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Thermal evaluation of an innovative type of unglazed solar collector for air preheating

Cristiana Croitoru[a]*, Ilinca Nastase[a], Ionut Voicu[b], Amina Meslem[c], Mihnea Sandu[a]

[a]Technical University of Civil Engineering Bucharest, CAMBI Research Center, Pache Protopopescu, 66, Bucharest, Romania
[b]University of Caen Basse Normandie, LUSAC-Site de St Lô, 120 rue de l'Exode, 50000 Saint Lô, France
[c]LGCGM EA3913, Equipe Matériaux et Thermo-Rhéologie, Université Européenne de Bretagne, Université Rennes 1, IUT de Rennes, 3 rue du Clos Courtel, BP 90422, 35704 Rennes Cedex 7, France

Abstract

Perforated solar walls pre-heat the fresh air introduced in the building when the air is forced to pass through this solar heated perforated facade. The heat transfer between the fluid and the metal is intensified depending especially on the flow's characteristics. An experimental campaign on an innovative solar collector was performed in the laboratory of Building Services from Technical University of Civil Engineering Bucharest. The solar collector with lobed perforations was analyzed and the results indicated that the system can attain a high thermal performance, but only for a certain range of airflow rates.

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Keywords: Solar energy; ventilated envelope element; lobed geometry

1. Introduction

The new European Directives concerning energy performance of buildings [1] imposes significant reduction of the energy consumption. For this reason, the EU Members have adopted drastic regulation in order to achieve high building performance. On the other hand, the indoor quality has become an important parameter when conceiving residential or office buildings. The requests of the occupants are more exigent and achieving the indoor comfort is one of the most

* Corresponding author. Tel.:
E-mail address: cristiana.croitoru@cambi.ro

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important challenges for civil engineers. Generally, building sector consumes 35.3% from the total energy demand [2, 3]. This energy demand is caused mainly by the HVAC (Heating Ventilating and Air Conditioning) Systems.

Nomenclature

P	heat transferred from the plate to the air [W]
m_{air}	mass flow rate [m^3/s]
ε	efficiency [%]
I_T	radiation level provided by the lamps [W/m^2]
A	surface of the plate [m^2]
$T_{air.plen}$	air temperature in plenum [°C]
T_{amb}	ambient temperature [°C]
T_{pl}	surface temperature on the metal plate [°C]

This system exploits solar radiation using collectors that are in the form of panel that can be installed on a wall or on the roof. Schematically, their general configuration is as follows:

At the outer surface of the system we find a metal sheet provided with perforations which are aspirating the air. The metal plate, installed at several centimeters from the building wall, creates a cavity (plenum) for circulating air passing through the perforations. This way, when the metal plate is heated by solar radiation, the air circulating from the bottom is heated along the latter and enters indoor with a ventilation system. A fan is placed on the top of the wall in order to create a negative pressure, forcing the air circulation.

Fig.1 - a) SolarWall Collector ; b) Maisel site using solar collectors

Such an example, using solar collectors, is the student residence "La Maisel" in Brittany[4] (see Figure 1). This site has 129m2 of solar wall and preheats by this system 2160 m3 /h fresh air for the building.

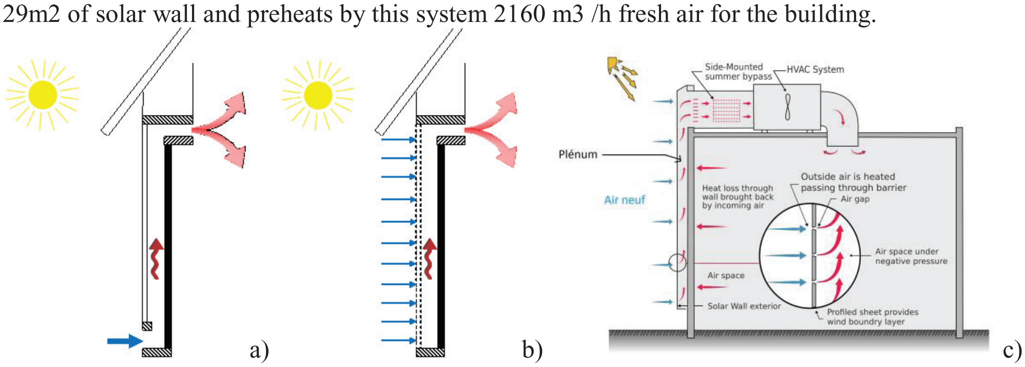


Fig.2: Sollar walls: a) Classical Trombe wall, b) Unglazed transpired solar wall, c) Mixed Glazed and Unglazed SollarWall® from Conserval Engineering Inc. [5]

Thus, the same study mentions that the site owner realizes an energy saving of 17,707 kWh per year and reduced annual greenhouse gas of about 4.24 tons. Generally, a SolarWall collector replaces, in fact, between 20-50% of traditional heating costs and greenhouse gas equivalent of 30 years (its lifetime). In addition, maintenance is low since this is a passive system. The economic and ecological interest of such a technology is therefore substantial. There are different types of unglazed solar collector, either prototype, either commercial product, as seen in Figure 2.

