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ACTIVE AND PASSIVE: CAN WE USE THE SAME STORAGE ?
A CASE STUDY

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ABSTRACT

The original feature of a prefabricated solar house, which has been analysed with the help of a dynamic simulation programme (TRNSYS 14.1), is to use the massive concrete internal walls both as a radiative element and a heat storage capacity. Heat distribution pipes embedded in the core of the walls can thus make the active solar system more simple. It has been demonstrated in a previous study that the increase of the solar collector surface leads to a non-linear growth of the solar fraction which tends toward an upper limit; this limit depends on the total walls' mass. In this study, we show that a 14 cm thick wall is optimal; a thicker wall does not bring any further auxiliary energy consumption reduction. Moreover, it seems that it is not useful to embed the pipes more than 8 to 10 cm inside the wall. There is thus effectively an optimal wall configuration for such a concept.

INTRODUCTION

A concept of a prefabricated solar house has been proposed by the firm Prefatech SA, Switzerland. This well insulated house ($U_{wall} = 0.25$ W/m^{2}K, $U_{windows} = 1.6$ W/m^{2}K) made of heavy precast concrete parts offers a large window area on its South face and an important (20 to 30 m^2) solar collector area on its roof; it is thus designed to efficiently use both passive and active components of solar energy. Its original feature is to use the massive internal wall as radiative element and heat storage capacity; heat distribution pipes embedded in the core of the walls can thus make the active solar system more simple and the investment cost lower.

In a previous study [Fromentin et al, 1996] it has been shown that, in the climate of the Swiss Plateau, it is not possible to reach a solar fraction much higher than 65% with this concept; the limitation is principally due to the limited heat storage capacity, i.e. the total mass of the walls.

The idea of this work was to try to improve this solar fraction (or to minimise the auxiliary energy consumption) and more precisely, to assess the influence of the wall parameters (thickness, embedded tubes position). Indeed, since both active and passive components of the solar energy collection system have to share the same storage capacity, a « conflict » appears between both of them. This situation gives rise to an optimisation potential.

The dynamic simulation model TRNSYS (version 14.1) has been used for this study, in combinaison with a special application of the multizone building model, able to tackle the dynamic behaviour of such a wall storage capacity.

DESCRIPTION OF THE ENERGETIC SYSTEM

The previous work [Fromentin et al, 1996] has been conducted on the house described in figure 1, and located on the Swiss Plateau (Taverage = 10°C, $G_h = 1300$ kWh/m$^2 \cdot$ year).

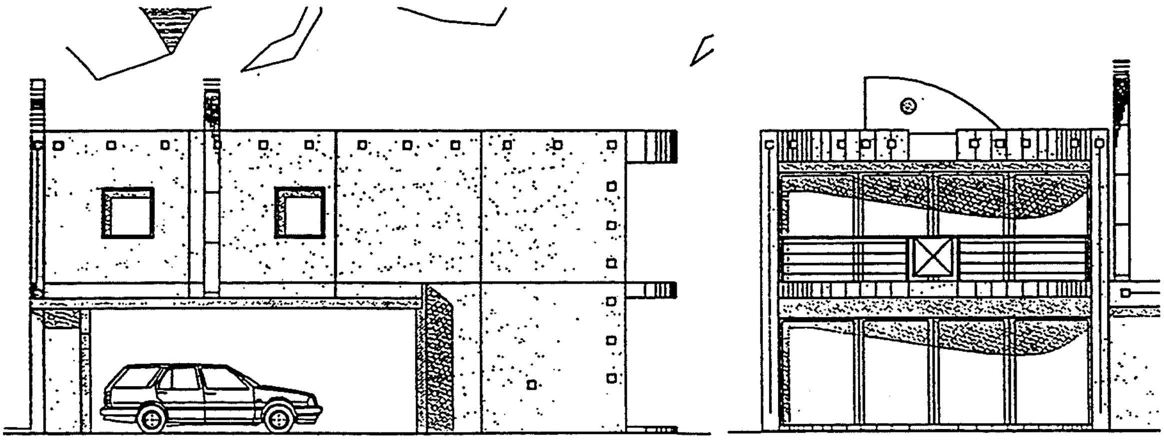


Figure 1: West and South fronts of the Prefatech solar house

30 m^2 of flat plate collectors ($\tau\alpha = 0.86$ [-], $F_R U_L = 4$ [W/m$^2 \cdot$ K]) are placed on the roof and a heat recovery system is installed on the exhaust air pipe (mechanical ventilation); having a heated floor area of 152 m^2, the energy consumption index for space heating does not exceed 15 kWh/year·m^2. Compared to the Swiss standard (in 1996) of 110 kWh/year · m^2, the house shows itself to be very efficient.

