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LATENT HEAT STORAGE IN A HIGH PERFORMANCE PASSIVE SOLAR HEATING SYSTEM

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Abstract

Calculations have been carried out on a high performance passive solar heating element with heat pipe energy transfer for different storage concepts. It is shown that the need for a store is strongly dependent on the system in which the element is integrated.
The advantage of using a phase change materials as storage medium instead of water is small for this application.

1. Introduction

Within the passive solar approach, the direct gain and convective loop systems are the most simple and therefore cheapest solutions. These kind of systems, however, are characterised by high indoor temperature swings and high solar heat supply on the hours of least demand.
A thermal storage wall has a advantageous accumulation of solar heat which results in low temperature swings and a time delay between the absorbtion of solar energy and the heat supply to the building.
The main disadvantage of a conventional thermal storage wall, however, is the higher temperature of the solar collecting surface which in combination with the high thermal capacity of the wall can lead to considerable heat loss to the outside. Multi-glazing can limit this heat loss to a certain extend, but is costly. Movable insulation is also expensive, has a slow response and needs careful attention for a reliable and effective operation. Furthermore, the extra mass introduced into the building may sometimes lead to extra costs particularly in multi-story buildings and valuable space within the building is occupied by the system.

2. Aim of the project

This project aims to develop a passive solar heating system which has the advantages as mentioned above. This can be achieved by the introduction of two special components:

a. A thermal diode tube, which acts with small temperature difference already as a high performance thermal conductor. It transfers heat from the collector to behind an insulation layer, but does not transfer heat in the reverse direction. With a low capacity collector the system responds rapidly to changes in outdoor conditions, while needing no movable parts or manually or automatically operated control equipment.

b. The heat storage. The significant decrease in volume of 50 per cents can be achieved by using water instead of concrete. A further decrease in volume, which is strongly dependent on the temperature range over which the store shall operate, might be reached by using a phase change material.

3. System description

The design of the passive solar element is based on the following mechanisms (see figure 1):

- One glass pane cover (1).
- Small air gap.
- Absorber plate (2) to collect the solar radiation (spectral selective).
- S-shaped heat pipes as thermal diode tubes to transfer the absorbed heat through a insulation layer (3).
- A back plate (4) to distribute the heat from the diode tubes to the (latent) heat storage elements (5).
- An air cavity is formed with a common insulation sheet (8) to separate the system from the room.
- When the air cavity is open to the room, air flows under the buoyancy force through the cavity (7), thus transferring the heat from the storage material (6) to the room. The cavity can be closed when there is no heat demand.

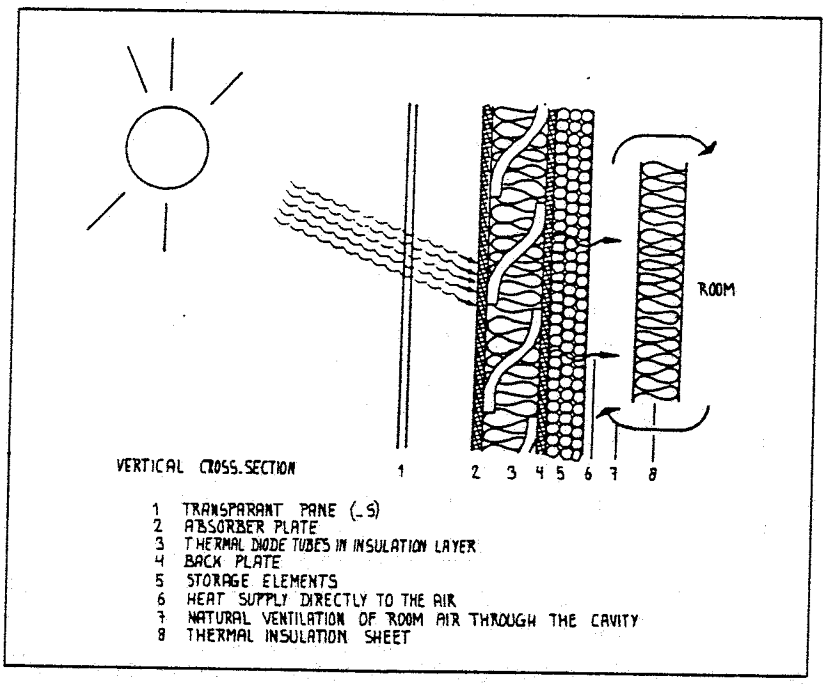

Figure 1: Schematic drawing of the high performance passive solar heating element.