Gunnewieck et al. [6] underlines the importance of a non-uniform flow and of a low velocity on the efficiency of unglazed transpired solar air collectors of large dimensions. In his thesis, Kutscher [7] studied thoroughly the phenomena of heat and flow transfer around the orifices using a CFD 2D model. He indicated that the heat transfer takes place mostly in front of the plate and in the perforation itself, on the back surface of the collector and accounted for the wind velocity effects. Van Decker [8] show that in no wind situation, about 62% of the temperature rise occur due to heat transfer in front-of plate, 28% in the orifice and 10% on the back of the collector, indicating the interest in studying the perforation geometry. Studies [9] support this direction in research and show theoretically that heat exchange, between metal plate and air can be optimum only for a certain type of geometry perforation, namely the geometry called "lobed".

The use solar passive systems are easy to implement and efficient from the accessibility point of view in the zones with solar potential. These systems can have a major contribution to achieve high building envelope performances and, in the same time, to save energy either for heating during cold season or for cooling during summer.

2. Method

One innovative idea is to use special geometry perforations for the solar collector, inorder to enhance the heat transfer between the metal and the air. Studies from CAMBI research centre showed the interest for using lobed geometries.


(a) (b)

Fig.3: Flow image from a) circular orifice; b) lobed orifice [10][11]

This special geometry, studied for innovative air inlets, was implemented on the perforated collector. For the same effective area (same equivalent diameter *De*) the perimeter of the lobed perforation is significantly larger than the circular one, increasing the contact edge between the airflow and the orifice's width. Under low or moderate Reynolds numbers, such as the one characterizing the flows in the solar collectors, the analysis of the elementary lobed jets shows that the lobed profile introduces a transverse shear in the lobe troughs [11-14] resulting a higher induction rate and a better mixing [11]. Other studies indicate that the heat transfer is highly increased due to lobed geometry [15-18], leading to interesting results. For the current study, the scope is to find the optimal configuration for perforations disposal on the plate. Five different configurations were tested. The metal sheet was covered with black paint in order to increase the absorption coefficient. The sixth plate from figure 4 was used as a reference since the metal plate is not painted. The equivalent diameter, De, of each perforation is 5 mm and the space between 2 orifices is 4*De*.

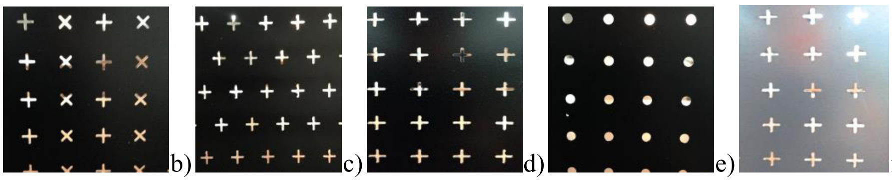
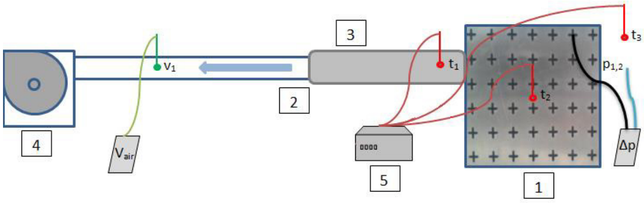

a) b) c) d) e) f)

Fig.4: Studies configurations: a) Type1 b) Type 2 c) Type 3 d) Type 4 e) Type 5 f) Type 6

The system is composed by three important parts: the collector, the heating system and the exhausting system. The perforated collectors are positioned on a rectangular box with thermally insulated walls. The box is attached through a circular pipe to an exhausting fan, forcing the air to pass through the perforated panel, fact that conducted to heating the air. The box is thermally insulated with polyurethane, and the space resulting between the plate and the back of the box is 15cm. The source of light was generated by six halide lamps of 500W each, which were simulating the sun radiation. The studies [19] indicate a radiation level of 800 W/m^2 so the lamps were evenly disposed to cover uniformly the metal plate.



