barn air is drawn back into the mixing room through a filter. To maintain circulation, some of the barn air is ventilated to the outside through exhaust fans located on the north wall. Three 200-mm fans and one 400-mm fan provide winter and summer ventilation. One 200-mm fan runs continuously; the other fans are thermostatically controlled. During the warmer months, the summer ventilation duct (also shown in Fig. 1) is opened, admitting outside air directly into the barn.

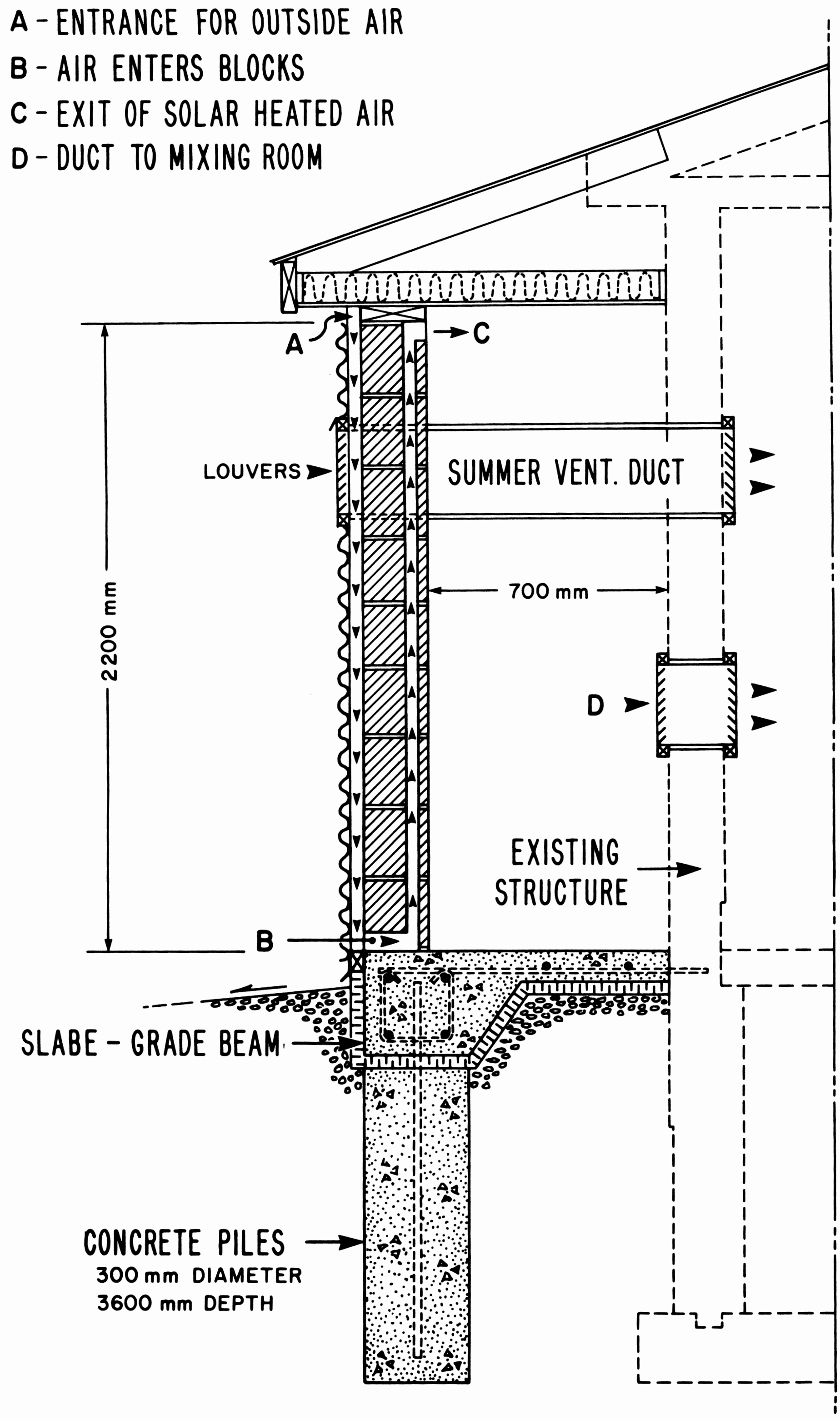

Figure 1. Solar collector/storage wall.

