Analysis of velocity and temperature fields inside an air solar collector – A numerical approach

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The numerical study is performed on a glazed transpired solar collector, investigating the effect of different distances between the glazing and the absorber (30 and 50 mm) for different airflow rates. The results show that the best solution among the tested configurations is using the 30 mm distance between the glazing and absorber, no matter what the air flow rate is. The efficiency of the glazed transpired solar collector (GTC) in this case is between 50%-61% for the range of airflow rates studied and higher with around 15% compared to configurations with larger distance between the glazing and absorber. The purpose of this study is to prove the efficiency increase due to pass-through elements disposals complementary with the passive components implementation, underlining the benefit of passive solar systems.

1. Introduction

Building sector is one of the biggest energy consumers, being responsible for more than 45% of the total worldwide energy demand [1]. Moreover, year by year the CO_2 emissions around the world are higher and global warming threats are more and more visible. In this context, the use of renewable energy sources in order to achieve indoor comfort and low energy consumptions is mandatory. The renewable sources can provide low-cost energy consumption when using passive systems. Among these renewable energies, the use solar systems are easy to implement and efficient from the accessibility point of view in the zones with solar potential. Among the renewable sources, solar thermal energy is considered to be one of the most promising solutions due to its abundance [2]. Air solar collector is a simple, low-cost, efficient pre-heating system and can be opaque or transparent, plate or transpired, with or without integrated energy storage [3, 4].

Transpired solar collectors are usually a cost-effective solution taking into account their low cost of investment, high efficiency [5] and fast return of investment [6]. Moreover, the transpired air solar collectors are market validated solutions being implemented already in large buildings across the world [7, 8]. The solar radiation, ambient (outdoor) temperature, air flow, orifices geometry, pitch, collector geometry, solar absorber material are very important parameters which defines the efficiency of a solar collector [9]. Also in order to assess the impact of a transpired solar collector it is important to determine the rise in temperature (ΔT, difference between the outlet air temperature and ambient air temperature), the efficiency of the solar collector (η) and the efficiency of heat transfer or heat exchange effectiveness (η_t) [7, 10].

In the last years, many numerical studies were performed at CAMBI Research Center (TUCEB) oriented toward improvement and a better understanding of the solar collectors, some of them being presented in [11-13]. The numerical approach from this study is performed on a glazed transpired solar collector, investigating the effect of different distances between the glazing and the absorber (30 and 50 mm) for different airflow rates.

2. Methods

For the numerical study, Ansys Fluent 19.2 commercial software was used. The studied geometry (Figure 1 A and B) was a reproduction of a real scale solar wall experimental setup presented in [14]. The geometry consists in a glass panel (2m x 1m) mounted at a certain distance in front of an aluminium (Al) sheet with the same dimensions (Figure 1 C). The thickness of the Al sheet is 2mm. The Al panel has 181 of square shaped perforations (50mm x 50mm) disposed interleaved as in the figures below.

A. B. C.

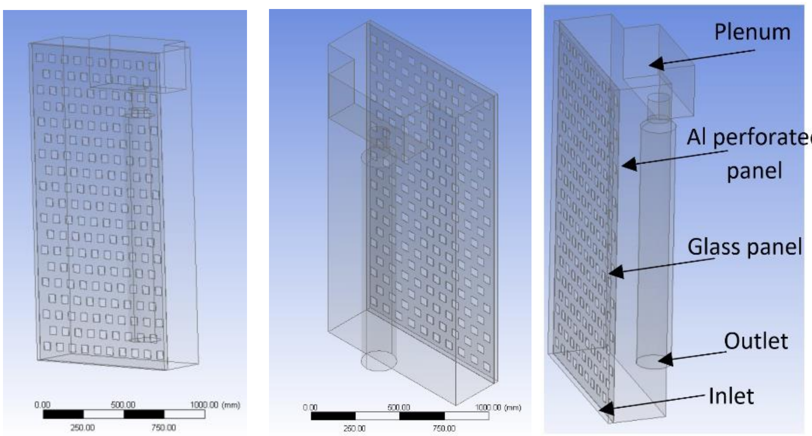


Figure 1. Solar wall studied geometry a) Front view, b) Back view, c) Parts of the studied geometry

In this study, two geometries were analysed. The differences between them consisted in the position of the glass panel relative to the Al sheet. In Figure 2A is presented the case with 30mm distance and in Figure 2B, 50mm case can be seen.