For the present study, the same house was used but, in order to simplify the analysis, solar energy has been used for space heating only, and not for hot water production.

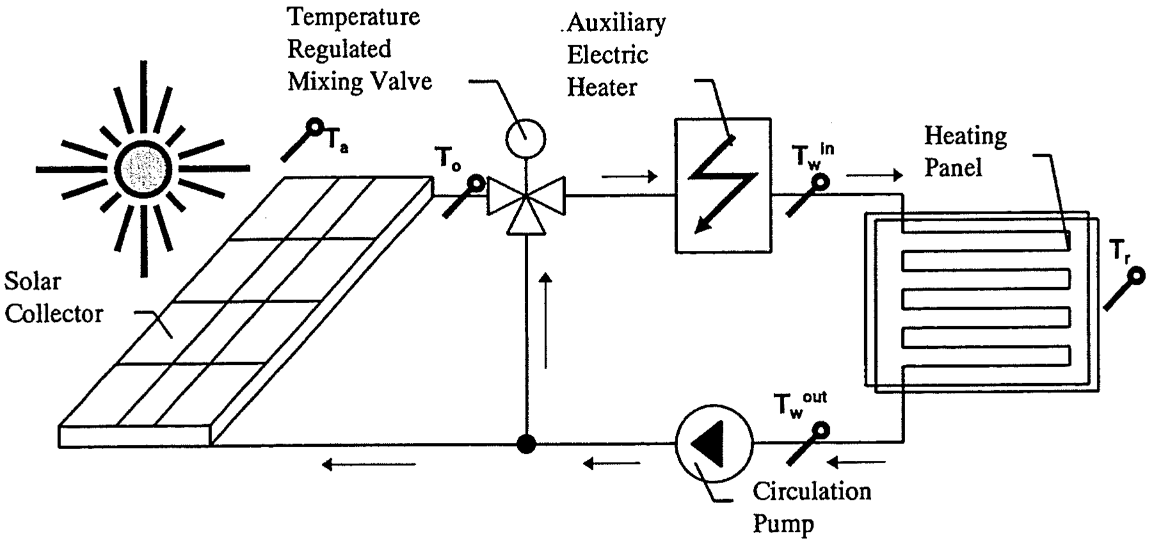
The inner part of the walls (167 m^2) is used both as radiative surface and heat storage capacity; 835 [m] of tube ($\emptyset$ = 17 mm) are embedded in the concrete. The system is voluntary very simple; no heat exchanger or heat storage tank are used (see figure 2).

The passive component of the solar energy enters the house through 26 m^2 of double glazing windows (g = 0.63 [-]), from which 21 m^2 face South; large overhangs protect the house during the summer. The other internal gains have been distributed during the day according to a realistic schedule, with an average value of 5 W/m^2.

The mechanical ventilation is equipped with a heat recovery system ($\eta \cong 75\%$); this corresponds to an equivalent air change rate of 0,2 [h^{-1}].

The solar collectors are operated as long as solar gains can be collected, but only if the room air temperature T_{int} is below 21°C. The auxiliary heater, placed in series after the solar collectors, supplies heat if the inlet fluid temperature in the walls is lower than the set point temperature, which varies between 20 and 30°C in relation to the outdoor air temperature. The auxiliary heater is stopped if the room air temperature exceeds 20°C, and is not started-up until this temperature decreases to 18°C.

The final layout of the simplified simulated system is shown in figure 2.



T_a	- ambient (outside air) temperature
T_o	- temperature of heat carrier from collector
T_r	- room temperature
T_w^{in}	- panel inlet fluid temperature
T_w^{out}	- panel outlet fluid temperature

Figure 2: Description of the simplified simulated system

SIMULATION MODEL

The simulation tool TRNSYS [1996] was chosen. Its modular and flexible structure allows the simulation of the whole system, including the interaction between the solar collector and the thermal behaviour of the house.

