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ADVANCED THERMAL SOLAR SYSTEM WITH HEAT STORAGE FOR RESIDENTIAL HOUSE SPACE HEATING

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ABSTRACT

Increasing energy consumption, shrinking resources and rising energy costs will have significant impact on our standard of living for future generations. In this situation, the development of alternative, cost effective sources of energy for residential housing has to be a priority. Designing energy efficient and affordable dwellings located in harsh climate regions like Canada, present significant challenges.
This paper presents the advanced technology and some of the unique features of a novel solar system that utilizes solar energy for space heating in residential housing and commercial buildings. The improvements in solar technology and integration of the solar system with the house envelope offers a significant cost reduction, to a level where the solar system can compete with the energy costs from existing sources.

In the year 2000, the Alberta Research Council Inc. (ARC) started to work on the development of thermal solar systems that were designed for application in residential housing for the purpose of space heating. As a result of this research activity, a cost effective thermal solar collector with direct heat storage (DHS) was developed and tested. During the last year, the prototype DHS solar system was installed on experimental shelter and extensively tested through the 2004-05 winter season.

ARC has conceived and proven a new concept that can collect solar energy and store the heat during the day and release the heat during the night. Conducted field tests in the winter season has demonstrated that DHS solar thermal panels can reduce space heating energy consumption by about 50% compared to traditional residential housing construction technology.

This paper delivers a description of the new solar technology and presents results of tests and performance evaluation.
Results of testing prove that this new technology could be implemented in a cost-competitive, environmentally responsible and sustainable manner.

INTRODUCTION

The peaking of the North American natural gas production in 2003 (ERA, 2004) presents a serious problem. North American natural gas reserves estimates now appear to have been excessively optimistic and North America natural gas production is now in decline (Hirsh, 2005). North America is moving to a period in its history in which it will no longer be self-reliant in meeting its growing natural gas needs. In Alberta, the production of natural gas achieved a peak in the year 2001. It is estimated that the remaining established natural gas reserves left in Alberta are sufficient for the next eight and half years only (AUB, 2004). In Canada, natural gas is the basic fuel used for heating in residential housing and commercial buildings. It is a time to stop wasting valuable and scarce resources of natural gas to produce heat that can be easily and cheaply provided by thermal solar systems. Under existing circumstances the development of alternative, cost effective sources of energy for residential housing has to be a priority

In Europe 40% of energy is consumed in buildings, more than by industry or transport. All over Europe a number of solar heat generation systems are on the rise. In Germany, which is the leading country, in 2004 the growth of the newly installed thermal collectors was about 750,000 m^2 with a total capacity of 525 MW (Stryi-Hipp, 2005). Solar thermal systems are installed on almost 20% of single family houses in Austria (Piria, 2005). However, in general the solar thermal systems market still remains in Europe at a very early stage of development. Globally, installed solar thermal systems capacity in 2004 was about 69 GW and presents one of the most important renewable energy sources worldwide.

The European Commission has presented its program and goals with respect to future development of renewable energy sources in the White Paper (Aitken, 1997). The strategic goal of the White Paper is to increase the market share of renewable sources of energy to 12% by the year 2010. In 2005 in Europe, to promote the thermal solar systems technology, a European Solar Thermal Platform was created. In Europe almost 50% of final energy consumption is used for heating purposes. In Canada, energy usage by residential and commercial buildings accounts for about 30% of the total consumed energy (Ayoub, 2000). Of the total energy consumption for an average Canadian house, 65% of energy is used for space heating, 20% for hot water generation and 15% in form of electricity. Hence, reducing energy usage for space heating, which takes the largest portion of energy, can make the greatest contribution to decrease the total energy consumption of Canadian houses. Table 1 shows the energy demand for a typical residential house in Canada and in Europe.

Table 1. Energy Consumption by Average Canadian and European Residential House

Energy usage	Canadian House*	European House
Space heating	65%	57%
Hot water generation	20%	25%
Electricity	15%	18%

** Average Canadian house consumes per year 150 GJ of heat and 26 GJ (7,200 kWh) of electricity (NRCan, 2002)*

In the past, the thermal solar market was dominated by domestic hot water systems, but recent years show the emergence of a new solar thermal system called a combi system. The combi solar system brings together the hot water generation and the space heating in one system. A typical hot water system size is about 5 m^2 whereas a combi system size ranges from 12 to 25 m^2.
The first industrial production lines for solar thermal collectors have just recently been completed, signaling the beginning of the solar industrialization era (Wittwer, 2005).