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 × 200 × 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 anenometer. A star-type pryanometer 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)

	Annual	Mid-October to mid-April	Percent
Sunshine hours	2453	827	34
Solar heat on vertical south-facing wall (kWh/m^2)	1530	755	49

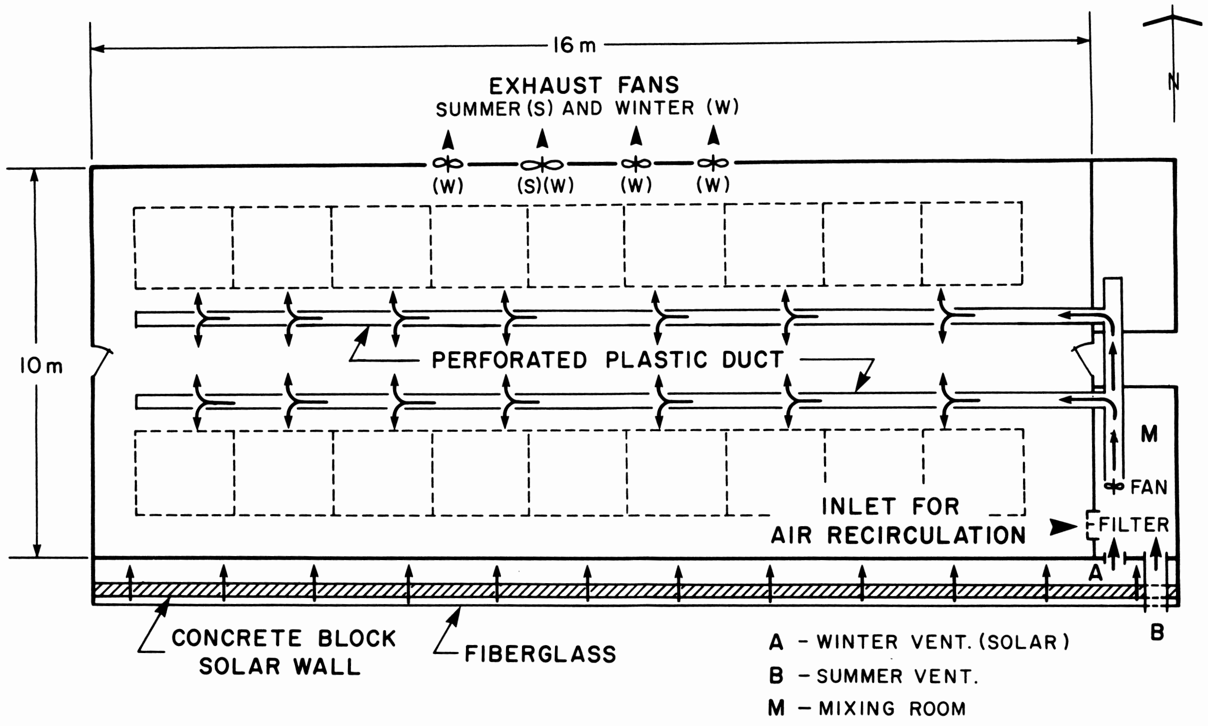

Figure 2. Plan view of the farrowing barn.

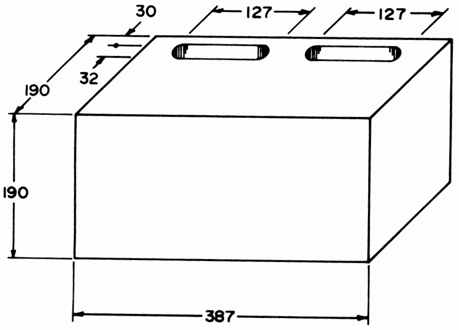

Figure 3. Semi-solid concrete blocks; dimensions are in millimetres.

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 (m^3/h)

d = averaged air density (kg/m^3)

C = air specific heat ($J/kg \cdot {}^\circ C$)

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.

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 II. SOLAR WALL PERFORMANCE, JANUARY TO MARCH, 1982

Period	Available solar energy (kWh)	Collected solar energy (kWh)	Colection efficiency (%)	Supplemental heat (total) (kWh)	Solar collector contribution (%)
1982					
Jan.	2898	1990	69	7892	20
Feb.	4118	2064	50	2319	47
Mar.	4146	1908	46	942	67
Total	11 162	5962	55 (avg)	11 153	45 (avg)

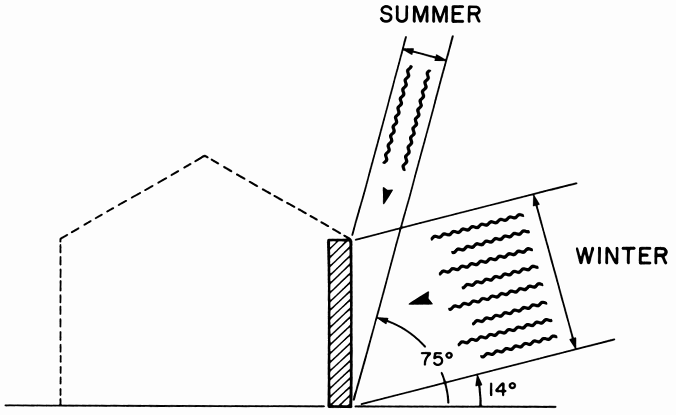

Figure 4. The sun's angle in relation to a vertical south-facing wall at Saskatoon in winter and summer.