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Comparison of various solar walls by simulation

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Abstract

The aim of the study is to evaluate the energetic performance of solar walls for the French climates and to compare various designs: Trombe walls with internal or external air circulation, preheating of the ventilation air, capacitive or light masonry.

For this evaluation, the simulation was chosen in order to model the dynamic behaviour of the building. Many runs were necessary for the sensitivity studies, so we decided to use the simplified simulation tool COMFIE, which was validated against the European program ESP.

The results of this study will be applied for a demonstration project including four passive solar and two active solar houses (architect: Jacques Michel). This experimental process is supported by the AFME, in the frame of a German-French cooperation project.

1 The passive solar design tool and its validation

COMFIE is a design tool for passive solar, including a simulation module and an expert interface. This tool is based upon an object oriented programming, which allows a user, not necessarily familiar with modelling, to describe a project on a computer: the concepts correspond to the real objects (materials, walls, windows,...).

Thanks to pointers, it is very easy to modify, replace, add or suppress any object in the structure. Such possibilities are quite adapted to the comparison of alternative designs. A first prototype of "expert interface" chooses the appropriate level of complexity for the calculations, analyses the results and may propose some modifications to the project, which the user may test or reject.

The model reduction technique used, based on the modal analysis, allows to simulate a multizone building on an AT computer or a Macintosh, within a few minutes per zone. Performing a simulation, the user can estimate the heating load during a reference year and study the thermal comfort in summer, a good image of which is given by histograms.

Each assumption of the simplified simulation has been validated separately by comparison with the European detailed model ESP: neglecting the thermal inertia of the TIM (transparent insulation material), combining convective and radiative exchanges into a single surface heat transfer coefficient, diffusing the solar radiation entering the building through the windows/tim, reducing the model and considering a simplified description of the climate (Short Reference Years). In both programs, the transparent insulation layer of a wall is modelled rather simply, by a global heat loss coefficient and a heat gain factor in terms of the angle of incidence. The objective is not to study the TIM itself, but to evaluate the yearly heating load of the building and the thermal comfort in summer.

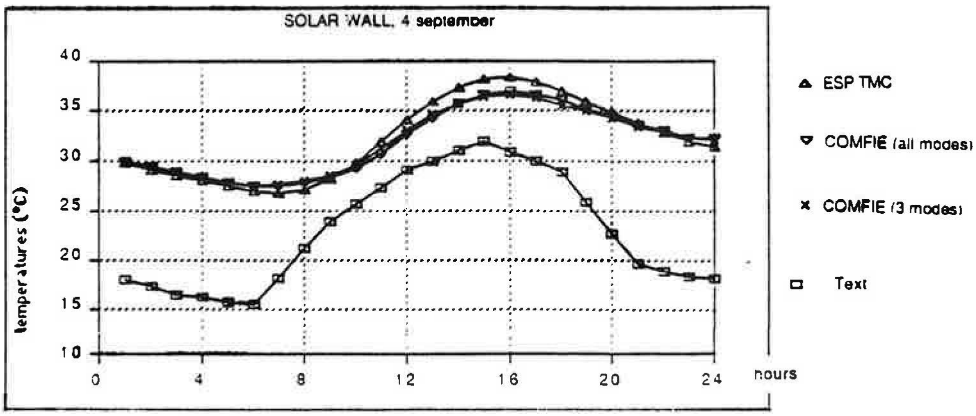

fig. 1 : Temperature profiles using ESP and COMFIE (reduced and unreduced models)

Table 2 : Productivity of the solar walls in kWh/(m2.year)

case	PARIS	CARPENTRAS	NICE
1 Collector storage	180 (165 = Nancy)	240	180 (320 = Alps)
2 Window	170	220	165
3 Trombe ext.	175	235	180
4 Trombe int.	150	195	160
5 Air collectors	210	215	155

In conclusion, the most propitious climate in France corresponds to the mediterranean Alps, where both the solar radiation and the heating demand are high. Preheating the ventilation air provides a good efficiency, but there may be a problem of filtration. The aerogel doesn't bring much for this application, because the reduction of the heat losses is balanced by the lower solar transmissivity. But this conclusion can be changed if the properties of such materials evoluate. If the opaque insulation of the house is external and if the thermal inertia is rather high, direct gain systems offer a reasonnable productivity.

The interest of the Trombe wall with internal air circulation is to avoid the external roller blind. In summer, the air flow can be stopped and the internal opaque insulation can protect from overheating, especially if the wall is protected by an horizontal overhang. This system may be an alternative to the sophisticated control of a shading device: the control of the air flow has an immediate effect, there is no need of a predictive control. In winter, the inverse air flow can be stopped, but according to simulation results, the minimal temperature in the air space is 15°C: the negative heat flux in the TIM walls is very low, even if the U value is not as high as using the same thickness of opaque insulation.

