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PERFORMANCE OF A HYBRID SOLAR WALL INTEGRATED INTO THE SOUTH FACADE DEDICATED FOR THE PASSIVE HEATING OF BUILDINGS

Actually building designers have to think about new strategies to achieve the best sustainable building designs. Well-planned passive heating strategies in building design may reduce significantly building's energy consumption. In this, paper a proposed designe of south façade of a room by integrating a hybrid solar wall and a window in case to heat passively a room is studied. The simulations for three-dimensional model of BIPV Trombe wall system have been carried out for December 10th, 2015. The temperature and velocity distribution of indoor air in different position inside the room are obtained from the simulation results. The obtained results show that the temperature difference between the inlet and the outlet of the solar wall can reach 9 °C. The 3D analysis of the proposed model show clearly that the window's thermal effect on the passive heating can't be neglected. Meanwhile, the simulation daily electrical efficiency conversion and average indoor air temperature of this system can reach 18 % and 28°C respectively for maximum solar radiation of 470 W/m².

Key words: natural ventilation, trombe wall, photovoltaique cells, hybrid solar wall.

Introduction

Control of natural ventilation answers to multiple issues. First, it allows the building to have a sufficient quality indoor air for the health of occupants, replacing stale air by the occupants and the various sources of pollution (kitchens, bathrooms, workshops, etc.) by fresh air. Secondly, it contributes to the sustainability of buildings by removing moisture that could cause damage.

Any solution for ventilation must be adapted to the local context, both climate, urban, technical and economic. Our prototype provides passive heating of a room based on the phenomenon of natural convection. The solar energy utilization in the field of the habitat to reduce its energy consumption was the subject of several studies. A technique of heating being based on a solar system of collecting, storage and restitution of heat was developed with the C.N.R.S. (France) by Professor Trombe [1].

The use of solar energy in the area of habitat to reduce its energy consumption has been the subject of several studies. Ramadan Bassiouny et al [2] also studied (2008) the influence of certain parameters on the thermal behavior of the solar chimney to optimize its design. The results obtained show that the width of the chimney has a very important influence on the ACH (air changes per hour) compared to that of the inlet section. The results show that there is an optimum intake section beyond what ACH begins to decrease. It was concluded that increasing the intake size three times only improves the ACH by almost 11 %. However, increasing the width of the stack by a factor of three improves by nearly 25 % ACH, keeping fixed the intake section. The same researchers studied in 2009 [3] subsequently a solar chimney placed on a sloping roof to see the influence of the inclination on the thermal behavior of the chimney. The results show the inclination significantly affects the rate of ventilation and the airflow, which crosses the chimney. This study shows that the optimum angle of inclination of the stack is between 45° and 75° to 28.4° latitude.

Guohua Gan et al [4] studied numerically natural ventilation through a vertical solar chimney by a CFD model. The simulation is performed using two fields, the first (*s*) identical to that of the cavity size of the stack, and the second (*L*) is extended. It has shown that the use of two areas for effective simulation for a variety of ventilation, however, the use of a single field identical to that of the cavity of the chimney size is favored for long chimneys where wall strength is dominant. Photovoltaic cells are adapted to receive the electrical gain using a hybrid solar wall, Basak kundakci and Zerrin Yilmaz [5] are studying the design parameters that influence the thermal efficiency of a solar wall such as the south facade.

A numerical model carried out by Bourdeau and Jaffrin [6] and Bourdeau et al [7] showed that the use of a wall of 3.5cm thickness can replace a wall of concrete 15cm. The use of the pcm reduces 90 % of mass of wall of storage and increases their effectiveness by a factor of 20 % [8].

Zlaweski et al [9] concluded that the solar energy that crosses the glazing is approximately 78 K·W·H/m²; the wall in PCM absorbs that 37.7 K·W·H/m², which accounts for 49 % of incidental energy. The wall in PCM generates 23.5 K·W·H/m² in the open cavity and this quantity accounts for 68 % of absorptive energy. Thus, the effectiveness of this wall does not exceed 30 %.The aim of this work is to produce a three-dimensional numerical model of the passive heating of a Place with a hybrid solar wall. This prototype is designed for cooling the *PV* cell and provide a passive heating to our home for the cold period of the year.

