Numerical Study of Natural Ventilation in BIPV Trombe Wall

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Abstract

To reduce energy consumption in buildings, passive solutions have been developed greatly like increasing the insulation of exterior walls. One way to improve the energy efficiency of buildings is to design multi-functional facades that capture the energy available locally: the principle of hybrid envelopes, able to both isolate, protect, but also capture, store, transport energy. Our study is about a solar collector made up mainly of a photovoltaic cell (receiving surface) and a wall of storage. The goal of this work is to heat naturally the habitat using a system which ensures initially the cooling of PV-cell. In this paper a simulation model have been made for a BIPV trombe wall. Computational fluid dynamic (CFD) has been applied to predict air temperature and velocity in the room during December 10th. The simulations for three-dimensional model BIPV trombe wall is carried out using the climatic data of Tlemcen, Algeria. The temperature variations at certain nodes and slices have been interpreted. Simulation result values of indoor air temperature during December 10th are presented and shows the influence of our hybrid solar wall on the thermal behavior of the habitat.

Keywords- Natural Ventilation, Trombe Wall, Photo-Voltaique Cells, Hybrid Solar Wall

I. 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.

The ventilation control is therefore in the context of reducing energy consumption, improving the quality of indoor air and improved hydrothermal comfort, especially in summer. It also helps to maintain good productivity in the business premises. Finally, as sound travels through the air, consider ventilation and acoustics always together.

Whether buildings are naturally or mechanically ventilated, they are designed and constructed to serve people and their requirements. An important requirement is that the indoor air quality should be felt as acceptable by most people and should have no adverse health effects. Furthermore, that the thermal environment is appropriate, i.e. felt neutral by most people with a minimum risk of draught.

These requirements are specified in different national and international guidelines and standards. For example, the CIBSE Guide provides guidelines on ventilation requirements and the thermal environment; EN ISO 7730 is a European and international standard on thermal comfort. A draft of a new European pre-standard, prENV 1752, has been elaborated on design criteria for the indoor environment in ventilated buildings. It covers both the thermal and the acoustic environment as well as indoor air quality.

ASHRAE has also developed a draft of a new ventilation standard, 62R based on similar principles as the European draft. One way to improve the energy performance of a building is well insulated to develop hybrid envelopes, multifunctional envelopes used both for protection, insulation, but also for the capture and storage of energy, with integrated processes in the outer walls. The frame becomes an energy system that transform local energies (solar, geothermal, wind, hydro, biomass...) to meet the needs: heat, cool, electricity.

Any solution for ventilation must be adapted to the local context, both climate, urban, technical and economic. Our prototype provides natural ventilation of the 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 is 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.

The main issue of the solar chimneys or trombe walls is the opposite thermo-circulation on the lower level of the opening, this phenomenon appears when the temperature of thermal mass (storage wall) becomes lower than that of the indoor air, this variation in temperature imposes the air flow to enter through the law inferior by creating an opposite thermocirculation. This phenomenon requires a preventive system that is the use of a plastic film placed in the lower vent, which plays a part of a valve to prevent the flow of air in the opposite direction.

