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# SUSTAINABLE ENERGY IN BUILDINGS BY CONTRIBUTION OF PASSIVE SOLAR WALL SYSTEM

BY

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**Abstract.** Due to the fact that the use and maintenance of buildings, in our country, absorbs about 40% of the entire energy consumption from primary sources it is important to consider this sector into the context of sustainable development. The sustainable development requires rethinking of the architectural concepts for the building in this regard.

If the use of solar energy means that significantly less fossil fuel will be consumed, solar systems must be readily adaptable to existing buildings as well as new buildings.

The paper presents some constructive solutions for building envelope, involving solar wall passive system, based on greenhouse effect, which was studied at the Civil and Industrial Buildings Department of our Faculty. Some passive system solutions were tested under real working conditions, through test-cells. In particular, paper reports the most meaningful aspects connected to the application of the system.

**Key words:** buildings; primary energy consumption; solar energy; passive wall.

## 1. Introduction

Opaque walls, and not only glazing, can collect solar energy. If a closed box glazed panel is fixed on the outdoor face of the wall results the simplest

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form of solar walls and the solar heat gain is amplified by greenhouse effect. Passive solar walls complement direct gains through glazing by delaying the energy transmitted thanks to their thermal inertia. This energy can be distributed into the heated room by simple heat transfer from the wall or also by air circulation.

The vertical glazed systems attached on the façades can be a benefit for the architectural aesthetics and improve the energy balance (in sense of smaller heat losses through the opaque envelope element). In addition, the thermal comfort conditions of the rooms behind the wall will have to gain.

More types of solar walls systems with different functional principles and energetic performances have been developed. The main of these are:

a) simple glazed box with locked air layer;

b) Trombe type, with thermal-drain-trap air circulation;

c) diode type, with forced air circulation;

d) glazed box with external air flux.

The simple glazed box with locked air layer passive solar wall system, even less efficient than the others, has more perspective to be used on large scale because its simplicity in construction and maintenance. Therefore, this system makes the object of the studies described in this paper.

## 2. Assessment Methodology

The analyses of the heat balance at the external face of the opaque reinforced concrete wall element will give an estimation of this system capacity to collect the solar energy (Fig. 1).

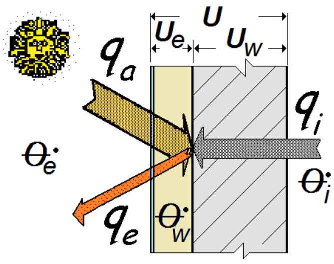


Fig. 1 – The heat balance on the absorbent face of the opaque wall.

In the hypothesis of stationary thermal flux transfer regime, some assumptions are admitted namely

a) energy is transferred through a unitary area of the wall, by conduction, from inside to outside face, with a constant flux density

$$q_i = (\theta_i - \theta_w)U_w, \quad (1)$$

where: $\theta_i$ is the indoor air temperature, $\theta_e$ – outdoor air temperature, $U_w$ – global heat transfer coefficient though the wall;

b) heat transfer through glazing into the building with the constant density ($q_a$) is proportional with the intensity of incident total solar radiation on the glazing ($I$), the glass transparency ($\tau$) and the absorption coefficient of the opaque wall face ($\alpha$)

$$q_a = \alpha\tau I; \tag{2}$$

c) heat loos to outdoor environment with a flux density

$$q_e = (\theta_w - \theta_e)U_e\,, \tag{3}$$

where: $\theta_w$ is the locked air layer air temperature, $U_e$ – global heat transfer coefficient though the locked air layer;

d) significant temperatures are: $\theta_i$ – indoor temperature, $\theta_e$ – outdoor temperature and $\theta_w$ – the mean temperature of the absorbent face of the massive reinforced concrete wall.

The energetic balance eq. for the external face of concrete wall is

$$q_e = q_i + q_a = q_i + \alpha\tau I; \tag{4}$$

finally it results that

$$q_i = (\theta_i - \theta_e)U - \alpha\tau I\frac{U}{U_e}, \tag{5}$$

where: $U_w$ is the global heat transfer coefficient for the wall, [W/(m$^2$.ºC)]; $U_e$ – the global heat transfer coefficient for the glazing, [W/(m$^2$.ºC)].