Physical model

Fig. 1 illustrates a schematic of the physical domain, with an attached hybrid solar wall of length L, and width d. The domain considers having a window (1 m × 1 m), and it is at 1 m height from the floor. The considered dimensions for this room were 3.5 m × 3 m × 3 m (Fig. 1), and the hybrid solar wall was considered 1.8 m length and 1.2 m width and the air gap was taken as 0.5 m.

The PV-Trombe wall system, as shown in Fig. 1, is composed of a semi-transparent PV cell panel, a thermal mass wall acting as a thermal absorber and an air duct in between. There are also two air vents for winter heating. The PV-TW wall system works as the original Trombe wall and its detailed description can be found in [10].

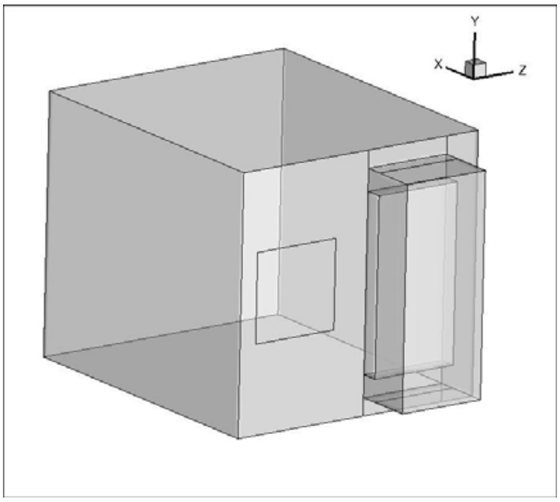


Fig. 1: A general schematic of the physical domain.

Boundary conditions:

Our area to be treated is a room in three dimensions (Fig. 2), has a hybrid solar wall and a window on the south façade. All walls of the studied rooms are adiabatique, except the south wall. The convection and the radiation heat flux effect are added at the south wall and the concrete roof.

Where the solar radiation values are from real climatic data of a typical day of Tlemcen. The convection heat transfer coefficient due to wind is defined by the equation (1) recommended by McAdams [11]:

$$h = 5.67 + 3.86V_{wind} \tag{1}$$

where V_{wind} is the wind velocity.

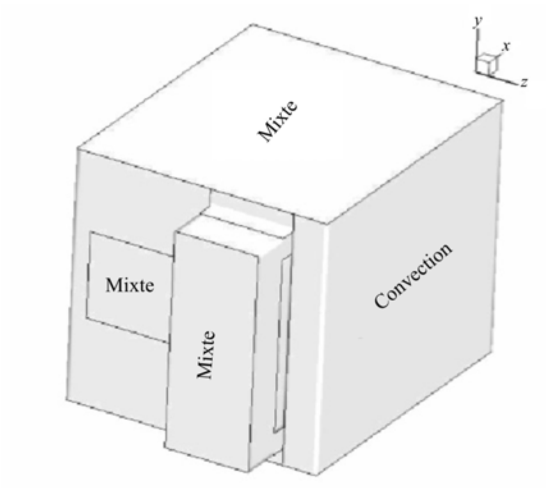


Fig. 2: Boundary condition adapted in CFD model.

The air inside the hybrid solar wall is heated by the greenhouse effect. The warm air, which is more light because it is less dense, rises, which causes the aspiration of the fresh air. The circulation of the air is made naturally without mechanics; this circulation ensures also the free cooling of our photovoltaique cell. The outlet at the top of solar wall is in the opposite direction of the inlet (in the bottom of the solar wall). The size of the inlet section of the solar wall is identical to that of the exit section. Simulation is carried out under the laminar mode, and the air is considered initially stable.