The problem of modelling such a system as described above could be divided into two parts. The first part deals with the influence of the dimensions and disposition of the pipes in the heating panel on the heat transfer inside the slab; it has been solved with an analytical approach proposed by Koschenz and Dorer [1996]. The two-dimensional temperature field in the plane of the pipes is replaced by a uniform slab temperature T_m, which is used for the calculation of the heat transfer across the wall. A thermal resistance between the fluid temperature T_w and the uniform slab temperature T_m is calculated , based on the convective heat transfer in the pipe, geometrical aspects and thermal characteristics of the heating panel. The second treats the effect of the thermal mass of the construction, simulated with the help of heat transfer functions. This one-dimensional problem is solved in the standard multi-zone building model TYPE 56. The uniform slab temperature T_m is simulated with a « virtual » zone located in the plane of the pipes (see figure 3).

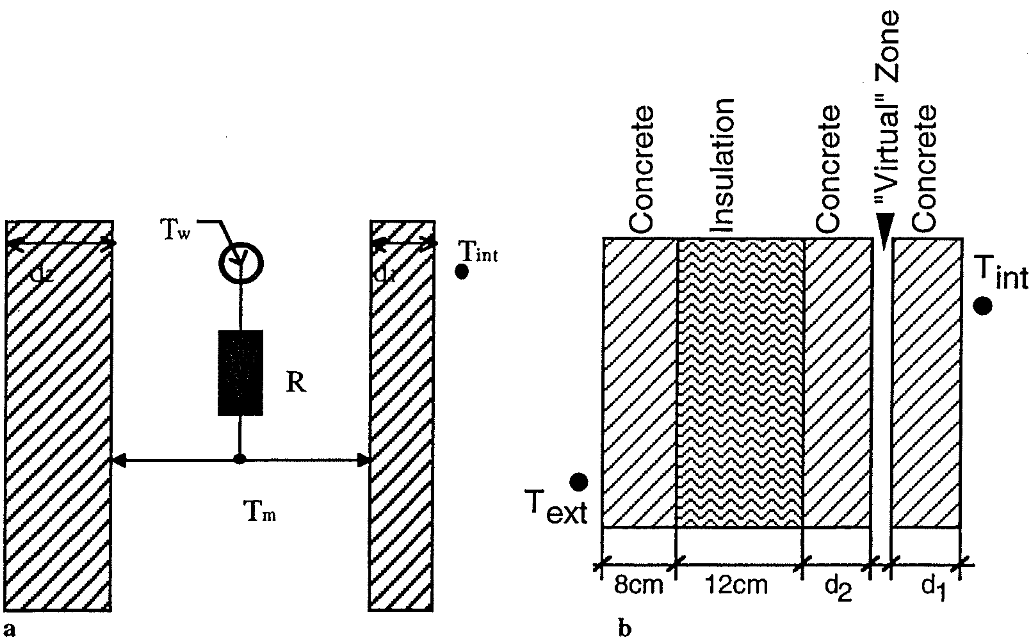


Figure 3 : a. Simplified one-dimensional model for the calculation of the heat transfer through the slab
b. Heating Panel Model as defined for TRNSYS

SIMULATION RESULTS

First of all, the simulation results show that the concept of the solar house is feasible; the ambient air temperature inside the house always lay inside the comfort-zone range when proper controlling schemes are used. Moreover, the fluid temperature of the heating system ($\cong T_0$) is always very low, around 25°C, even during the winter; this has a very beneficial effect on the overall efficiency of the system.

Two distinct runs of simulations have been conducted; the set A to evaluate the influence of the wall thickness and the set B to look at the influence of the embedded pipes position in the wall.

Results of set A can be seen in figure 4; the annual auxiliary energy consumption, the active solar heat and the passive solar gains are shown in relation to the wall thickness. The inner wall thickness varies from 6 to 20 cm, with the embedded pipes always situated in the middle.