But

$$U(\theta_i - \theta_e) = q_w \tag{6}$$

represents the heat loss throw the whole wall system (opaque concrete wall plus air layer) without considering the solar radiation income. It results that the heat flux that goes outside throw the wall is equal with the heat loss throw the whole wall system minus the energy gain by solar radiation

$$q_i = q_w - q_s\,. \tag{7}$$

In other words, a *passive solar wall system* is characterized by the flux density of the wasted thermal energy

$$q_w = U(\theta_i - \theta_e) \tag{8}$$

and by the income solar energy gain:

$$q_m = \alpha\tau \frac{U}{U_e} I \,. \tag{9}$$

Nevertheless, the assumption regarding the stationary thermal regime is available just for a certain period of the day. In practice is used the mean intensity of the total solar radiation or with the whole solar energy received along 24 h. The mean solar energy contribution can be defined by

$$q_{sm} = \tau\alpha \frac{UE}{24U_e} \quad \text{or} \quad q_{sm} = \alpha\tau \frac{UI_{\text{med}}}{U_e}, \tag{10}$$

where: $E$ is the actual quantity of energy receipted by a unit surface in 24 hours (measured in W/m$^2$.day) and $I_{\text{med}}$ – the intensity of the solar beam (radiation) incident to the surface.

The solar wall system can be characterised by the ratio between the energy gain from the sun ($q_{gm}$) and the energy lost by the system ($q_{lm}$)

$$r = \frac{q_{gm}}{q_{lm}} = \frac{\tau\alpha \frac{UI_{\text{med}}}{U_e}}{U\Delta\theta_m} = \frac{\tau\alpha}{U_e} \cdot \frac{I_{\text{med}}}{\Delta\theta_m}. \tag{111}$$

The expression is a product of two factors

$$f_w = \frac{\tau\alpha}{U_e} \quad \text{and} \quad f_s = \frac{I_{\text{med}}}{\Delta\theta_m} \tag{122}$$

meaning that the efficiency of a solar wall system is given by the constructive features (as transparency of the glass, the absorption capacity of the wall surface, the thermal resistance of the glassing and air layer…) and also by the climatic characteristics of place where the system is used (the mean intensity of solar radiation, the mean temperature difference). The system is more efficient for a climate with sunny days but with moderate external temperatures or in period of transition between cold and hot seasons.

If there are known the internal and external temperatures and the temperature in the wall surface, the efficiency of the solar wall system can be evaluated with:

$$r = \frac{q_{wm} - q_{im}}{q_{wm}} = 1 - \frac{q_{im}}{q_{wm}} = 1 - \frac{U_w}{U} \cdot \frac{\theta_i - \theta_w}{\theta_i - \theta_e}. \tag{13}$$

So, $r$ will be grater if the ratios $U_w/U$ and $(\theta_i - \theta_w)/(\theta_i - \theta_e)$ will be smaller. The ideal situation could be if the value of $r$ coefficient is greater or equal to one. That means that energy gain from the sun compensates the energy lost through the wall.

## 3. Some Experiments Concerning the Efficiency of Passive Solar Wall with Locked Air Layer System

### 3.1. Testing Facilities

The tests has been carried out using test-cells of 0.8 × 1.2 m, with different type of glazing sheets and locked air layer, placed on the southern face of massive reinforced concrete external wall of building from our school. For glazing surface ordinary materials as transparent glass sheet, channel glass strips, glass blocks masonry has been preferred because these are used on a large scale in the building industry. Using different options for: the width of the locked air layer, the absorbent surfaces and thermal resistance of the solid wall, seven distinct systems have been tested (Fig. 2).

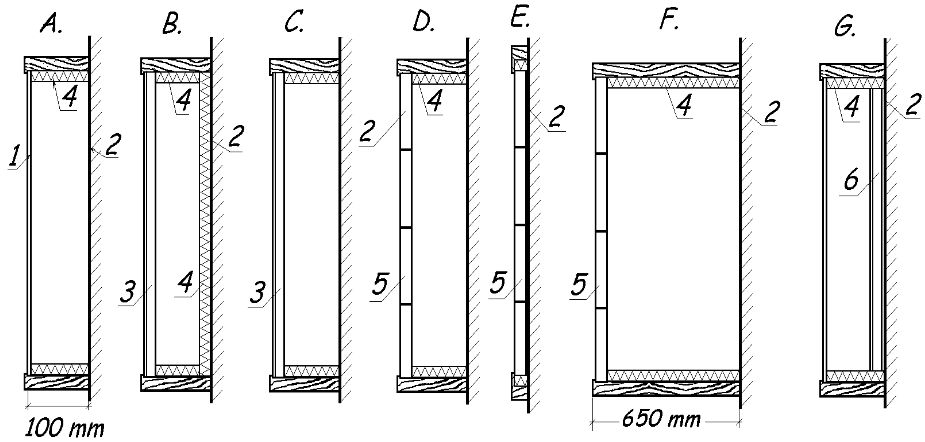


Fig. 2 – Seven types of solar wall systems: *1* – clear glass; *2* – reinforced concrete wall; *3* – chanel glass strip; *4* – polystyrene; *5* – glass block/brick masonry; *6* – asbestos fibre cement profiled sheet.