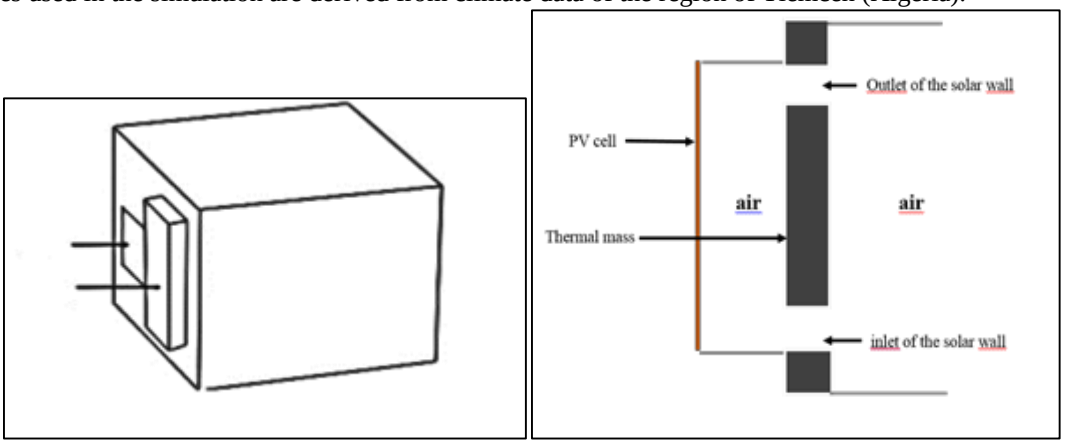
A numerical model carried out by Bourdeau and Jaffrin [6] and Bourdeau et al [7] showed that the use of a wall of 3.5cm thickness can replace a wall of concrete 15cm. The use of the PCM reduces 90% of mass of wall of storage and increases their effectiveness by a factor of 20% [8]. The numerical results presented by selka, show that using PCM in wall as energy storage components may reduce of the room temperature about 6 to 7 K of temperature depending the floor level (first floor spaces or ground floor spaces). This shows that the application of PCM significantly reduces variations of the inside temperature of the test room by absorbing heat during daytime and releasing it at night [9,10].

Zlaweski et al [10] concluded that the solar energy that crosses the glazing is approximately 78 KWH/m², the wall in PCM absorbs that 37.7 KWH/m², which accounts for 49% of incidental energy. The wall in PCM generates 23.5 KWH/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 passive heating our home for the cold period of the year.

II. PHYSICAL MODEL

The geometry of the problem is presented in Fig 1. This is a room 3.5 m in length (x) and 3m wide (y) and 2.9m of height (z). Flow is assumed in laminar natural convection by adjusting the effect of bousinesq. Intensity of solar radiation is considered unsteady. Values used in the simulation are derived from climate data of the region of Tlemcen (Algeria).



a) Window b) Hybrid solar wall

Fig. 1: The Geometry of Solved System

The solar wall is a simple and interest of harnessing solar energy. It consists of a vertical wall with heavy masonry and facing south with two orifice enabling the circulation of air between the chimney and the greenhouse formed by the receiving surface of the wall and photovoltaic cell which precedes (Fig. 2). The latter is an optoelectronic device able to receiving and converting light energy directly sunlight into electricity.

The storage wall transmits the collected solar energy in two ways, some is transferred by conduction through the wall that restores within the local by convection, while the second part is transmitted by natural circulation of hot air located in the solar chimney through the orifices, and such movement is the subject of our photovoltaic cell cooling.

In this study, we have a photovoltaic cell semitransparent type 2.45m² of surface, the coverage of the solar wall is considered on aluminum, and the walls of the room on brick, however the ceiling and the floor are on concrete. Table 1 shows the physical characteristics of the materials used.

Table 1: Thermo physical properties of materials used in simulation

Material	*Parameters*	*Numerical values*
Wall (brick)	*Thickness (m)* *Density (Kg/m^3)* *Thermal conductivity (W/mK)* *Specific heat (kJ/kg.K)*	*0.2* *1800* *0.814* *840*
Ceiling (concrete)	*Thickness (m)* *Density (Kg/m^3)* *Thermal conductivity (W/mK)* *Specific heat (kJ/kg.K)*	*0.2* *2200* *1.75* *880*
Floor (concrete)	*Thickness (m)* *Density (Kg/m^3)* *Thermal conductivity (W/mK)*	*0.3* *2200* *1.75*
Window (glass)	*Thickness (m)* *Density (Kg/m^3)* *Thermal conductivity (W/mK)* *Specific heat (kJ/kg.K)*	*0.002* *2515* *1.4*
PV panel (silicium)	*Thickness (m)* *Density (Kg/m^3)* *Thermal conductivity (W/mK)*	*0.0005* *2300* *0.036*
cover of the solar wall (aluminium)	*Thickness (m)* *Density (Kg/m^3)* *Thermal conductivity (W/mK)*	*0.002* *2719* *202.4*