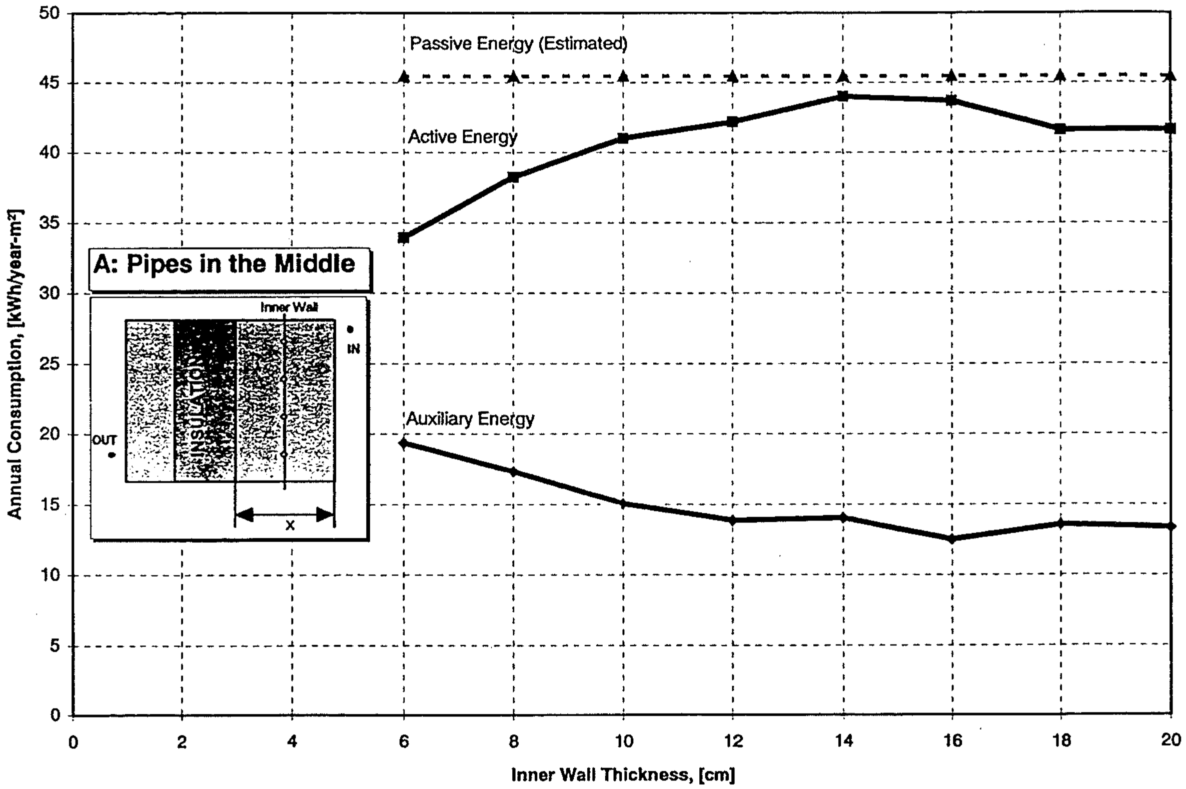


Figure 4 : Annual auxiliary energy consumption and active and passive solar energy use as a function of the inner wall thickness; the tubes lay in the middle of the wall. The passive component is estimated from the solar energy entering the house with a utilisation factor of 1

As expected, the utilisation of the active component of the solar energy increases with a growth of the wall thickness. It appears however that after a certain point (around 12 to 14 cm), a further increase of the wall thickness does not bring any reduction of the auxiliary energy consumption.

Concerning the location of the pipes in the wall (simulation set B, inner wall thickness = 14 cm), the results are less obvious (see figure 5); however, we can observe a tendency toward a minimal annual auxiliary energy consumption for tubes embedded 8 to 10 cm inside the wall.