The thermal characteristics of a heat pipe in inclined position can be shortly described as follows: the heat pipe is basically a closed hollow tube partially filled with a working fluidum, in equilibrium with its vapor. When the lower end is heated the fluid absorbs this heat by evaporating. At the - colder - upper end the vapor will condense and release the latent heat, the liquid will return to the lower end by gravity force. With reverse temperature difference the upper end will dry out and no heat transfer takes place in this element (thermal diode effect). The working fluid and the heat pipe tubing are chosen on the basis of the operating temperature and their mutual compatibility.

4. Optimization of heat store

The need for a heat store as part of the element is strongly dependent on the complete system or house for which the element shall be applied. No heat store shall be used for a badly insulated house for which the heat demand during the day is usually larger than the net gain through the windows. All collected energy can and shall be used directly. A heat store shall be integrated only if heat demand and heat supply are out of phase. The optimization of the dimensions of the store is strongly dependent on the other components of the complete element. The quality of the collector influences the optimum size of the store and the choice of the storage material. A high performance collector (high absorption, low emission) can operate over a relatively large temperature range without a significant decrease of efficiency. This results in a relatively large temperature range of operation for the store as well and a decrease in storage volume.

A collector with a lower absorption and/or a higher emission shows a decrease of efficiency already at lower temperature levels. Therefore, the store can be used only over smaller temperature ranges, resulting in the need for larger storage volumes. The interest for latent heat storage materials increases for decreasing temperature ranges for operation, due to a relatively larger reduction of the volume.

The storage volume and material is influenced as well by the heat exchange capacity rate for discharging the store. Larger temperature differences are needed for a poor heat exchange to have sufficient heat in the house.

A storage material with a transition of phase just above the room temperature requires a much better heat exchange from storage material to the heat transfer fluid (air) than a higher temperature phase change material.

4.1 Method

Detailed computer calculations have been done on the high performance passive wall element integrated in a house for three different heat demand patterns. The model calculates the heat demand of the house from ambient temperature, solar radiation, wind, insulation, net gain through

windows, internal heat gains, requested indoor temperature etc.
The performance of the store shall be influenced by the other components of the complete element. A realistic choice has been made of the dimensions of these components after a series of optimization calculations. These dimensions have then been taken constant for the variation of the measures of the store. A choice has been made for single glass, spectral selective coating on absorber (absorption of 0.95 and emission of 0.10), ten heat pipes per square meter collector surface and a variable store and a variable surface and heat exchange capacity rate at discharging the store.
The solar contribution, being the net gains of the element per square meter, has been calculated for different design concepts. The reduction of the heat losses through the wall, caused by the good insulation of the element, have not been added to the solar contribution. This is actually an extra gain. The heat demand of the good insulated house decreases with 8 kWh/m^2 and for the normal insulated house with 40 kWh/m^2 per heating season (see section 5.1).

5. Results

5.1 Results of the size of a water store

Calculations have been carried out on the influence of the size of a water store for three different demand patterns of the house:

I. Good insulated house, occupants absent during day-time.
II. Good insulated house, occupants at home during day-time.
III. Normally insulated house, occupants at home during day-time.

The size of the water store has been varied up to 80 litres per square meter collector surface, which is equal to an 8 cm thick water layer over the whole collector surface.
The total solar radiation on the collector surface was 470 kWh/m^2 over the heating season. Figure 2 shows the influence of the storage volume on the solar contribution of the heat demand of the house for the three demand patterns. Curve III shows that this normally insulated house has a high heat demand and that all collected heat can be used directly. A heat

store is not necessary here. Curves I and II show a large influence of the store. The solar contribution is 30-40 kWh/m^2 without heat storage, whereas it is increased up to 130-140 kWh/m^2 for a 40 litres per square meter heat store. The need for a heat store, dependent on the demand pattern is shown clearly.

