INNOVATIVE VENTILATED ENVELOPE ELEMENTS FOR SOLAR HEAT RECOVERY IN LOW ENERGY BUILDINGS

Croitoru Cristiana Verona [1,2]; Bode Florin Ioan [1,3]; Meslem, Amina [4]; Nastase Ilinca [1]
[1]CAMBI Research Centre, Technical University of Civil Engineering Bucharest, [2]Politehnica University Bucharest, [3] Technical University of Cluj-Napoca, Romania; [4]: LASIE Laboratory, University of La Rochelle, France.

ABSTRACT

Several measurements were performed on an innovative perforated solar wall. It is made of metal cladding with perforations, installed at several tens of centimeters from a building wall, thus creating a cavity, heated by the solar radiation from the sun. Ventilation fans create negative pressure in the cavity, drawing in the solar heated air through the perforated panel. The results found in literature were compared with experimental results. A good agreement was found. In the CFD study, changing the geometry of the perforations will increase on one hand the perforation's perimeter and it would generate complex fluid dynamics, resulting in a higher efficiency of heat recovery of these devices.

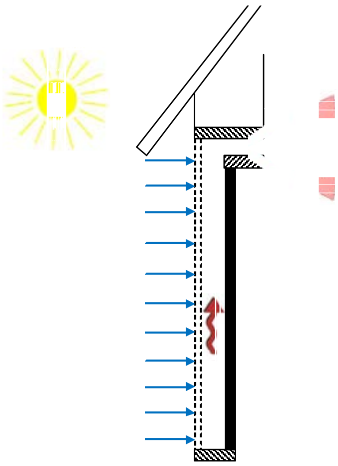
INTRODUCTION

The new European Directives concerning energy performance of buildings 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 important challenges for civil engineers. Generally, building sector consumes 35.3% from the total energy demand. This energy demand is caused mainly by the HVAC (Heating Ventilating and Air Conditioning) Systems. During the cold season in cold countries, the heat demand of the building represents the highest percentage from the total amount of energy demand, while during the summer, air treatment or ventilation is a major consumer of electrical energy. In this context, the use of renewable energies is an attractive solution for fulfilling the two requirements: indoor quality and energy efficiency. Among these renewable energies, the use solar passive systems are easy to implement and efficient from the accessibility point of view in the zones with solar potential.

The Unglazed Transpired Solar Wall (UTSW) is made of metal cladding with perforations, installed at several tens of centimeters from a building wall, thus creating a cavity.

The schematic drawing of this type of solar collector is as illustrated in Fig. 1. The metal cladding is heated by the solar radiation from the sun and ventilation fans create negative pressure in the air cavity, drawing in the solar heated air through the perforated panel. The air is generally taken off the top of the wall (due to air temperature gradients in the cavity) ensuring that all of the produced solar heat is collected, and then distributed in the building via the ventilation system.

A literature survey lead us to some interesting conclusions: (i) a consequent part of the heat transfer between the air and the solar collector is occurring during its passage through the perforation orifices; (ii) it is preferable to have a non-uniform flow on the back of the plate.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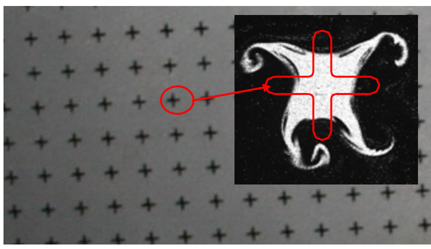
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Fig. 1 a) Schematic drawing of an unglazed transpired wall, b) Innovative perforated panel developed at ULR [1]