Results and discussion

The following sections present the numerical results obtained from three-dimensional unsteady-state turbulent simulations using the standard k − ε model with an enhanced wall function for the attached solar chimney model.

The simulation has been carried out with data of a day during wintertime December 10th in Tlemcen (Altitude 750 m, Latitude 35° 28' and Longitude 17°1'). The hourly variation of global and diffuse horizontal solar radiation during the 24 hours of the selected day is shown in Fig. 3.

After designing the models using Gambit software, their networking is made by organized networks. The boundary conditions of the models are defined model based on Fig. 2, although these conditions can be altered by “Fluent software” in the next stages of the analysis.

The commercial CFD software package, FLUENT, which is based on the finite volume approach was used for the simulation in three dimensions using the segregated solver.

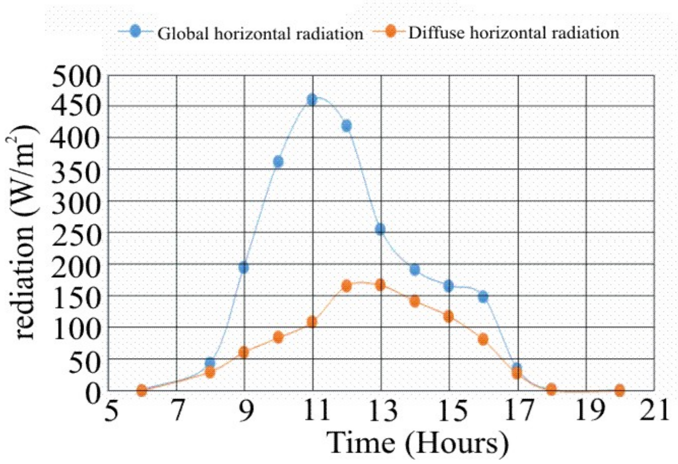


Fig. 3 The hourly solar radiation in Tlemcen during December the 10th.

In the second stage, the models are utilized in "Fluent software" (Fluent 6.3.26), the solution condition is described as followings:

- Solver: Pressure based.
- Space: 3D.
- Formulation: Implicit.
- Time: unsteady.
- Operating pressure: 101325P.
- The convergence criterion was set equal to 10 – 6 for all parameters.

To verify the precision of the developed numerical model we propose to compare the obtained results with those obtained experimentally by Basak kundakci and Zerrin Yilmaz [4] who studied a trombe wall system with single glass, double glass and *PV* panels. Fig. 4 represents the hourly change in surface temperature of the *PV* cell recorded for two successive days. A comparison shows that our results that appear in doted black curve agree well with that of literature [4]. This prove the good accuracy of the method proposed in this work.

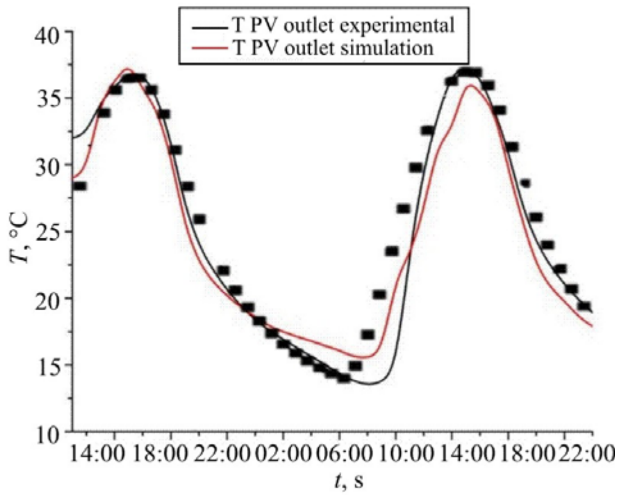


Fig. 4: Validation of results.

Fig. 5 and Fig. 6 show the temperature contour recorded every tow hour starting at 07:00. The higher values of solar radiation increase the air temperature inside the chimney and the air temperature difference between the inlet and the outlet of the hybrid solar wall increased too (Fig. 5).