III. MATHEMATICAL MODEL

Base on the forgoing assumption the governing equations are

A. On the Level of Indoor Air

1) Equation of Continuity

$$\frac{\partial \rho_{air}}{\partial t} + \frac{\partial}{\partial x_{ij}}(\rho_{air} u) = 0 \quad (1)$$

2) Momentum Equation

$$\frac{\partial(\rho_{air}\phi)}{\partial t} + div(\rho_{air}\phi u) = div(\Gamma grad\phi) \quad (2)$$

3) Equation of Energy

Energy conservation in our fluid (air):

$$\rho_{air} c_{p\ air}\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = \lambda_{air}\left(\frac{d^2T}{\partial x^2} + \frac{d^2T}{\partial y^2} + \frac{d^2T}{\partial z^2}\right) \quad (3)$$

B. On the Level of the Photovoltaic Cell (with Dimensions Blade of Air)

The photovoltaic cell is of mixed type, the heat flow generated by the cell is calculated according to the equation of following Energy.

$$\rho_s c_{ps}\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = \lambda_s\left(\frac{d^2T}{\partial x^2} + \frac{d^2T}{\partial y^2} + \frac{d^2T}{\partial z^2}\right) \quad (4)$$

C. On the level of the absorber

Energy balance on the level of the thermal mass that represent the absorber of our hybrid solar wall is mentioned in the folowing energy equation:

$$\rho_{abs} c_{pabs}\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = \lambda_{abs}\left(\frac{d^2T}{\partial x^2} + \frac{d^2T}{\partial y^2} + \frac{d^2T}{\partial z^2}\right) \quad (5)$$

IV. BOUNDARY CONDITIONS

Our area to be treated is a room in three dimensions (Fig. 1), has a hybrid solar wall on the south façade. The results presented in this article are from the simulation under the commercial code Fluent 6.3, which gives the possibility to treat flows of compressible fluids and heat transfer according to the Navier stocks equations.

The modeling of our problem under flowing 6.3 is carried out by adapting the radiation model, by introducing the geographical coordinates of Tlemecn (Algeria), as well as the values of solar radiation correspondant at the day December 10th. The first order upwind scheme was used for solving the momentum and energy equation. The relaxation factors values was

takend by defect (automatically). Convergence cretiria were set as $10^{-6}$for continuity, momentum and thermal energy, and the maximal number of iterations for every time step was taken 30.

To receive more sunshine time we placed our hybrid solar collector on the south side of the room. We take the real case depending on weather conditions in the region of Tlemcen to test the applicability of the model. The floored room is considered adiabatic, while the room walls and the slab are of mixed type. Sky temperature and wind speed are calculated using the following equations [2]:

$$T_{sky} = 0.0552T_a^{1.5} \quad , \quad h_{wind} = 2.8 + 3.0V_{wind}$$

T_a : Ambient temperature.
V_{wind} : Wind velocity.

The free cooling of the photovoltaic cell is carried out using the flow of air through the chimney 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.