Besides hot water and space heating applications, process heat with a 200ºC temperature range, is a very interesting area for application. Large scale utilization of solar thermal energy systems is closely related with the availability of low-cost, effective heat storage systems. For effective heat storage a new system that applies phase change materials is under development.

As outlined earlier, existing natural gas proven deposits, at the current rate of production, are sufficient only for the next eight years. As a result a serious shortage of natural gas in the near future can be expected. Progress in solar modules technology and integration of the solar systems with improved house envelope offer, a significant renewable energy cost decrease to the level where the solar system can compete with the cost of energy from traditional sources of energy.

SOLAR COLLECTOR DESCRIPTION

In 2002, at ARC's lab, the first solar thermal collector with the ability for direct heat storage (DHS) was developed. A phase change material (PCM) with a melting/solidification temperature of 29ºC was used for heat storage. When the PCM undergoes the phase change, it can absorb or release a large amount of energy (~190 kJ/kg) as latent heat. The phase change material was introduced into the DHS collector in the form of a matt with PCM enclosed in the capsules. The DHS solar system generates and store on-site thermal energy for the purpose of space heating. During the daytime the wall installed DHS solar collector is charged by the sun and accumulates heat for the night.

The thermal solar collector with direct heat storage (DHS) consists of a thin solar radiation absorption layer combined with a PCM matt that is covered with a transparent cover as shown in Figure1. During the day, when the panel is exposed to the sun, the collector absorbs the solar radiation, generates heat and uses it for phase change material melting. During the night, the melted PCM solidifies and delivers heat that keeps the panel warm for a prolonged period of time, practically most of the night. The purpose of the DHS panel is to keep the outside wall temperature warm (over 20ºC), to prevent heat loss through the wall. There is negligible heat transfer and heat loss if the differential temperature is close to zero.

The DHS thermal solar collector is designed to be integrated with a house envelope and accumulate the thermal energy directly into the wall of the dwelling. The ARC manufactured DHS solar panel is shown in Figure 1b. In 2003, the prototype DHS collector was assembled as a stand alone movable module and tested over the winter period. Using a set of temperature sensors arranged inside the DHS panel, data on temperature distribution was collected and evaluated. A series of tests were performed at different levels of the solar irradiation and at different ambient temperatures. To perform an evaluation of the DHS system, two reference surfaces (black painted metal plate and standard vinyl siding) were also introduced into the testing system. An example of the results for the prototype DHS collector and reference walls is shown in Figure 2. As can be seen, the temperature of the wall equipped with a DHS panel even on a short, semi-cloudy winter day can be kept at over 20ºC through most of the night (until 7 am of the next day). The results proved to be very positive from the perspective of the system’s performance and thus validated further development the DHS solar system concept.

A solar collector with a direct heat storage system that utilizes the phase changing material, has a number of innovative aspects, including:

- No requirement for any circulating fluid system with pumps, pipes or heat exchangers. (This reduces system costs, simplifies installation and design requirements in new buildings and makes it feasible as a retrofit option for existing buildings.);
- Improvement of the thermal insulating capability of the wall that adds to the thermal mass of the wall thus stabilizing the wall temperature;

- Ability for heat storage not only makes it possible to maximize solar energy capture and utilization during winter-time, but also has the ability to prevent overheating during hot summer days, thus reducing the amount of energy required for air conditioning.