The measurements have been made for a pair of boxes simultaneously. One of the boxes was always the structure with transparent glass, as reference. The temperatures have been measured with cooper – constantan thermocouples connected to electronic millivoltmetre with multiple entrances.

The temperature measurement points are situated in some location of interest for the problem in study (see Fig. 3ig. 3). This points are situated: on the internal face of the massive wall in the area if influence of the solar wall system (points *6* & *7*), on the absorbent surface inside the box (points *1* & *3*), in the air (inside the box points *2* & *4* ) outside near the wall point *5*, inside near the wall point *8*. Temperatures have been measured and recorded hourly, by operator between 6 o'clock and 23 o'clock, and automatically in the rest of the day. With the values of temperature recorder each day have been calculated mean temperatures for a period of measurement.

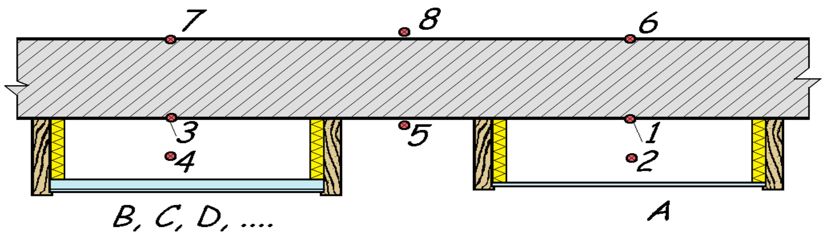

Fig. 3 – The position of temperature measurement points.

The measurements have been carried out between February 17 and July 22, on periods of 1 to 7 days as follows in Table 1.

**Table 1**
*Measurements Program*

| Period | Solar system | Period | Solar system |
|---|---|---|---|
| 17...25 February | *A* and *B* | 11...13 July | *A* and *E* |
| 16...30 March | *A* and *B* | 18...20 July | *A* and *G* |
| 28...30 June | *A* and *C* | 22 July | *A* and *F* |
| 7 July | *A* and *D* | | |

The solution *A* have been used each time from the flowing reasons:

a) it is the simplest solution system easy to construct by any owner of an individual dwelling building;

b) it have been used as reference system;

c) it's efficiently have been studied for different seasons.

**Table 2**
*Thermal Characteristics of the Systems*

| System | $U_w$, [W/m$^2$.ºC] | $U_e$, [W/m$^2$.ºC] | $U$, [W/m$^2$.ºC] |
|---|---|---|---|
| *A* | 2.80 | 5.34 | 1.84 |
| *B* | 0.98 | 3.27 | 0.75 |
| *C* | 2.81 | 3.27 | 1.51 |
| *D* | 2.80 | 1.91 | 1.13 |
| *E* | 2.80 | 2.58 | 1.34 |
| *F* | 2.80 | 1.77 | 1.08 |
| *G* | 1.25 | 5.34 | 1.58 |

**Table 3**
*Thermal Characteristics of the System A*

| Period / Mean values | 17...25 February | 16...24 March | 28...30 June |
|---|---|---|---|
| $Tw_{mean}$ | 12.26 | 15.22 | 29.97 |
| $Ti_{mean}$ | 17.50 | 17.80 | 22.10 |
| $Te_{mean}$ | 3.13 | 0.46 | 21.06 |
| $Ti_{mean} – Te_{mean}$ | 14.37 | 17.34 | –0.96 |
| $Ti_{mean} – Tw_{mean}$ | 5.24 | 2.58 | –7.87 |
| $r = 1– (K_w/K)[(Ti\text{-}Tw)/(Ti – Te)$ | 5.24 | 0.77 | –11.46 |