On the other hand, passive mixing techniques applied to HVAC air diffusion terminal units have been developed greatly during the past decade, since a collaborative research team from the University of La Rochelle and UTCB dedicated numerous studies to these devices [2-11]. A new research direction has been started last year at La Rochelle University (ULR) regarding the possibility of using passive control for enhancing heat transfer in impinging jet flows [12]. All these studies use a special geometry of nozzles, ailerons or orifices, which is called “lobed geometry”. An example of such geometry is the lobed orifice**.** In Fig.1 b is presented a perforated panel with lobed orifices (cross shaped or 4-lobed orifices). For the same effective area (same equivalent diameter) the perimeter of the lobed jet is much larger than the one of the circular orifice, increasing the contact boundary between the air flow passing through the orifice and the orifice’s thickness. Under low or moderate Reynolds numbers, such as the one characterizing the flows in the UTSW, the analysis of the elementary lobed nozzle and orifice jets shows that the lobed shape introduces a transverse shear in the lobe troughs [7, 13-15].

EMPLOYED METHODS

Experimental study

The experimental study was performed in controlled laboratory conditions with indoor temperature and relative humidity permanently monitored. Two types of perforated panels were tested. The baseline panel with round shape perforations and the innovative panel with lobed cross-shaped perforations. The equivalent diameter De of both geometries of orifices was 5mm.

The porosity for each type of tested perforated panel is given by the distance between two adjacent orifices, from centre to centre, S=4De.

The perforated panels 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.

At a distance of 30 cm of the plate four Metal Halide Flood Lights were placed, each corresponding to a lightning level of 400 W.

The plate has a perforated surface of 1 m^2 and collects only a certain percentage of the total radiative intensity emitted by the lamps. The radiation transmitted effectively between the source of light and the plate was considered to be around 800 W/m^2 (value in agreement with the experimental conditions from [16]).

Three temperature probes (K-type thermocouples) were used to determine the air temperature of the ambient (T_{amb}), the air temperature inside the box (T_{box})and the air temperature at the inlet of the exhaust pipe (T_{pipe}).

The extracted volumetric flow rate was varied between 10 and 150m^3/h. The flow rate was evaluated using an omnidirectional velocity probe from TSI, which was placed inside the exhaust pipe.

Fig. 2 Experimental set-up photograph: Radiation lamps and a perforated panel

Numerical case study

Numerical simulations by CFD approach using a RANS (Reynolds Averaged Navier Stokes) model were performed to study the airflow and heat transfer through the two types of perforations for different values of the airflow.

Given some considerations of symmetry and in order to save numerical resources for a finer mesh, the numerical study was performed for a smaller perforated cladding corresponding to a part of the experimental panel. The model comprises 25 perforations (Fig. 3), with the same spacement S=4De between two adjacent center of orifices, as in the experimental case. The metal cladding has a size of 10 cm by 10 cm positioned at 15 cm from the exhaust surface. In this study, our idea is to test the capabilities of the CFD models to reproduce from the global point of view our previous experimental results [17] in order to investigate in a next step which is the influence of the flow's dynamics on the heat transfer enhancement.

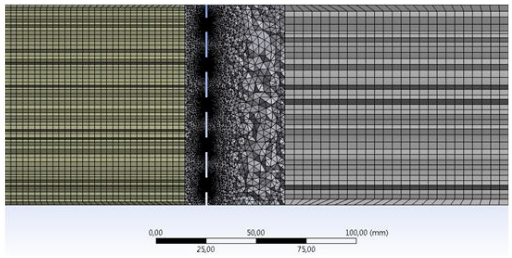

Fig. 3 Section through the used mesh

The boundary conditions on the perforated plated considered an imposed thermal flux such as in the experimental case. The rest of the walls are considered with 0 W heat-fluxes. The air is aspired through the perforations.

The accuracy of a CFD simulation depends, in a high percentage, on the way of replicating the geometry that defines the calculation domain and the heat sources, with specific boundary conditions. The computational domain comprises 4.5 million hybrid cells: both tetrahedral and hexahedral cells for a better characterization of the flow. Inside the orifices a first layer of 0.2mm was applied with a growth factor of 1.15. Outside the orifices influences, the mesh on the plate has a first layer of 5mm, with a growth factor of 1.15. The viscous model was chosen to be k-omega SST in agreement to previous studies performed on lobed perforations[18].