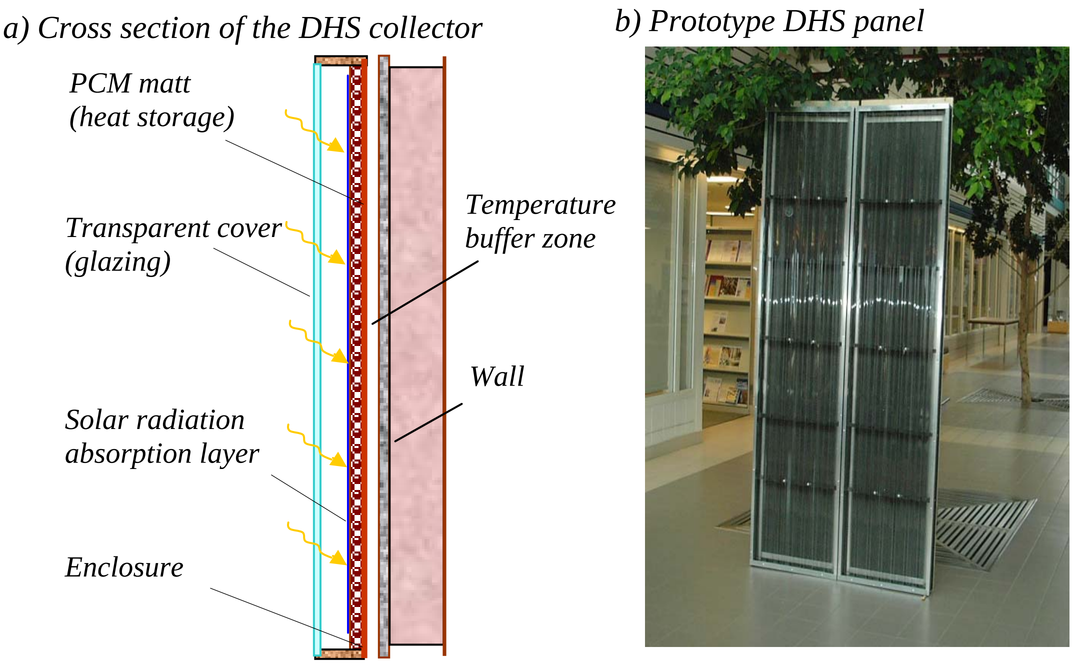


Figure 1: DHS solar collector concept and DHS panel applied for testing in the pilot-scale system.

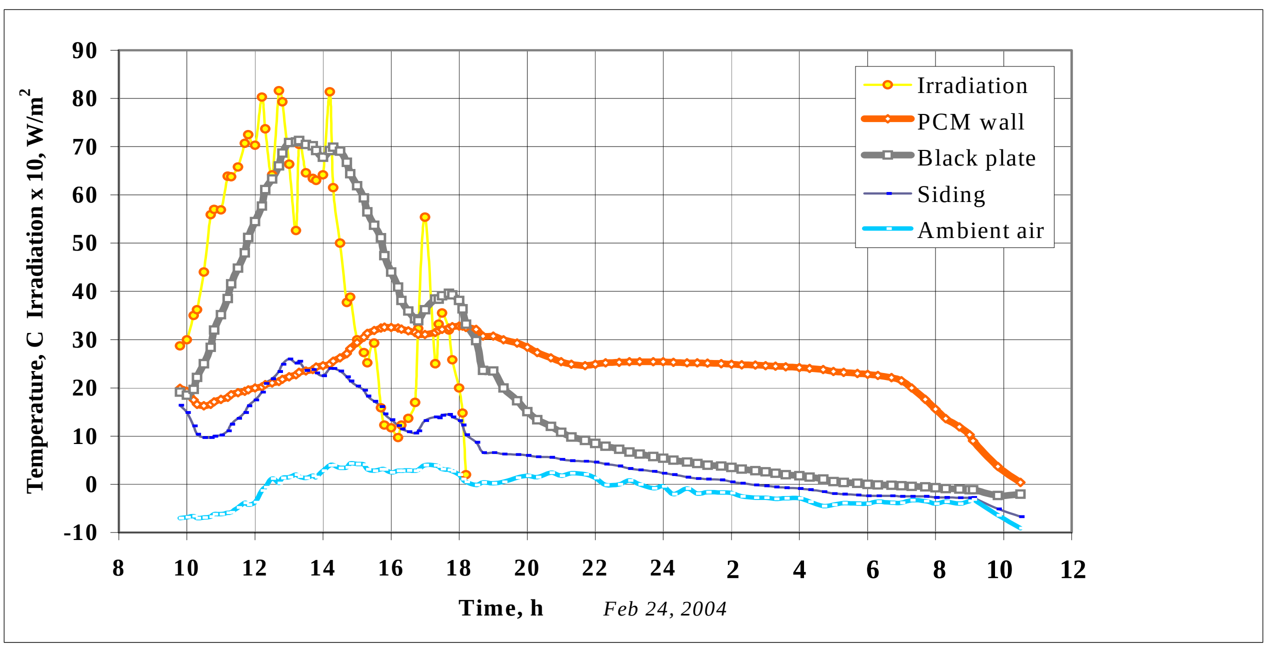


Figure 2: Temperature profiles for DHS solar collector and reference walls recorded over a 24 hour testing period.