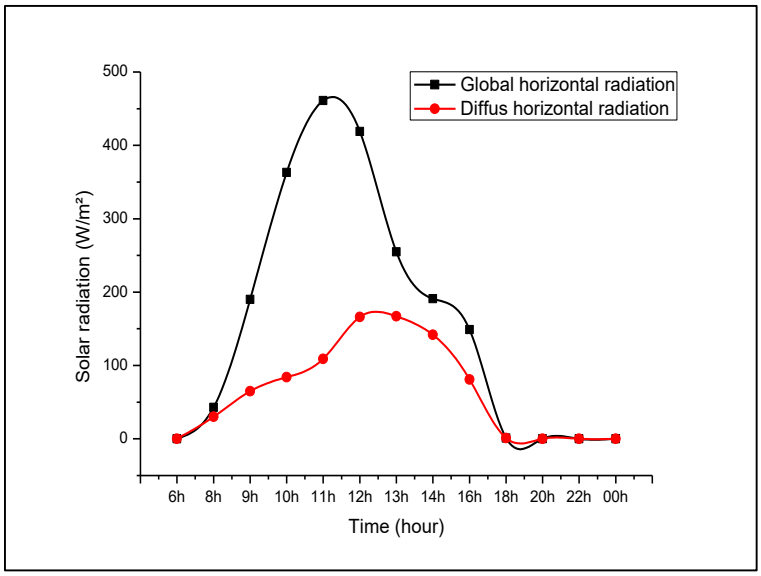


Fig. 2: The hourly solar radiation in Tlemcen

The city of Tlemcen is located in the semi-warm area (-1,31° longitude, 34,87 ° attitude), these climatic characteristics requires the use of energy for heating needs during the cold winter.

Fig. 2 shows the evolution of the solar radiation and the ambient temperature of the city of Tlemcen marked the December 10th. A maximum radiation is 462 W/m² and a maximum ambient temperature less than 15 °C. With such climatic conditions heat solution become essential to solve the cold problem.

V. RESULTS

To evaluate the accuracy of our numerical model realized under fluent 6.3, one carried out a study into two dimension by adapting the same boundary conditions taken in the experimental study of basak [5].

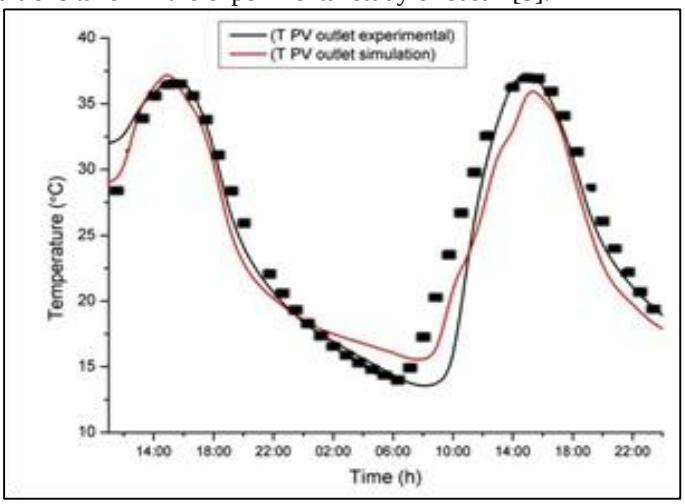
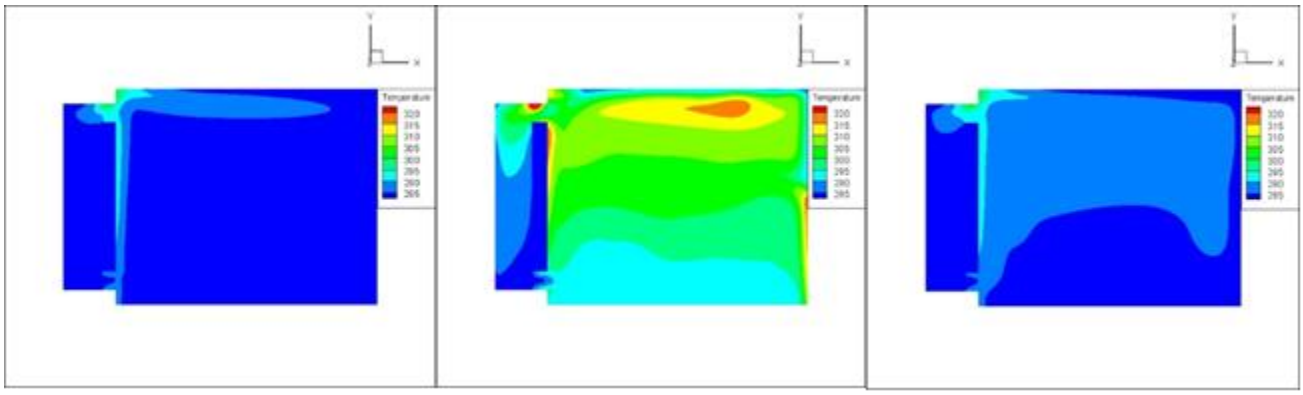