A. B.

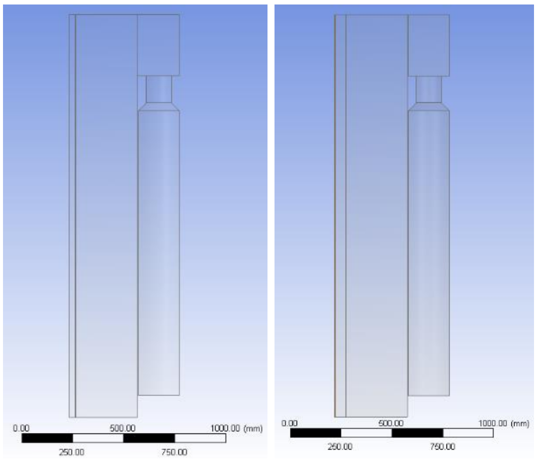
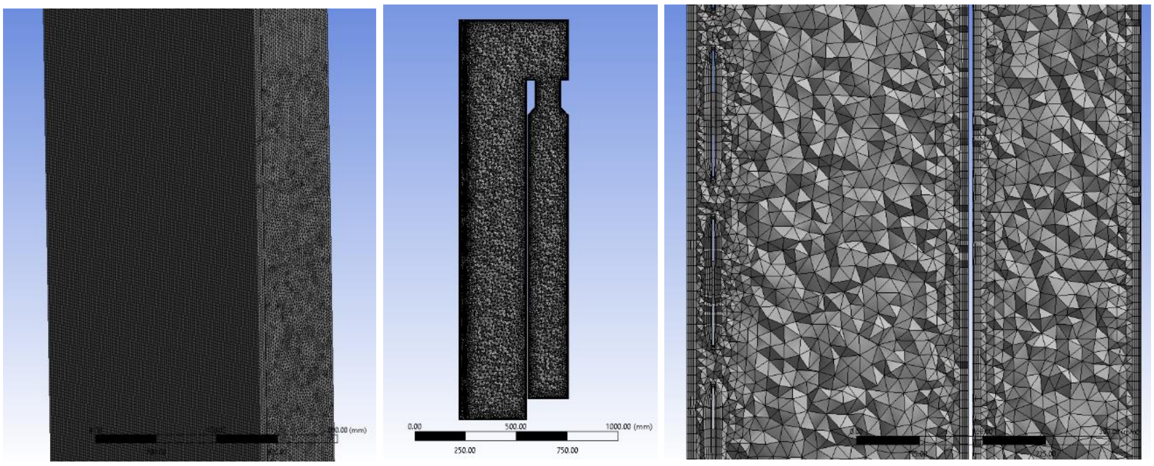


Figure 2 Analyzed cases a) 30mm case b) 50mm case

A mesh independency study was carried out between 714000, 1450000, 2950000 and 4130000 tetrahedral elements and the 2.95 million elements grid was chosen for further studies. Due to coarser perforated absorber, the CFD model supported finer meshes for whole system of solar collector.



A. B. C.

Figure 3. 2.95 million tetrahedral elements a) front view b) longitudinal section c) closeup longitudinal section