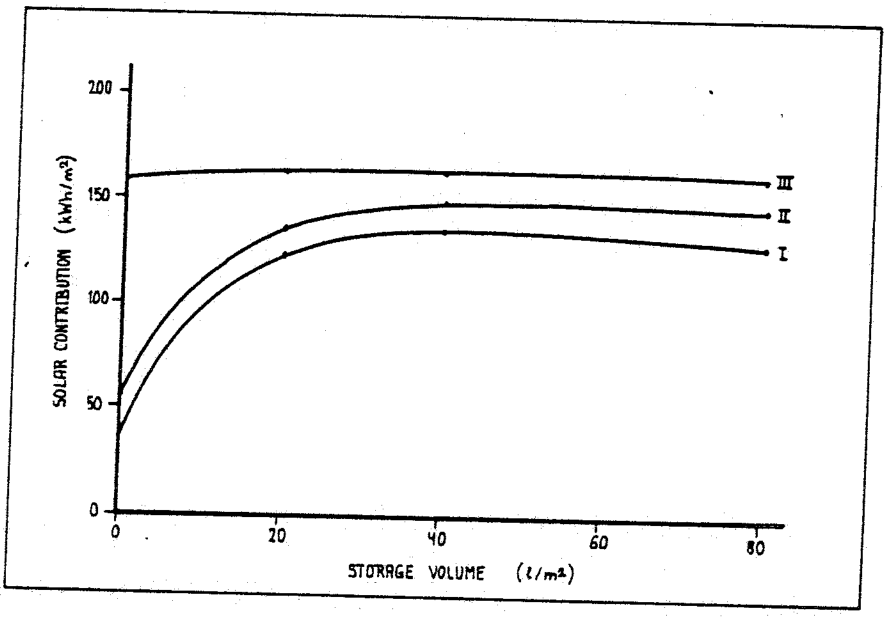

Figure 2: Influence of water storage volume on solar contribution for three heat demand patterns.

5.2 Results for different storage media

Calculations have been done on demand pattern I for water, paraffin waxes and salt hydrates. The used paraffin wax was Shell paraffin wax 52/54, with a transition of phase around 53°C. The influence of a 10 degree shift of the transition of phase to a higher and to a lower temperature level has been investigated as well. The used salt hydrate was from Dow Chemical with a transition of phase around 57°C. The influence of a 15 and a 30 degree shift to a lower temperature has been investigated as well.

The calculations have been done for a normal natural convective heat flow in the cavity for discharging, a two times better heat transfer from storage medium to the air (which can be achieved by using fins) and a five times better heat transfer (which can be achieved by using a ventilator).

The volume of the storage media has been varied.

Table 1 shows the solar contribution for different storage media and for different heat transfer coefficients from storage medium to air. The storage capacity was for each variant equal to the storage capacity over a temperature range of 20-80°C of a water store of 40 l/m^2. The temperature dependent storage capacity of the element filled with water, paraffin 52/54 and salt hydrate 57 is shown in figure 3. The volume of storage material is for paraffin 52/54 equal to the volume of water, for the salt hydrate a volume reduction of 30% occurs.