The air temperature rise in the proposed model is proportional to the solar irradiation intensity. An increase in solar intensity increases the *PV* cell temperature and consequently increases the air temperature inside the hybrid solar wall. We can see clearly that the important values of temperature are recorded near the *PV* cell and the window. The air inside the room is warmed naturally by the solar chimney effect explained bellow.

Fig. 4 show that the window has more significant effect in the passive heating of the air inside the room. The thermal effect of adapting a window in the south wall cannot be neglected, the raison that prove that the study of a similar problem could be in three dimension.

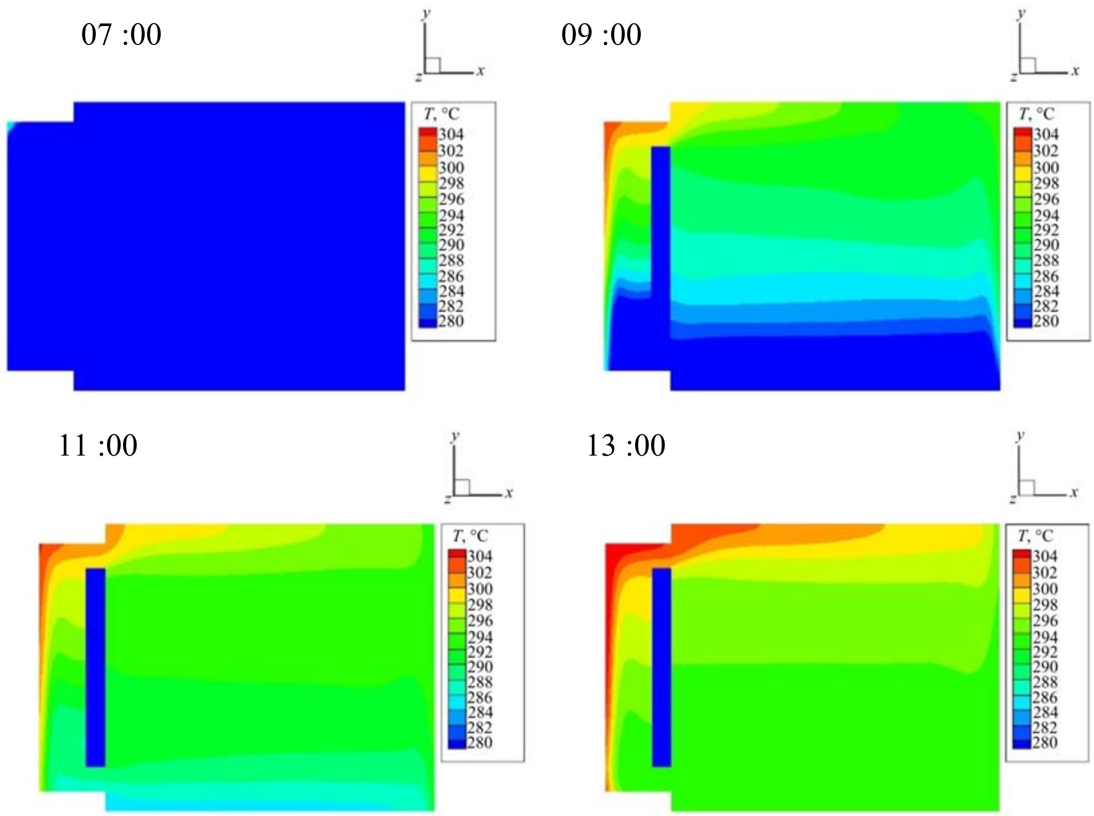


Fig. 5: Temperature contour recorded every two hours (z=2.4m).

Fig. 7 showed the air temperature distribution inside the hybrid solar wall near the *PV* cell (a) and the air temperature distribution inside the room near the window (b). The figure indicates the significant temperature changes corresponding to solar intensity variations. Further, as intensity increases, there is an increase in all temperatures. During all the day, we notice that the *PV* records the most important temperature. As seen in the Fig. 7 the temperature, reach 304K near the *PV* and 300K near the window.