RESULTS AND DISCUSSION

The studies performed for solar walls systems showed good results in terms of energy efficiency. In this context the use of solar passive systems is encouraged by national regulations as they can have a significant contribution to achieve high performances and to save energy for winter heating and for summer cooling. A quick survey allows us to be aware of the huge possibilities of such devices in energy recovery. For instance, the CFD study of Arulanadam et al. **[19]** concludes that not only metal cladding could be used for the perforated absorber but even low conductivity materials can lead to acceptable thermal efficiency of the system, for low porosity of the transpired plate absorbers and for low velocity flow situations. But studies such as the ones of Van Decker et al. **[20]**, Gunnewieck et al. **[21, 22]** are very interesting from our point of view, given the information related on the direct possibilities of improvement of these devices. The early numerical study of Gunnewieck et al. **[21]** highlights the importance of a non-uniform flow and of a low velocity on the efficiency of unglazed transpired solar air heaters of large area. Van Decker et al. **[20]** show that in no-wind conditions, about 62% of the ultimate temperature rise of the air is predicted to occur on front-of plate, 28% in the hole and 10% on the back of the plate.

Cordeau and Barrington [23] in their study of an UTSW used for bringing fresh air in a broiler barn, reveal that the efficiency of the solar air pre-heaters reached 65% for wind velocities under 2 m/s, but dropped below 25% for wind velocities exceeding 7 m/s, with an annual return on investment of 4.7%. Different other case studies of UTSW [16, 21-31] pointed out *an energy efficiency of the system used from 52% to 68%, being an important benefit in terms of fossil energy consumptions savings*.

In the present study, the heat transferred from the plate to the air (P) was quantified by the air temperature rise, using:

$$P=m_{air}*c_p*(T_{pipe}-T_{amb}) \quad (1)$$

where m_{air} is the mass flow rate.

The efficiency of the panel was defined as:

$$\varepsilon=\frac{P}{I_T A_{pl}} \quad (2)$$

where P is the heat transferred from the plate to the air, I_T is the irradiation provided by the lamps to the plate's level and A is the surface of the plate of 1 m^2.

In Fig. 4 we represented the evolution of the variation of the heat transferred with the velocity on the hole in the experimental case. The cross shaped holes seem to be more efficient compared to the round orifices, with a maximum difference of heat transfer around 30 W. As it is visible in this figure, the higher the velocity, the higher the heat transferred form the plate to the airflow.