DHS SOLAR SYSTEM OPERATION

The heat loss in houses and buildings is driven by the temperature difference between outdoor and indoor temperatures. The amount of heat transferred, except for differential temperature, depends on the quality of the thermal insulation in wall. In winter, the significant temperature differential drives the energy transfer out of the house.

The installation on the house walls of the DHS solar panels (see Figure 1 and Figure 3) forms a thermal buffer zone around the house. In winter, as a result of heat accumulation, the buffer zone temperature stays significantly higher than the ambient temperature thus reducing heat loss through the walls. However, the DHS system can block heat loss as long as the day-accumulated heat is available.

At the present stage of research, the stand-alone shelter with DHS solar collector was assembled as a prototype system (see Figure 3). Using a set of temperature sensors arranged inside of the DHS panel and across the wall, relevant data is collected and used for performance evaluation.

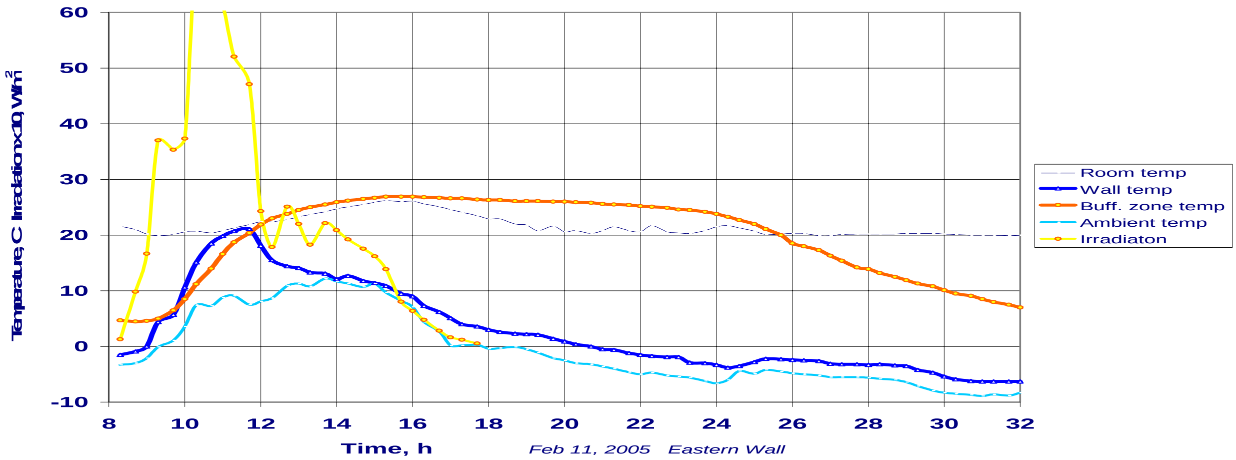
Figure 3: Experimental shelter for DHS solar system evaluation.

In the experimental system three walls of the shelter were equipped with DHS panels. In the current solar thermal systems practice, the east and west exposed walls, and their potential for solar energy collecting and utilization, are often overlooked.