On the other hand, an active system may have a better productivity: the heat is transmitted by an air flow into the center of the house. The losses are lower than if the solar gains are absorbed and stored in the outer skin, even if protected by a TIM. A higher productivity is hoped, the first calculations give 220 kWh/(m2.y) in the east of France, using 5 cm TIM on the roof (cf fig. 4). But the control of such a system must be carefully designed. Here also, the air collector must be well insulated from the house and highly ventilated in summer in order to prevent from overheating. Inverse thermosiphon flow must be avoided in winter.

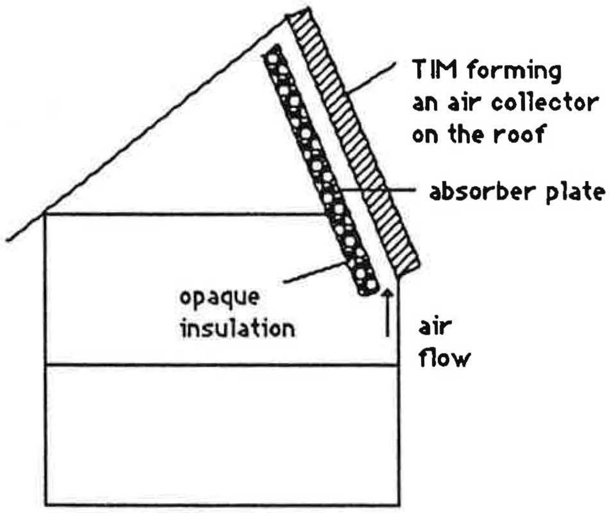

fig. 4 : Description of the active system using TIM on the roof

Perspectives and demonstration project

Six houses will be built in the east of France (Mouzon), in the frame of a solar social housing project. Four houses are passive, including Trombe walls with an internal air circulation. Two houses are active, solar air collectors being formed by a TIM roof. In each of the three groups of two houses, a reference house including standard polycarbonate material is compared with a TIM house. Compared to a reference opaque insulated house, the 14 m2 TIM walls should save about 40% of the total load. The energetic interest as well as architectural and building aspects of TIMs will be evaluated by an experimental follow-up, conducted by both French and German institutes.

examples of the figure 3). The productivity is calculated by comparison with a reference building, where the U-value of the walls (opaque insulation) is 0,75 W/(m2.K). This corresponds to the U-value considered for the solar wall with 10cm polycarbonate honeycomb instead of the opaque insulation.

Table 1 : Influence of various parameters on the productivity of a TIM wall

Sensitivity in %	-40% -25% -10% 0% +10%
TIM transmission (ref 0.78)	0.70 … 0.86
TIM U-value (ref. 1 W/(m2.K))	1.1 … 0.9
absorptivity (ref. 0.9)	0.6 … 0.95
thickness of the masonry wall (ref. 16 cm)	50 cm … 5 cm
material (ref. concrete)	aerated brick … magnesium brick
orientation (ref. due south)	west … south west
slope (ref vertical)	= latitude
area of tim wall (ref. 10 m2)	15 m2 … 5 m2
occupancy (ref. housing)	office … housing

Of course the productivity is no appropriate concept because it depends upon the reference building considered, but it gives an estimation of the energetic interest of TIMs in architecture.