Fig. 3: validation of results

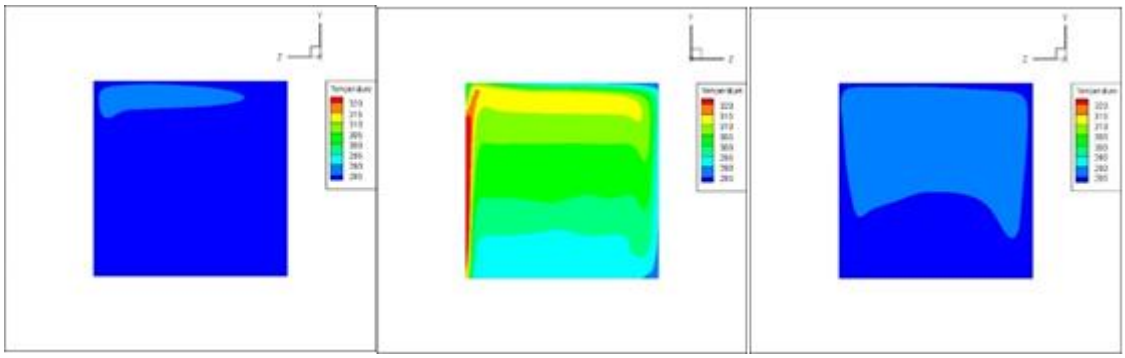
Fig. 3 represents the hourly change in surface temperature of the PV cell recorded for two successive days. The two graphs in red and black are the experimental results and of simulation successively of Basak kundakci and Zerrin Yilmaz [4] what appears into dotted are our results.

Our PV cell temperature result agree well with experimental and simulated result of Basak kundakci and Zerrin Yilmaz [4], This validates the correctness of the simulation model.



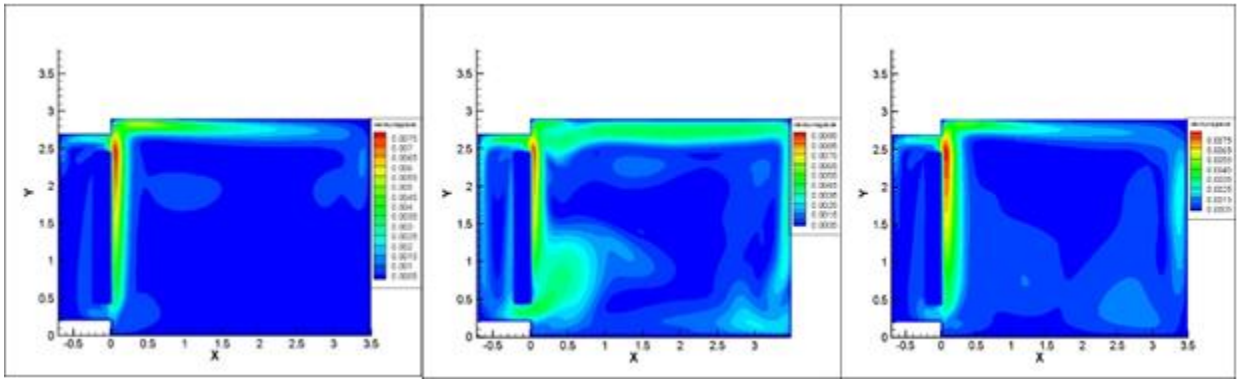
a) b) c)