**Table 4**
*Thermal Characteristics of the Systems B and C*

| Period / Mean values | 17...25 February system *B* | 16...24 March system *B* | 28...30 June system *C* |
|---|---|---|---|
| $Tw_{mean}$ | 14.41 | 18.83 | 27.93 |
| $Ti_{mean}$ | 17.51 | 17.80 | 2.10 |
| $Te_{mean}$ | 3.13 | 0.46 | 23.06 |
| $Ti_{mean} – Te_{mean}$ | 14.37 | 17.34 | –0.64 |
| $Ti_{mean} – Tw_{mean}$ | 3.09 | -1.03 | –5.51 |
| $r = 1– (K_w/K)[(Ti – Tw)/(Ti – Te)$ | 0.60 | 1.07 | –15.02 |

**Table 5**
*Thermal Characteristics of the Systems D, E and F*

| Period / Mean values | 7 July system *D* | 11...13 July system *E* | 22 July system *F* |
|---|---|---|---|
| $Tw_{mean}$ | 26.02 | 22.80 | 24.16 |
| $Ti_{mean}$ | 22.08 | 21.38 | 22.79 |
| $Te_{mean}$ | 23.03 | 19.54 | 20.31 |
| $Ti_{mean} – Te_{mean}$ | –0.95 | 1.84 | 2.18 |
| $Ti_{mean} – Tw_{mean}$ | –3.94 | 1.42 | –1.37 |
| $r = 1 – (K_w/K)[(Ti – Tw)/(Ti – Te)$ | –9.23 | –0.61 | –0.63 |

**Table 6**
*Thermal Characteristics of the Systema A and G*

| Period / Mean values | 18 July system *G* | 18 July system *A* |
|---|---|---|
| $Tw_{mean}$ | 33.61 | 28.37 |
| $Ti_{mean}$ | 23.65 | 23.6 |
| $Te_{mean}$ | 26.80 | 26.80 |
| $Ti_{mean} – Te_{mean}$ | –3.15 | –3.15 |
| $Ti_{mean} – Tw_{mean}$ | –9.96 | –4.72 |
| $r = 1 – (K_w/K)[(Ti – Tw)/(Ti – Te)$ | –3.65 | –2.28 |

### 3.2. Results

The results of the tests are integrated in tables and graphs. Some of significant graphs are presented below. The temperatures of the absorbent surface of the wall, for each solar wall system, are compared with that of the system *A*.

From the analyse of the results some outstanding aspects can be mentioned:

a) In February and March the maximum value of the temperature (33.16$^o$C and 38.44$^o$C) measured for the system *B* are with 38% and 24% greater than in the case of system *A* (24ºC and 31ºC).

b) In the case of *C* system the measured temperatures are close to those measured in the case *A* ($\Delta T \cong$ 3.5ºC) meaning that the difference of glass transparency has no grate influence in the system.

c) In the case of systems with glass blocks (*D*, *E*, *F*) the temperature of the absorbent surface are lower than in case *A*'. So in case *D* temperatures are lower with 8.5ºC, in case *E* with 6ºC and in case *F* with 3.75ºC.

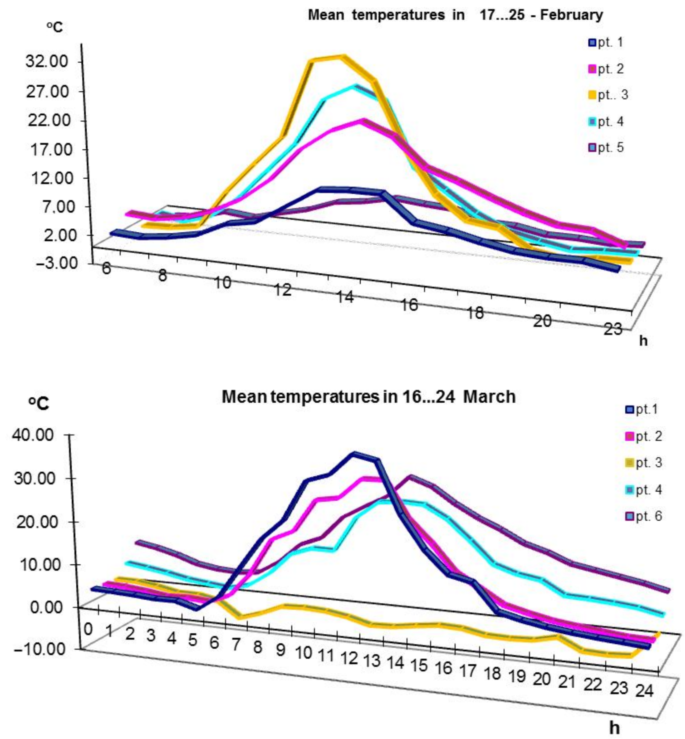


Fig. 4 – The mean temperatures of different points in some studied cases.

d) In the system *G* the absorbent surface simulates the fiber cement sheet facing included ion the greenhouse structure. In this case, the temperatures are close to that of the case *B*.

e) The temperature of the internal face of the wall behind the solar system (points *6* & *8*) is just with maximum 1ºC different to the temperature of the same wall face in another point where there are not thermal systems attached (ex. point *7*). This reflects the capacity of the 40 cm thick massive reinforced concrete wall to assimilate the thermal energy.