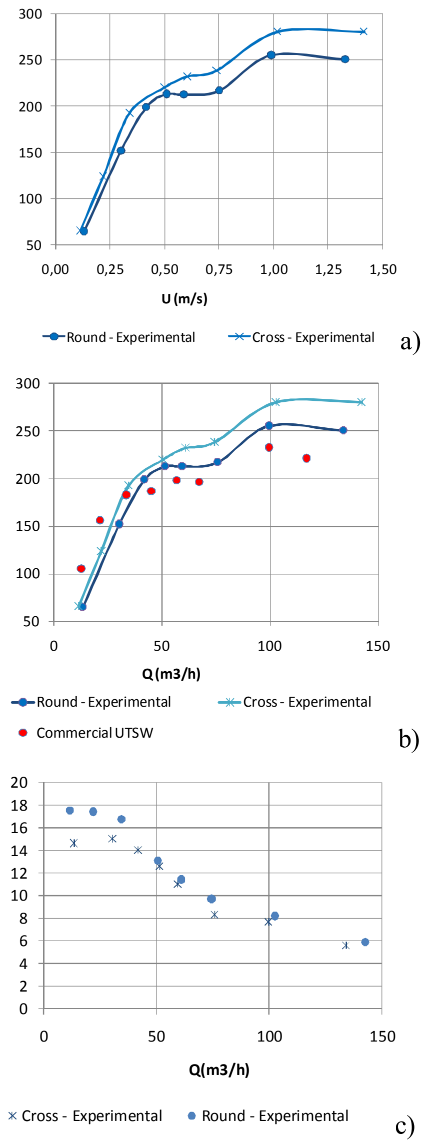

Fig. 4 a) Heat transfer evolution as a function of the velocity in the pipe; b) Heat transfer evolution as a function of the airflow and comparison with a commercial USTW, c) Temperature difference as a function of the airflow

On the other hand, the difference between the ambient temperature and the temperature of the airflow aspirated through the perforated plate decreases with the velocity or airflow increase. We can observe in Fig. 4 that the lobed orifices lead to a faster decrease in temperature.

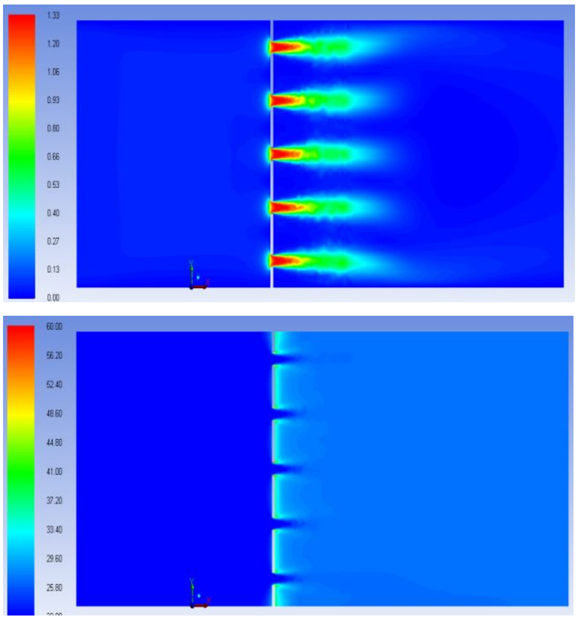

Fig. 5 CFD fields for the round perforations at a flow rate of 96 m^3/h: a) velocity, b) temperature

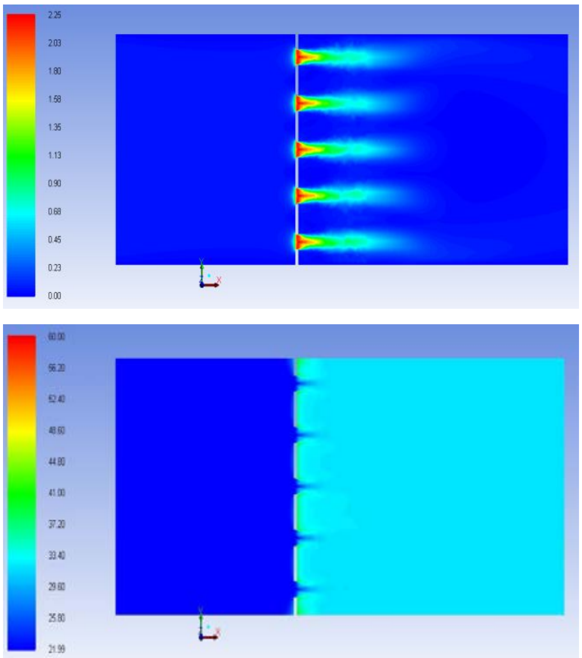

Fig. 6 CFD fields for the cross-shaped perforations at a flow rate of 101 m^3/h: a) velocity, b) temperature

Let us take a look to the CFD results compared to the experimental data. In Figs. 5 and 6 we present typical velocity and temperature fields in a plane passing through one of the perforation's rows adjacent to the median plane.