The Fig. 8 shows the evolution of the temperature fields inside the test room. The heat generated in the level of the *PV* cell and the window has a significant impact on the temperature distribution inside the room as seen in Fig. 8. The highly temperature recorded inside the room are located on the top near the ceiling (≤ 302K).

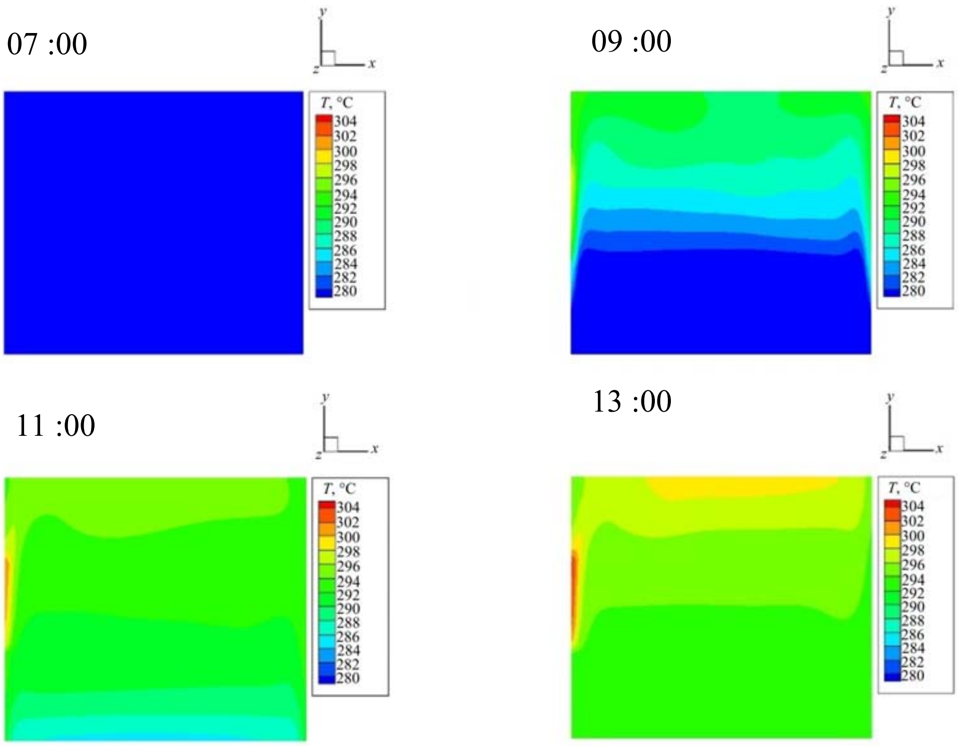
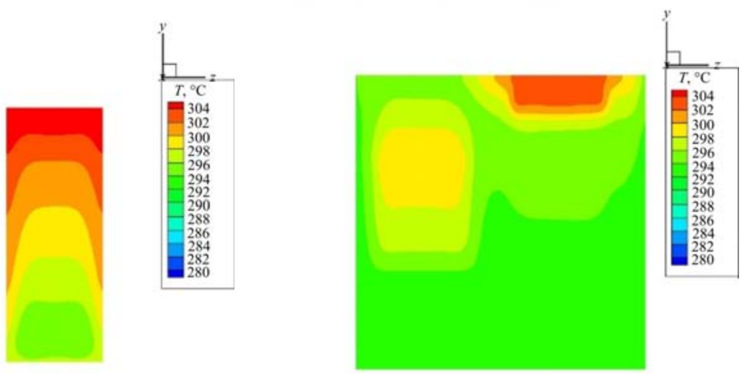


Fig. 6: Temperature contour recorded every two hours (z=1m).



a) *b)*

Fig. 7: Temperature contour near the PV cell (a) and the window (b)