Legend: probes t1 – air temperature at outlet; t2 – metal cladding temperature; t3 – ambient air temperature; t4 – black bulb temperature positioned between perforated cladding and the lamps; v1 – air velocity in the center of the tube; p1,2 – pressure probes one placed inside the box and the other placed in the ambience in order to calculate the pressure loss;

Fig.5 Sketch of the experimental facility: 1) heated metal perforated cladding; 2) air extraction pipe with temperature and velocity probes: t1 and v1; 3) insulation of the air extraction pipe for accurate temperature measurements; 4) exhaust fan; 5)temperature measurement data acquisition;

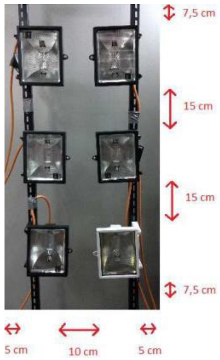


Fig.6: Halide lamps used for sun-simulation fixed evenly in order to offer a uniform heat flux

The fan, passing a 10 cm diameter duct, exhausts the air from the box. The fan can provide an aspiration airflow varying from 30 to 250 m3/h per square meter of collector.

The measurement equipment used for this experimental campaign will allow the calculation of the collector's efficiency. The velocity was measured with a TSI anemometer, model 7545, measuring the velocity at 10 diameters from the outlet to have an uniform flow. The mean velocity was integrated on the surface of the duct section, obtaining the airflow. Several thermocouples type K coupled to ALMENMO 2890-9 were used to evaluate the temperature of heated air at the outlet, ambiental air and collector surface.

Using all the data collected, we have evaluated several quantities in order to be able to compare the collectors giving their thermal characteristics. In this study, the heat transferred from the plate to the air (P) was quantified by the air temperature rise, using:

$$P = mair * cp * (Tair.plen - Tamb) \quad (1)$$

Three temperature probes (K-type thermocouples) were used to measure the air temperature of the ambient (Tamb), the surface temperature on the metal plate (Tpl) and the air temperature at the exhaust pipe (Tair.plen). The extracted volumetric airflow rate was varied between 30 and 225 m3/h/m2. We define the thermal efficiency in order to characterize the thermal behavior:

$$\varepsilon = (T_{air.plen} - T_{amb})/(T_{pl} - T_{amb}) \quad (2)$$

The results presented further show interesting values. The lobed geometry collector behaves better than round one, but the question is which configuration has the best performance.

3. Results

Regarding the results, the importance of a high absorbance factor for the metal cladding is highlighted when comparing the temperature difference for Type 4 and Type 6 (black painted and not-covered grey metal) for the entire range of airflows(Fig7 a). The same graphic indicates a higher difference in temperature for lower airflows (less than 150 $m^3/h/m^2$). The results found are in agreement with the literature[19], indicating that low airflows conduct to better results.

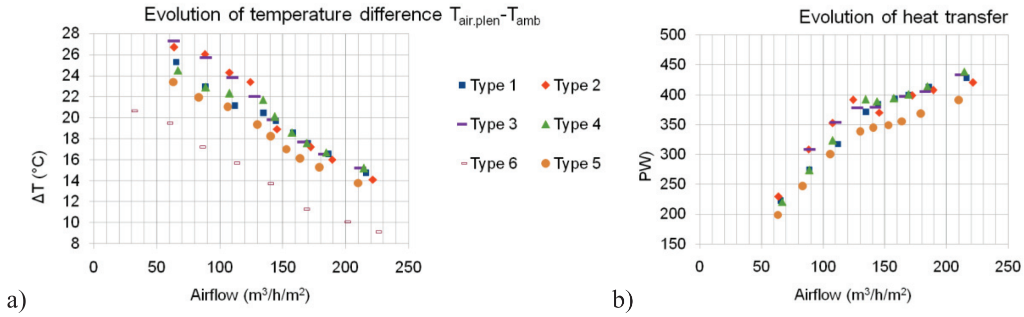


Fig.7 Thermal behaviour for the perforated solar collectors a) Evolution of temperature difference between the heated air and the ambient air for all 6 cases; b)Evolution of heat transfer when considering all 5 cases of black painted claddings

On the other hand, considering all the cases where the cladding is painted in black, the results indicate a better performance for lobed cases, placing the round perforation cladding on the last place regarding the heat transfer, especially when we have larger values for the airflow (more than 15% increase for lobed geometries). The difference of 15% for the heat transfer is easily observed for airflows between 80 and 220 m3/h/m2, indicating an optimal range for this application. Note that the heat transfer follows, for each of the plates, an evolution of natural logarithm type. However, dissimilarities remain as a quantitative point of view. In effect, the Type 5 reveals a maximum of about 390 W and the other plates, a maximum of the order of 440 W for the same flow.