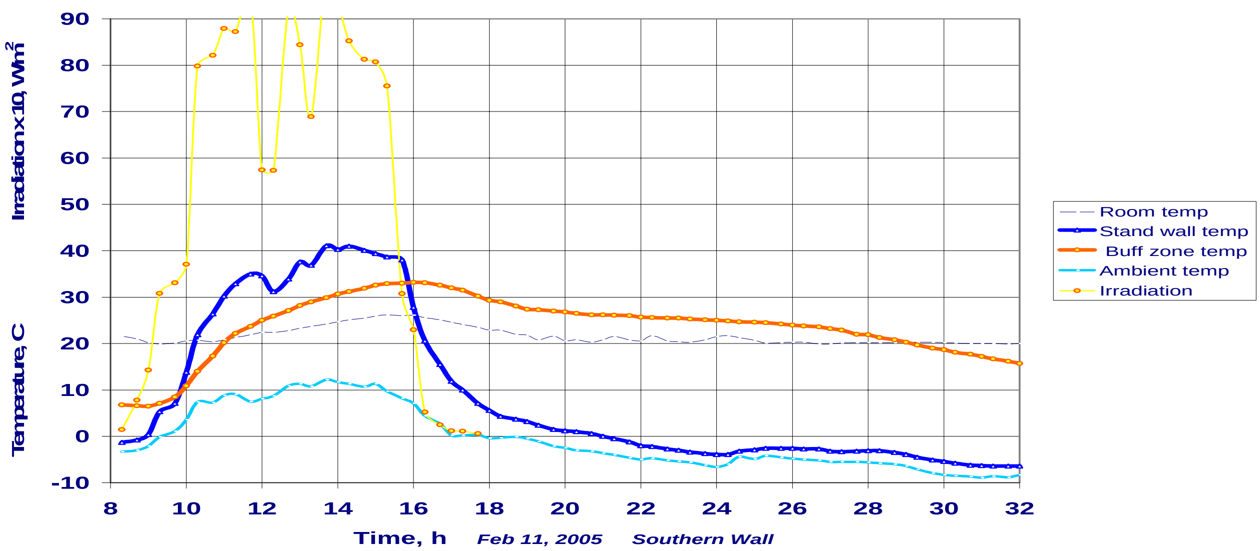
An example of buffer zone temperature changes during a 24 hour cycle for eastern, southern and western walls are shown in Figure 4. For purposes of reference the temperature of a typical house wall with vinyl siding is also presented.

Application of a three wall system significantly increases the heat gain potential as illustrated in Figure 5. The solar gain potential for walls changes throughout the winter season as a result of variations in the length of day and in the solar radiation incidence angle.

a) Eastern Wall



b) Southern Wall



c) Western Wall

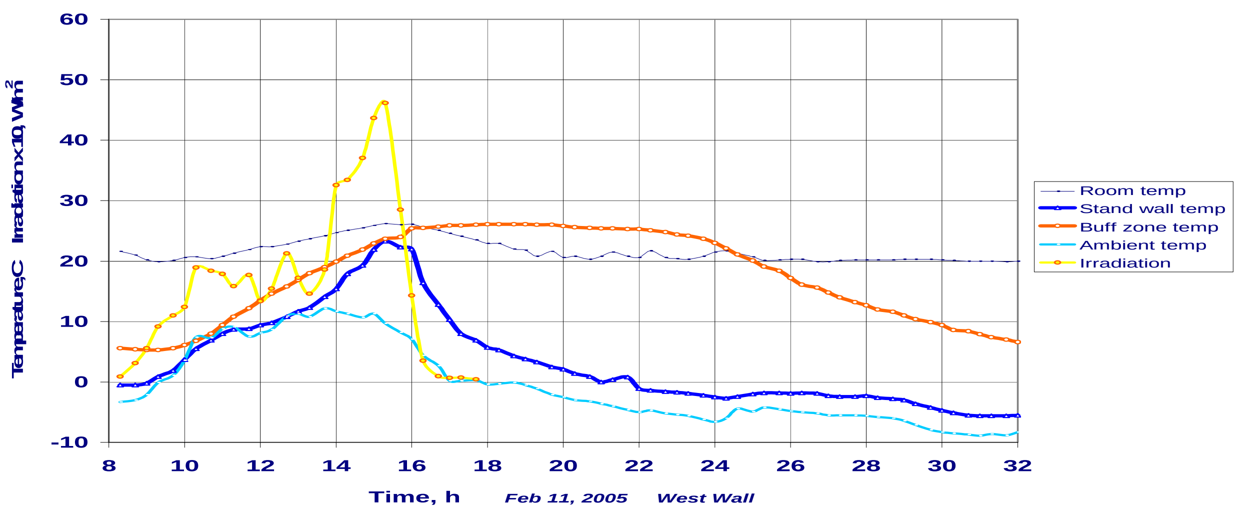


Figure 4: Examples of temperature profiles for eastern, southern and western walls.