In Fig. 7 we superposed experimental and numerical data for the temperature differences obtained for the two type of perforations. While in the case of the round shape perforation the temperature difference between the ambient temperature and the temperature of the airflow aspirated through the perforated plate are little underestimated, in the case of the lobed perforation they are rather overestimated. We notice however the similarity between the experimental data of Leon et al. [16] and our numerical data.

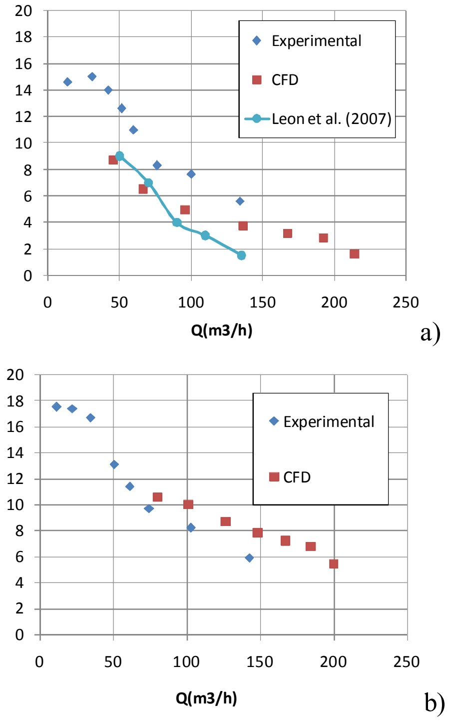

Fig. 7 Temperature difference as a function of the airflow: a) circular perforations b) cross shaped perforations

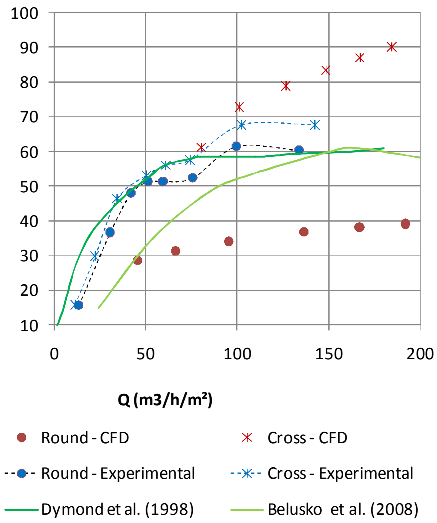

Fig. 8 UTSW efficiency for different volumetric flow rates

In Fig. 8 are given thermal efficiencies for the two UTSW from experimental and numerical cases, in comparison with the data obtained by using a commercial UTSW and the two models proposed by Belusko et al. et Shukla et al. for UTSW without wind and with circular perforations with the same equivalent diameter as in our case [29, 32]. For both perforation rates studied in the present experimental campaign we can see an advantage of the innovative perforated plate with lobed orifices compared to the baseline round orifices panels. They present also a clear advantage for high flow rates when compared to the analytical models of Belusko et al. and Shukla et al. for panels with circular perforations.

The CFD model gives for in the case of the circular perforation much underestimated efficiency values which points out the fact that there are improvements to be done to the numerical model. However, in the case of the cross-shaped perforations several numerical points are close to the experimental values.

CONCLUSION

The study was a first CFD test on an unglazed transpired solar collector (UTSW) which is equipped with cross shape perforations. Because such geometries require very fine meshes, a scaled model of the experimental would be the answer to numerical modelling for such case. The results showed very good agreement with the experimental study, fact that validated our model. This lead us further to a case study, where different airflow rates were tested. The efficiencies calculated proved the advantage of cross-shaped models in comparison t o classical ones. More of that, the comparison of a classical UTSW with a new one with innovative perforation geometries leads to interesting results, with more than 15% increase in thermal efficiency for volumetric flow rates higher than 100 m^3/h. Several studies have been performed which showed what are the most cited parameters (wind speed, suction speed, radiation etc.) and what is their influence on the thermal behaviour of an UTSW, but some other less common effects such perforation shapes still need further investigation.

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