Fig. 4: The temperature distribution of the indoor air ((x,y)slice, z=2 m)



a) b) c)

Fig. 5: The temperature distribution of the indoor air ((y,z) slice, x=1.5 m)



a) b) c)

Fig. 6: The velocity distribution of the indoor air ((x,y) slice), z=2 m

Fig. 4 (a, b, c) shows the temperature contours marked at 6.00, 14.00 and 18.00 for 2 m distance along the (z) axis. As seen in the unsteady evolution of the air temperature inside the room (Fig. 4), the representation contours show the inhomogeneity of profiles. Heating the room established with the airflow is expressed in the propagation of heat acquired. With a large temperature gradient in the vertical direction during the day.

Fig. 5 show the contours of air temperature in the room recorded at 6.00 am, 14.00 and 18.00, in the position (x = 1.5 m). According to changes in temperature we notice a degradation of temperature from red to blue. The red signifies the hottest area presented near the roof, and the blue is coldest one, here the areas closest to the ground. Distribution of temperature in the room is not homogeneous, we noted that the air begins to heated early in the morning as a result of solar radiation trapped in the chimney of hybrid solar wall . However, there has been a considerable degradation temperature in the room (Fig. 5.c) simultaneously with lowering the intensity of solar radiation. Exposure of the air that is in the solar wall to incoming solar

radiation heats the air and therefore its density falls and it rises occupying the area near the roof and the heat released from the slab explains the important values of the temperature stored in the top layer of the chamber.

Fig. 6 show the dynamic field speeds of air inside the room recorded at at 6.00, 14.00 and 18.00. The dynamic range show that the flow is characterized by relatively high speeds especially in areas near the roof. The great values of air speed are focused on the level of the roof and the absorber (thermal mass), as well as the openings of inlet and outlet of the solar wall. As seen in (Fig. 6.a) recorded at 6.00 show that the air in the chimney is almost stable, and then it starts to accelerate until it reaches its max value (0.0095 m/s) at 14.00 (Fig. 6.b), after it decrease at 18.00.

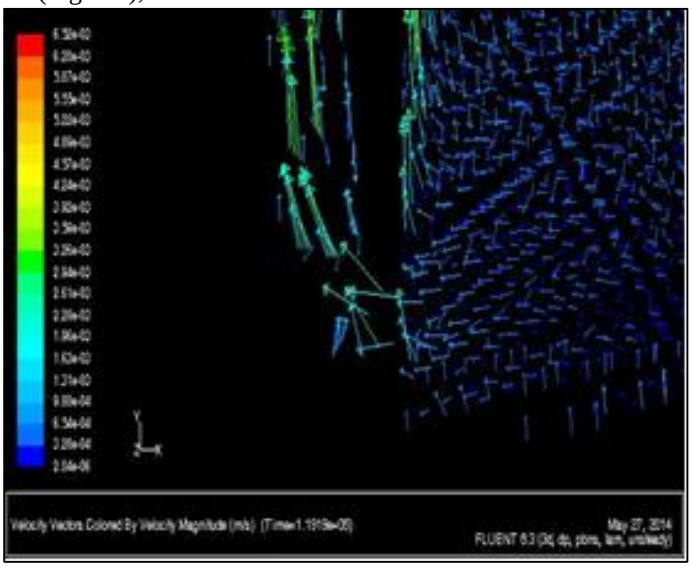


Fig. 7: Distribution of the Flight Path Vectors on the level of the inlet of the solar Wall