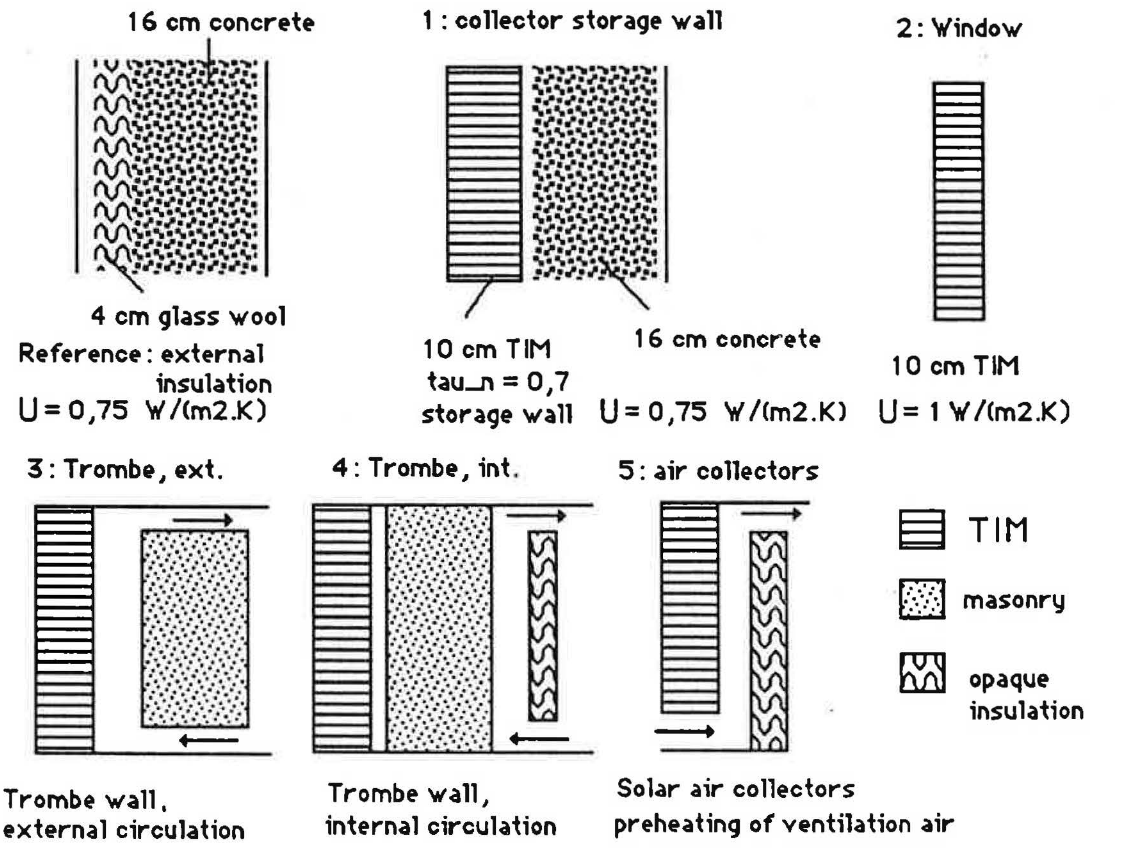

fig. 3 : comparison of various solar walls

Various validation studies were performed, e.g. versus experimental measurements on a PASSYS test cell at the University of Stuttgart. In a numerical validation work concerning the yearly heating load of a house or the productivity of a tim wall, the discrepancy between ESP and COMFIE stayed within a few percent. The reduction of the climate (two representative weeks per season) has little effect on the global heating load, but 10% discrepancy was observed on the productivity. As an example, the temperature profiles obtained for the hottest day without solar protection is given in fig. 1 above.

The evaluation of the summer comfort can be represented by temperature histograms, giving for each temperature the number of hours during which the building is at this temperature. Reducing the climate may change the critical period considered but using the same climate (Test Reference Year), both programs give similar results (cf fig. 2). Compared to ESP, COMFIE underestimates slightly the overheating.

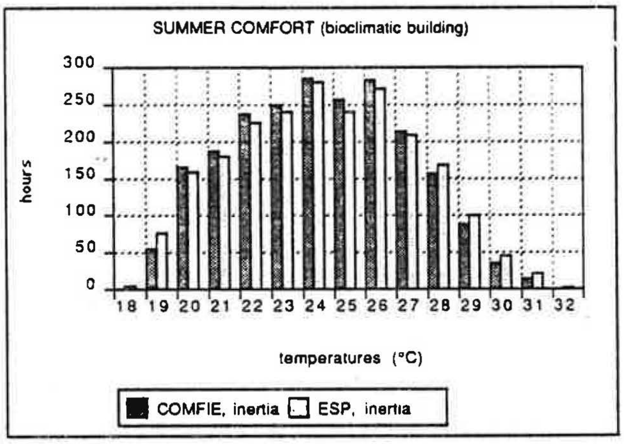

fig. 2 : Temperature histograms obtained using ESP and COMFIE

2 Sensitivity study on a collector storage TIM wall

Considering a TIM collector storage wall, a sensitivity study was achieved in order to evaluate the effect of various design parameters on the productivity of the wall.

The TIM is modelled by a U-value of 1 W/(m2.K) accounting for the thermal bridge in the frame and the dehumidification air flow in the component. The transmission factor of solar radiation at a normal incidence, including the proportion absorbed and reemitted towards the inside, is 0.78 and its variation in terms of the angle of incidence is taken from IEA results. These values will be measured eventually at the CSTB (Grenoble) using a "megasphere" of three meters diamater, allowing to measure large size samples.

The reference wall is assumed painted black with an absorptivity factor of 0.9, varied between 0.6 (brick) and 0.95 (mat black). The thickness of the masonry has been varied between 5 and 50 cm. The material can have a high conductivity (magnesium brick) or a low one (aerated brick). The orientation, the slope and the area of the solar wall are also important. The reference building is a standard house in Paris (100 m2 living area). In an office building, the occupancy is intermittent (presence between 9h and 18h). The results are presented in table 1 hereunder.

There seems to be an optimal thickness of the masonry wall: a too thin wall does not store much energy, a too thick wall transmit less heat to the inside. But the effect of this parameter is rather low, which allows to use TIM in various retrofit situations. Though, a low conductivity material (aerated brick) reduces the performance. Large areas of solar walls offer a better solar fraction but a lower productivity per square meter. In an office building, the gain is smaller because the night restitution of the heat is not valorized.

3 Comparison of various solar walls

The collector storage wall described above is one possible design, but air circulation, like in Trombe walls, gives the possibility of various other designs.

The productivity of transparently insulated walls was calculated for various climates (from Paris to Nice), for several quantities and orientations of solar walls and various designs (see the