In this study the performance of the solar wall systems is expressed as the ratio between the thermal energy gain from the sun and the energy loss by heat transfer throw the wall. For estimation, the mean hourly temperatures of each measurement period have been used. The glass elements have been considered with the following values for the transparency factor: $\tau = 0.9$ for the clear glass sheet, $\tau = 0.8$ for the channel glass strip, and $\tau = 0.55$ for the glass blocks units masonry. To obtain a greater absorption factor ($\alpha = 0.9$), the external face of the massive wall has been painted with dark colour.

As regards the efficiency of the solar walls to extract solar energy for the systems, the study bring up the following aspects:

1º In the case of system *A*:

a) between 17 and 25 February 40% of the thermal energy lost throw, the wall is covered by the solar energy accumulation.

b) between 16 and 24 March 77% of the thermal energy is covered by the solar energy gains, and this is a very good ratio.

2º Both systems *A* and *B* present good performances. In February the solar energy accumulation represents 60% from the thermal looses and in March, the ratio is 107%.

3º In the cases *E* and *F* the performances are close to those of *A* but are more aesthetical than the last one.

4º The presence of the asbestos fibre cement profiled sheet (in the system *G*) provide a larger absorbent surface (in the same testing area). Therefore the maximum temperature ($T_{max}$ = 51.76ºC) and the mean temperature ($T_{mean}$ = 33.61ºC) are higher than $T_{max}$ = 43.8ºC and $T_{mean}$ = 28.37ºC from the system *A*.

5º During the hot period (May, June) the thermal flux which pass (by conduction) in the building through the solar wall is 11 (*A*) or 15 (*B*, *C*) times greater than in simple massive wall.

## 4. Conclusions

The research brought to the fore that solar walls systems (based on greenhouse effect) can be an option for the glassed part of the building anvelope. These, combined with the supplementary thermal insulation of the opaque part provide a real tool in the thermal retrofitting strategies. The systems are more efficient in regions with atmospheric conditions characterized by sunny days and moderate external temperatures. A problem that must be solved with reasonable technologic and economic means, in these systems, is the excessive heat absorption in the hot seasons.

Looking for a global optimisation of the buildings, architects and engineers should therefore favour the interdisciplinary and integrated approaches of the mechanical and thermal retrofitting of the buildings in order to improve different aspects of the building in one go. It is particularly not contradictory to aim simultaneously at a coherent structural consolidation together with an aesthetical approach, an energy consumption reduction and a comfort improvement.

## REFERENCES


Bliuc I., Radu A., *Advanced Research on Bow Windows: Thermal Shield and Greenhouse Effect Analysis*. Contract ERB CT98-0508 INCO-COPERNICUS PROGRAME, September 2000.

Meroni I., De Slvia A., Porro L., Pollastro C., *Soluzioni innovative per il contenimento dei consumi energetici*. L'instalatore Europeo, **14**, *5* (2000).

Meroni I., Lollini R., Pollastro C., De Slvia A., *Innovative Passive And Hybrid Dynamic Envelope Systems: Case Studies, Solar Energy in Buildings*. Internat. Conf. on Solar Energy in Build., Lausanne, October 3-4, 2001, 343-348.

* * * *Bátiment solaires passifs en Europe*. Study published by CFF, 1992.


ENERGIE DURABILĂ ÎN CLĂDIRI PRIN CONTRIBUŢIA PEREŢILOR CU SISTEM SOLAR PASIV


(Rezumat)

Se sintetizează rezultatele unor studii realizate in vederea determinării comportării şi a eficienţei pereţilor cu efect de seră. Au fost testate diverse sisteme constructive vitrate ataşate unui perete exterior din baton armat, realizate sub forma unor „celule de probă” amplasate pe un perete de faţadă.

Studiile au evidenţiat că aceste sisteme sunt eficiente mai ales in perioadele de tranziţie de tip iarnă-vară (şi invers) cu vreme însorită şi temperaturi exterioare coborâte.