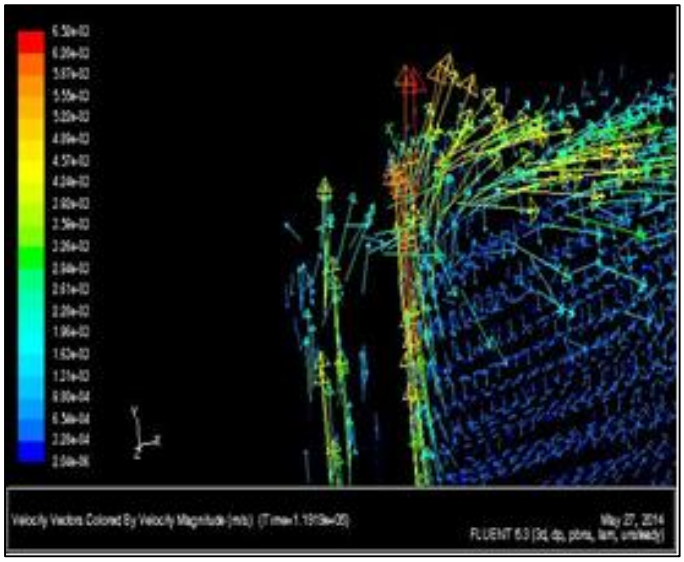


Fig. 8: Distribution of the Flight Path Vectors on the level of the outlet of the solar Wall

The velocity vectors presented in Fig. 7 and Fig. 8, shows that the flow is characterized by relatively high speeds in particular in the zones located close to the roof. As well as the air accelerates on the level of the inlet of the solar wall by creating in form an aspiration of air of the room what requires that the flow be directed towards the roof (Fig. 8).

The upward arrows from the inlet of the solar wall (Fig. 7) to the outlet (Fig. 8) ensures the correct direction of flow and they follow the shape of the local this confirms the continuity of flow. The structure of the airflow in the room is shown in Fig.7 and Fig.8 shows that the flow is directed from the lower opening (inlet of the solar wall) towards the upper opening (outlet of the solar wall), this movement allows the extraction of fresh air from the room and replace it with hot air.

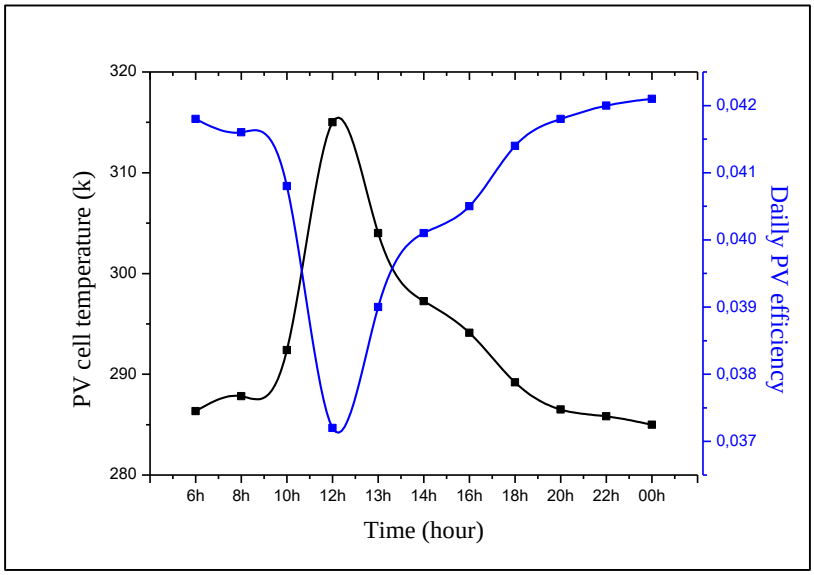


Fig. 9: The hourly change in the efficiency and the temperature of the PV cell

The photovoltaic energy conversion is strongly dependent on the temperature applied. In terrestrial applications, solar cells are generally exposed to temperatures of operation ranging from 10°C to 50°C. Photovoltaic cells requires proper ventilation to avoid overheating of the cells that affects greatly on their electric performance. Fig. 9 show the hourly change in PV cells efficiency and temperature during December 10th. As seen in Fig. 9 at 10.00 the temperature is 13°C. The PV cells temperature increase and reach 40°C at 12.00 when the efficiency of the PV cell is lowest (0.036), then it decrease for the following hours until reach its lowest values in the night when the efficiency reach its max value (0.042). From this, we can draw a conclusion that our system can solve the problem of overheating of PV cells by natural ventilation phenomenon that occurs inside the solar chimney.