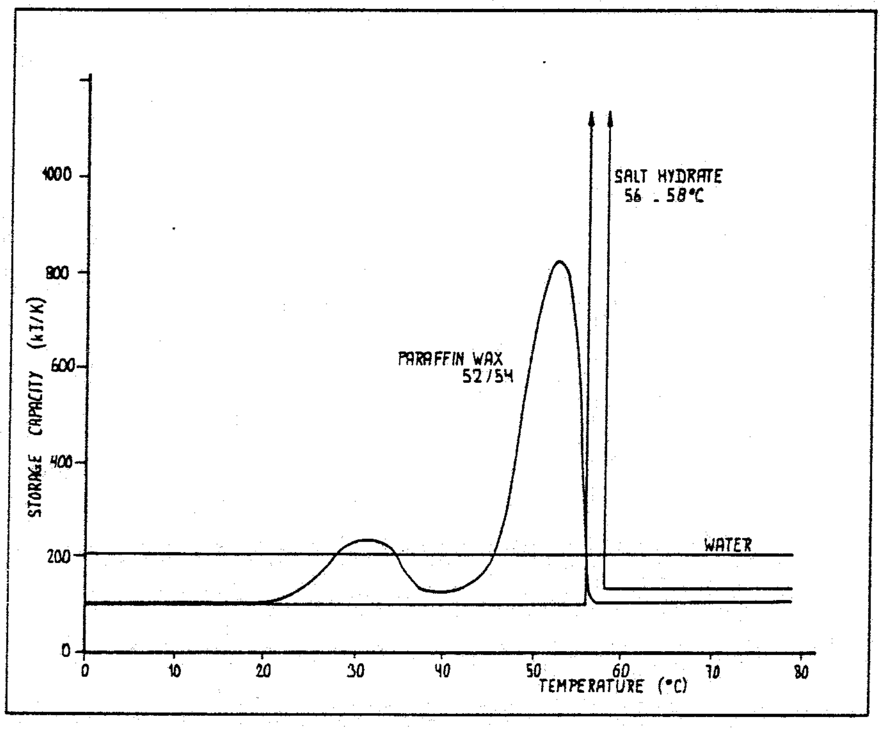

Figure 3: Storage capacity as a function of the temperature.

The use of fins increases the solar contribution with about 20 kWh/m^2 and therefore fins should be applied. An extra solar contribution of about 16 kWh/m^2 can be achieved by applying a ventilator, which shall not be cost effective.

Table 1: Solar contribution to heat demand (kWh/m^2).

storage material	heat exchange		
	"normal" (1x)	fins (2x)	ventilator (5x)
None	31	33	-
Water	116	135	153
Paraffin wax 63 (= 53+10)	122	140	150
Paraffin wax 53	119	141	157
Paraffin wax 43 (= 53-10)	111	138	158
Salt hydrate 57	121	134	141
Salt hydrate 42 (= 57-15)	119	143	155
Salt hydrate 27 (= 57-30)	104	123	150

It is shown that there can be a small advantage in using a phase change material. The lowest temperature salt hydrate (27°C) requires a forced convection for discharging (ventilator), the driving force for heat exchange (salt hydrate temperature minus room temperature) is too small for sufficient heat exchange by natural convective air flow.

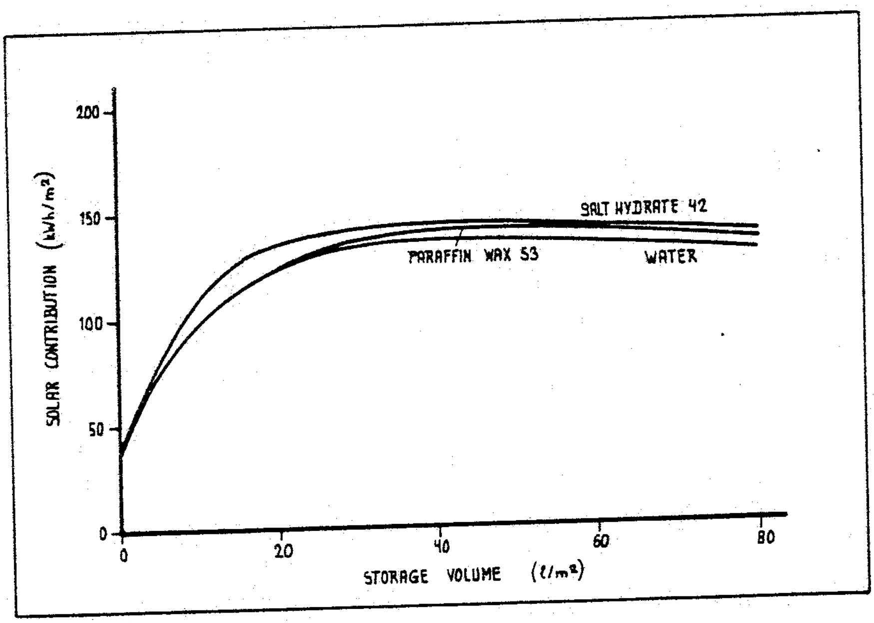

Figure 4: Influence of storage material volume on solar contribution for three storage materials.

Figure 4 shows the solar contribution for water, paraffin wax 53 and salt hydrate 42 as a function of storage medium volume.
A volume reduction of about 30% is possible when a salt hydrate is applied without a decrease of the solar contribution.

Concluding remarks

The need for a store, dependent on the heat demand is shown. The advantage of using a phase change material for heat storage in this particular application is small, since the temperature range over which the store can be used is in the order of 60°C. Only a small volume reduction of about 30 percents is possible by using a salt hydrate. No significant volume reduction can be achieved for paraffin waxes.
The use of a phase change material shall not be cost effective for this particular application.