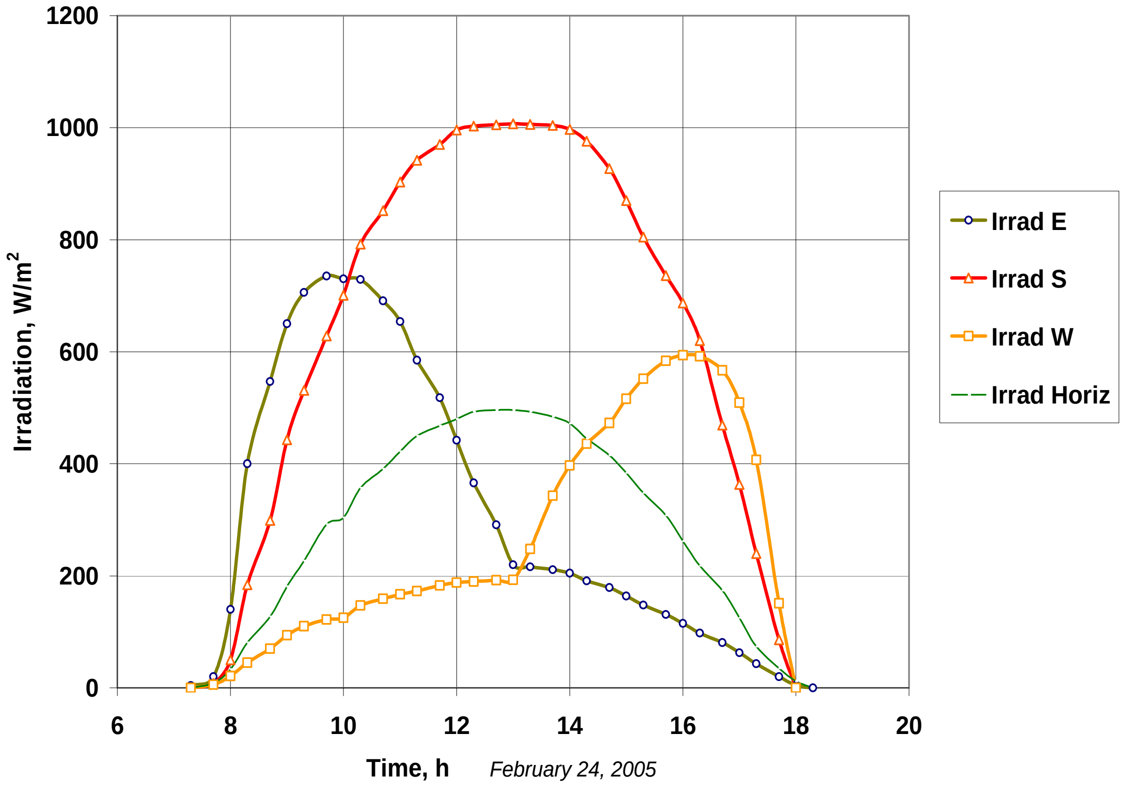


Figure 5: Solar irradiation and energy gain potential for east, south and west oriented collecting walls.

DHS SYSTEM PERFORMANCE EVALUATION

In the second phase of research, the shelter with a wall installed DHS solar system, together with two other similar size shelters, was tested over the whole winter period. The two other shelters were constructed using standard technology (stick frame and mineral wool) and SIP panel technology (structural insulated panel with styrofoam). These two shelters were used as a reference structures. Figure 6 shows the differences in the shelters wall structures. The thermal DHS solar system applied the ARC-developed solar DHS modules.