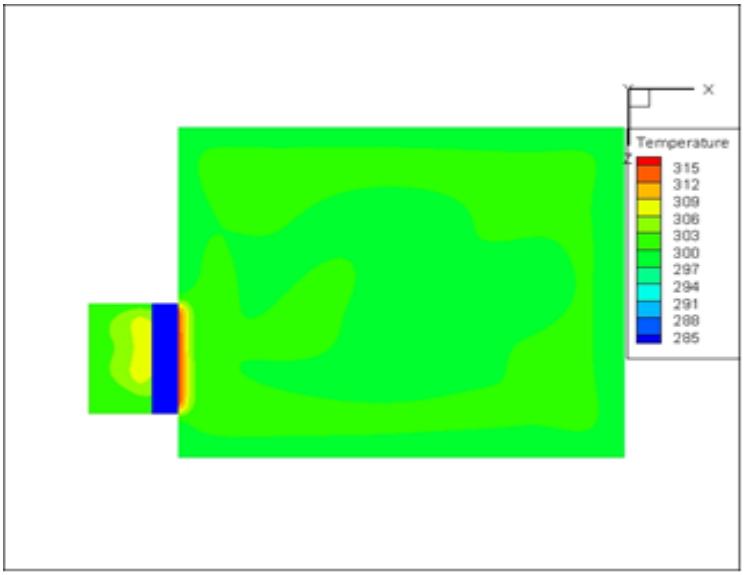


Fig. 10: Temperature distribution in the room at 14:00 ((x,z) slice, y=1.5 m)

The temperature distributions of indoor air at 14.00, at y=1.5 m, on December 10th are seen in Fig. 10. One can easily noticed that the indoor air of the room be heated until it reach an important temperature (in the neighborhood of 300 K), with the presence of a hotter zone on the level of the termal mass.

The time evolution of the ambient air temperature During December 10th shows that the town of Tlemcen has a cold climate during the wintry time, which requires a heating system to eliminate the problem in buildings and the work places. The ambient air temperature and the simulation results of indoor air temperature are compared as seen.

Indoor air temperature is 10 °c at 6.00 when the ambient air temperature is 2°c. It increases up to 25°c at12.00. The temperature difference between the ambient air and the indoor air reaches up 15 °c at 12.00 when we have the highest value of solar radiation (462 w/m²).

VI. CONCLUSION

In this work, we numerically studied the thermal behavior of natural convection airflow for one day of the year. This study can be a real application in the field of ecological habitats and solar hybrids.

In our study, one used the flowing code (CFD) for the modeling of the system. CFD code offers additional functionalities of thermal analysis of the flow of the fluids, which enable us to study non-stationary simulations of compressible fluid. Moreover, allows us to introduce the effect of the solar radiation effects.

This study shows that the solar wall is an effective solution for the passive heating of the buildings .one notices according to the velocity evolution of air that one has a permanent circulation even at the non-sunny hours but with low speed values. By adapting a solar wall, the temperature of air of the room can reach the 25 °C when the ambient temperature is lower than 15 °C. 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.

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

NOMENCLATURE

Symbols	
C	heat capacity, [J/kg K]
T	Temperature, [K]
T	Time, [s]
U	velocity vector component at x-direction, [m/s]
V	velocity vector component at y-direction, [m/s]
W	velocity vector component at z-direction, [m/s]
Greek letters	
ρ	Density, [kg/m3]
λ	effective thermal conductivity [W/m K]
Subscripts abs	Absorber (Thermal mass)

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