The temperature difference evolution also indicates that there is an interest in analyzing the thermal behaviour for two different ranges: 50-150 m3/h/m2 and 150-250 m3/h/m2.

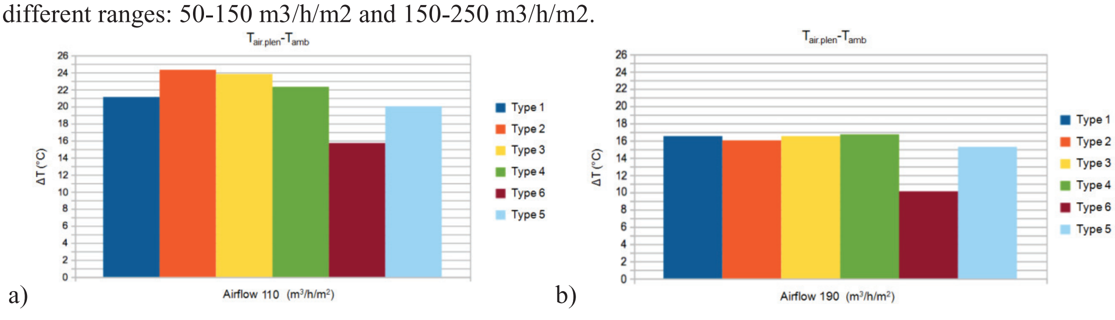


Fig.8 Temperature difference for the perforated solar collectors a) airflow 110 $m^3/h/m^2$ b) airflow 190 $m^3/h/m^2$

The 6 types of perforated collectors perform differently for these two ranges. We have chosen for each range a specific airflow: 110 and 190 $m^3/h/m^2$ for which we have evaluated the temperature difference. For the first value, Type 2 and Type 3 perfom better, while in the other case we cannot see a significant difference. We can conclude that for a specific range of airflows we can chose a certain type of collector with lobed geometry, which os more appropriated for the expected results.

The results can be also expressed in thermal efficiency as defined in Equation 2.

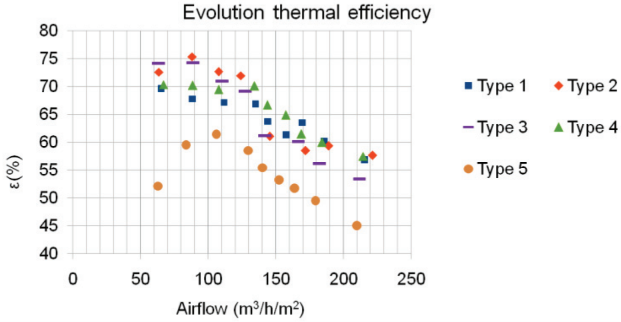


Fig.9 Temperature difference for the perforated solar collectors a) airflow 110 $m^3/h/m^2$ b) airflow 190 $m^3/h/m^2$

Considering the concept of saving energy has a vital role in systems explotation, our choice for a certain cladding will orient towards a collector capable of providing high heat transfer. Given the results it is obvious that a lobed geometry perforation will provide these charactersitics, when comparing with classical collectors with round orifices. According to the results, choosing a lobed geometry for the collectro will provide an average gain of about 15%. Thus, we have experimentally shown that incorporating lobed geometry is energetically and economically more valuable than a circular geometry.

4. Conclusions

As a general first conclusion, after an overview of the specialized literature, we can conclude that solar thermal technologies are not yet playing the important role they deserve in the reduction of buildings' fossil energy consumption and consequent greenhouse gas emissions, even though the increasing oil price has constantly increase. This encourages us to proceed in finding new ways of improving the previous passive heat recuperative ventilated façade elements. At our knowledge, this is the first time when passive control of the orifice geometry is proposed for solar transpired collectors.

The round geometry induce a lower transfer , around 15% less than lobed geompetry implemented in solar collectors. The black covering of the metal cladding increases with up to 25% the efficiency. Thus, we have experimentally shown that implementing lobed geometry is energetically and economically more valuable than a circular geometry.

For lower ranges of airflows, the Type 2 (interleaved "×" and "+" perforations) and Type 3 (not aligned "+" perforations) induce a higher heat transfer in comparaison with other lobed geometries and Type 2 provided the higher efficiency at an airflow of 90 m3/h/m2.

Further studies are necessary for improvement of such systems, as special cladding covering, increased surface for heat transfer, optimisation of ventilation system etc.

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