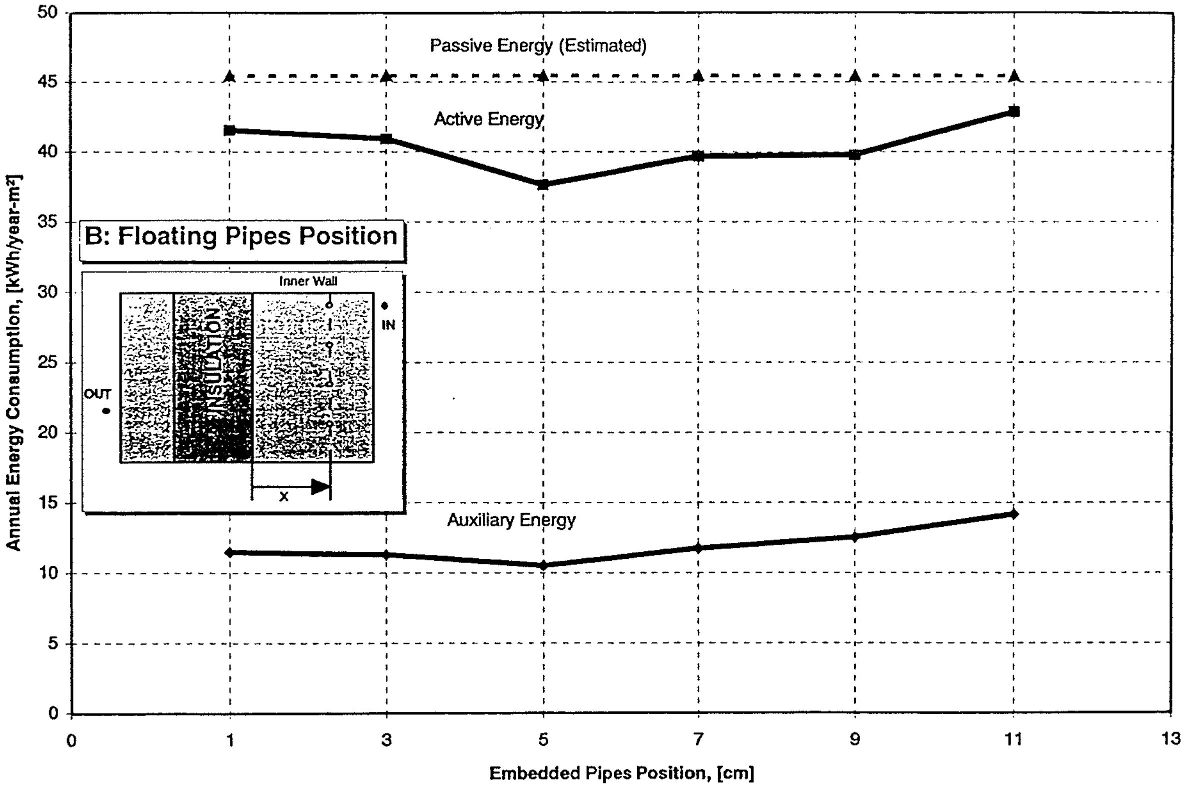


Figure 5 : Annual auxiliary energy consumption and active and passive solar energy use as a function of the embedded pipes position (inner wall thickness = 14 cm)

The peaks observed at some points on the figures are probably due to calculation round off linked to the simulation time step.

DISCUSSION AND CONCLUSIONS

Yes! If we recall our very first question, it is possible to use the same storage for both active and passive components of the solar energy.

In our specific case, it seems that there is an optimum of the inner wall thickness around 14 cm; below this value we can not optimally use the active part of the solar energy (storage capacity too small) and more concrete does not further reduce the auxiliary energy consumption. Concerning the embedded pipes position, a distance of 8 to 10 cm inside the wall seems optimal, even if the effect there is relatively small. Thus, for this specific case, the « optimal » solution is a 14 cm thick inner wall with tubes positioned 8 to 10 cm inside the wall.

When analysing our results, some problems occur. For example, it is not possible to calculate directly the effectively used passive component of the solar energy; in the figures 4 and 5, only estimations of its magnitude have been shown, assuming an utilisation factor of 1. This last assumption is probably optimistic, especially in the case of a thin wall and when the embedded pipes are close to the surface. Another problem is caused by the fluctuating total heat demand due to varying heat losses through the walls; indeed, the embedded pipes' position and, more important, the fluid temperature of the heating system vary and have an influence on these losses. Thus, strictly speaking, the conflict passive-active has not been studied but evaluated.

Since this work is only a case study, these results can not be extrapolated or transferred to other configurations without a thorough examination.

In such a concept, it has appeared that the control strategy is a dominant factor, probably more than the wall thickness. This is one reason why the active solar system is so effective; since we do not produce hot water, the working temperature of the system is always very low, providing good efficiency of the solar collectors.

With this work, we have shown that we are able to relatively well simulate the behaviour of such a solar concept. However, we do not claim that all the different phenomena such as, for example, the conflict between the passive and the active components of the solar energy inside such a wall are mastered. There still remains a great deal of research to be carried out.

Taking into account the hot water preparation as well as comparing our results to a more classical active solar system, having its own heat storage in a water tank, are future examples of research possibilities.

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