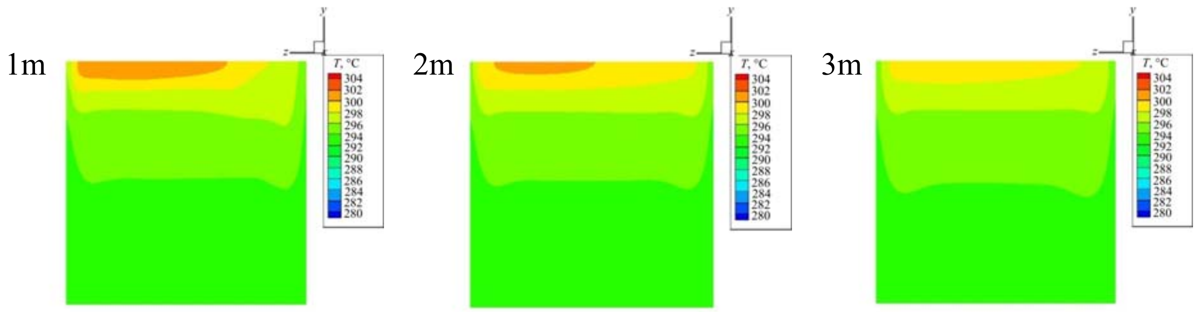


Fig. 8: Temperature contour in 1, 2 and 3m along the X-axis from the south façade respectively

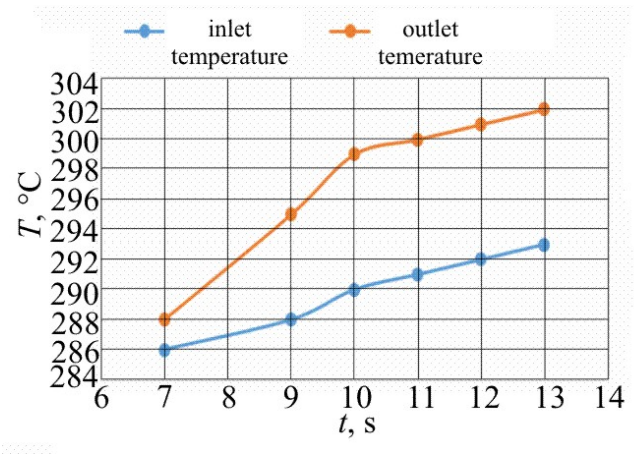


Fig. 9 Temperature variation at inlet an outlet of the hybrid solar wall

As seen in Fig. 9 the following inlet and outlet hybrid solar wall temperatures are compared. The fresh air inside the room will be changed with one wormed naturally by the greenhouse effect inside the hybrid solar wall during the day. The air temperature in the inlet and the outlet of the hybrid solar wall reach the maximum value at 13^{00} which is 302K and 293K respectively.

Fig. 10 shows the hourly electrical efficiency change with *PV* cell surface temperature during the selected day December 10^{th}. Where PV cell conversion efficiency related to the cell temperature as:

$$\eta_{pv} = \eta_0 \left(1 - 0.0045\left(T - 298.15\right)\right) \quad (2)$$

η_0 is the electrical efficiency under standard conditions (1000 W/m², 25 °C) [12].

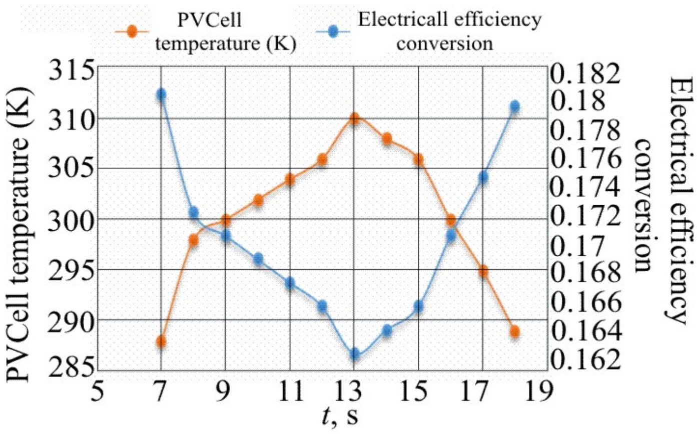


Fig. 10: The hourly change in the efficiency and the temperature of the PV cell in both of models