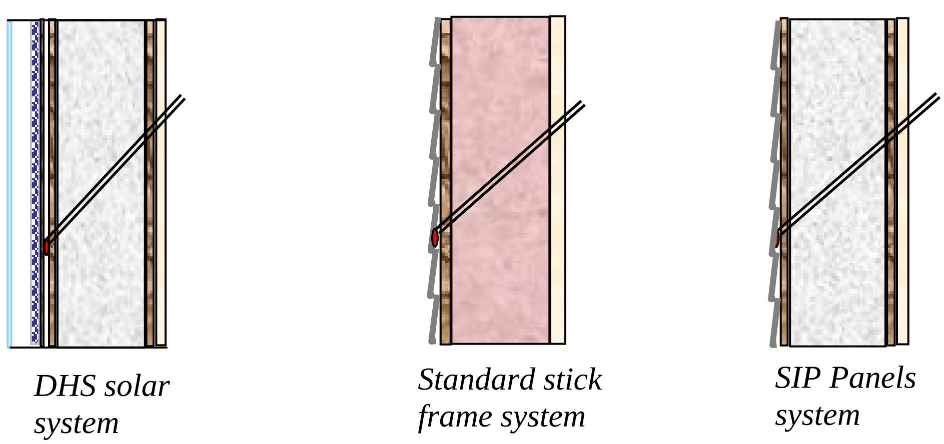


Figure 6: Wall structures for experimental shelters.

The experimental shelters, shown in Figure 7, were electrically heated and the internal temperature was controlled by thermostats set at 20ºC. During the 2004/2005 winter-season, a series of tests were performed at different weather conditions. The set of shelters operating at exactly the same conditions provide an opportunity to learn about performance under unbiased conditions.

Figure 7: Experimental shelters used for the DHS solar system performance evaluation.

Figure 8 shows the example of the data on energy consumption for the shelters tested. The reduction of the energy consumption on this day (Feb 28, 2005) was 66% for the DHS solar system and 32% for the SIP panels being referenced for a standard house solution. Data on energy consumption for different days recorded in February 2005 are presented in Figure 9.

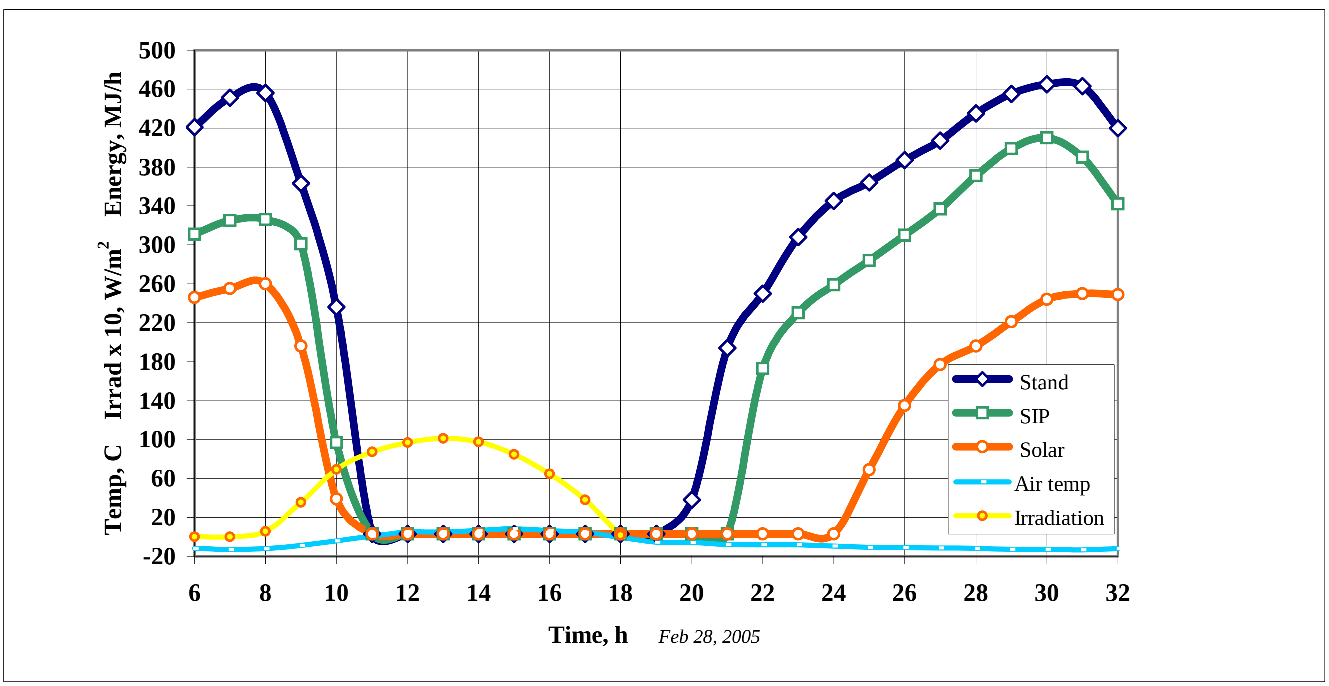


Figure 8: Energy consumption for space heating by pilot-scale systems (February 28, 2005).

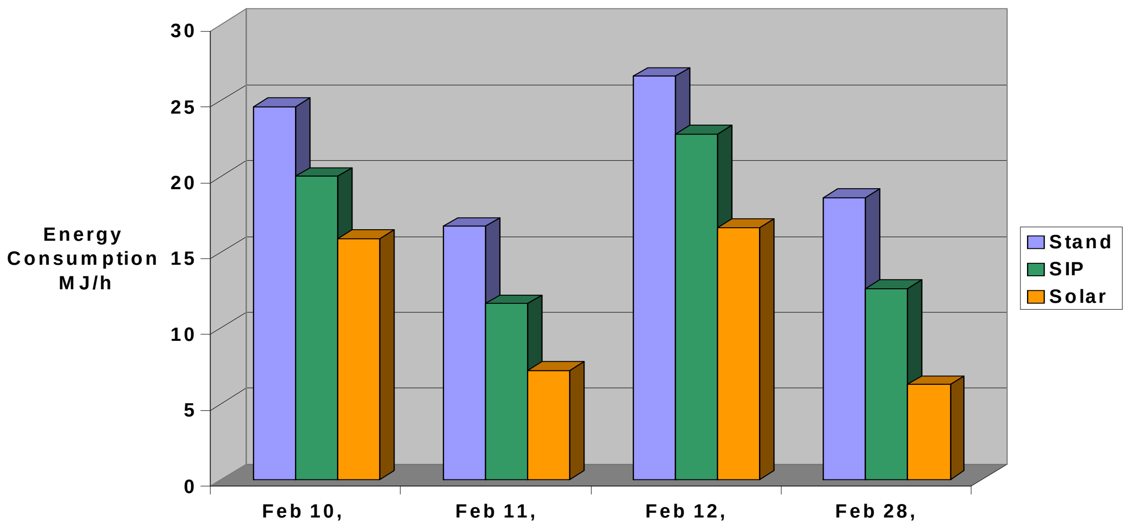


Figure 9: Examples of the systems performance (energy consumption) for space heating for different house models as recorded in February 2005.

SUMMARY AND CONCLUSIONS

The performed tests show that as a result of the DHS solar module application, during winter weather conditions, the house wall surface temperature can be kept warm for many hours after sunset, often until the early morning of the next day. Even on short winter days very positive results were obtained. Application of the DHS solar system in residential housing would result in a potential reduction in the natural gas consumption of this sector by about 50%.

The results of evaluation proved to be very positive from the perspective of the system's performance and thus validate further development of the DHS solar system concept.

The ARC research program encompassed development of a very efficient solar energy collecting and heat storage system, and a cost effective integration of solar systems with the house envelope. Although the potential of DHS solar technology has been demonstrated, further innovation will be needed develop the panels into a marketable product.

The DHS solar technology could have a number of significant implications for Alberta and Canada. First, it can lead to a significant reduction in energy consumption and greenhouse gas (GHG) emission from residential and commercial buildings in Canada. Because space heating is by far the greatest component of total energy consumption in the residential sector, the DHS solar system would have much greater impact than photovoltaic power and solar hot water systems. Second, DHS solar technology can also help to alleviate the pressure on natural gas consumption. It has been well recognized that North America as a whole has a great challenge to meet natural gas demand in the coming decades. Third, Alberta has large brine deposits that can provide a source for phase change material. That combined with a strong construction and building materials industry means that Alberta is well positioned to reap the benefits of the innovation described in this paper. The mining of the brine, materials processing, and product manufacturing related to DHS solar technology can have a significant economic impact to Alberta.

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