The *PV* cells has the ability to produce electricity during the day as long as it was exposed to the solar radiation. As seen in Fig. 10, the electrical efficiency conversion has its highest value that was recorded at 06^{00} which is 18.02 % while the surface temperature of the *PV* cells has its lowest value of 14°C. The electrical efficiency drops to its lowest value of the day at 13^{00} which is 16.3 % when the surface temperature of the *PV* cells increases to its highest value of 37°C. Then, the electrical efficiency conversion increases to 17.94 % at 18^{00} as the surface temperature of the *PV* cells decreases to 16°C.

Conclusion

The aim of this work is to present a thermal performance of hybrid solar wall integrated in a passive solar building in Tlemcen. The numerical simulation using the segregated solver with real climatic data conditions of Tlemcen city.

This study shows firstly that the solar wall is an effective solution for the passive heating of the buildings. By adapting a solar wall, the temperature of air of the room can reach the 28 °C when the ambient temperature is lower than 21 °C.

Secondly, the results obtained show that our hybrid solar wall ensures a good cooling of the photovoltaic cell that enabled us thereafter to reach a better electric output.

It is interesting to note that the excess heat released by the PV-Cell is used for heating passively our room; despite the PV cell is cooled down by the fresh air aspired from the room.

There exist several improvements to increase the effectiveness of our solar wall, like the use increase the insolation of surrounding wall to limit the heat losses towards the outside, or the integration of the pcm to prolong the operating time of our wall of storage.

References

1. D. M. Utzinger. ‘Analysis of Building Components Related to Direct Solar Heating of Building’, M. S. Thesis, University of Winconsin, Madison, (1979).
2. Ramadan Bassiouny, Nader S. A. Koura. An analytical and numerical study of solar chimney use for room natural ventilation, Energy and Buildings 40 (2008) 865 – 873.

3. Ramadan Bassiouny, Nader S. A. Korah. Effect of solar chimney inclination angle on space flowpattern and ventilation rate, Energy and Buildings 41 (2009) 190 – 196.
4. Guohui Gan. Simulation of buoyancy-driven natural ventilation of buildings-Impact of computational domain, Energy and Buildings 42 (2010) 1290 – 1300
5. Basak Kundakci Koyunbaba , Zerrin Yilmaz, The comparison of Trombe wall systems with single glass, double glass and PV Panels, Renewable Energy 45 (2012) 111 – 118.
6. Bourdeau, L., Jaffrin, A.. 1979. Actual performance of a latent heat diode wall. In: Proceedings of Izmir International Symposium II on Solar Energy Fundamentals and applications, Izmir Turkey.
7. Bourdeau, L.. 1980. Study of two passive solar systems containing phase change materials for thermal storage. In: Hayes, J., Snyder, R. (Eds.), Proceedings of the Fifth National Passive Solar Conference, 19 – 26 October, Amherst, Newark, DE, American Solar Energy Society, p. 297.
8. Knowles, T., 1983. Proportioning composites for efficient thermal storage walls. Solar Energy 31 (3), 319 – 326.
9. Laurent Zalewski, Annabelle Joulin, Steten el Lassue, Yvan Dutil, Daniel Rousse, Experimental study of small-scale solar wall integrating phase change material, Solar Energy 86 (2012) 208 – 219
10. Ji Jie, Yi Hua, He Wei, Pei Gang, Lu Jianping, Jiang Bin. Modeling of a novel Trombe wall with *PV* cells, Building and Environment, in press.
11. Mc Adams, W.H. 1954. Heat Transmission, third edition, McGraw-Hill, New York
12. Zondag HA, de Vries DW, van Helden WGJ, van Zolingen RJC, van Steenhoven AA. The thermal and electrical yield of a PV-thermal collector. Sol Energy 2002; 72(2):113 – 28.

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