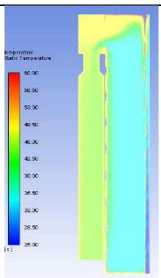
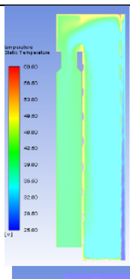
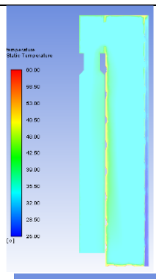
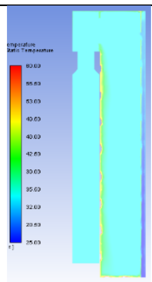
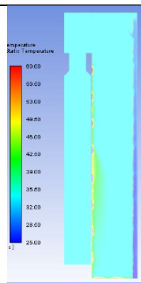
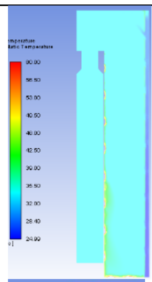
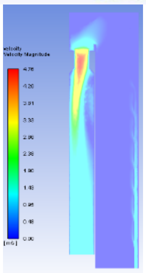
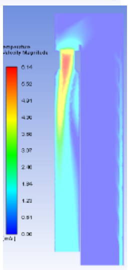
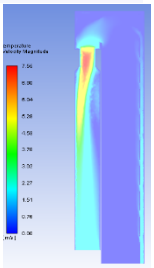
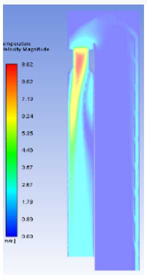
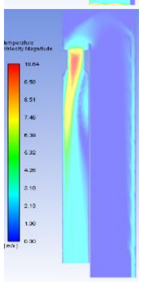
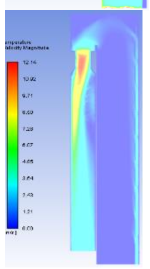
Realizable k-e model was used as viscous model with enhanced wall treatment for the near wall treatment [15]. Energy equation was activated, and density was calculated for air as ideal gas. Solar load was taken into consideration using Solar Ray Tracing module with a direct solar irradiation of 800W/m^2 and diffuse solar irradiation 150W/m^2. Sun direction vector was computed from solar calculator for Timisoara city (Romania). To take into consideration the radiation inside the box, S2S radiation model was employed.

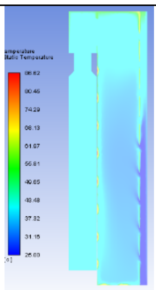
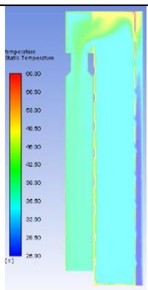
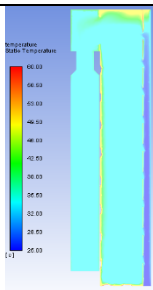
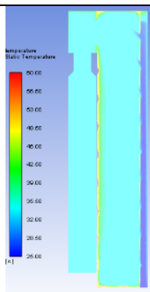
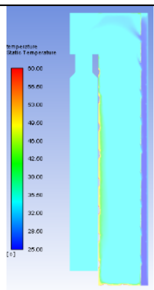
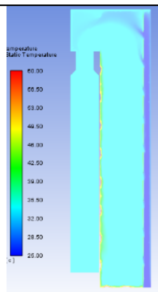
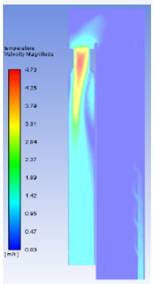
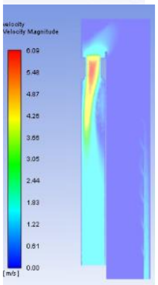
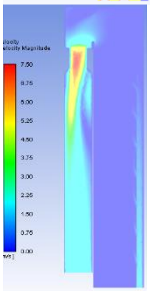
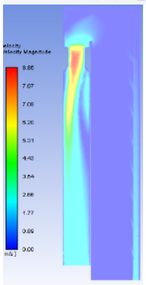
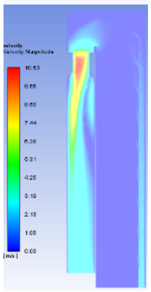
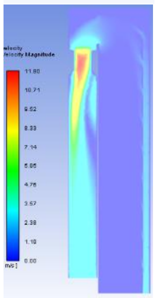
As boundary conditions for inlet, a pressure inlet with 0 Pa was imposed. For the outlet, given the fact that in the experimental setup we have a fan in this area [14], mass flow outlet was used for six different flow rates corresponding to 158, 203, 250, 296, 354, 397 m^3/h.

3. Results

The results indicated different thermal and dynamic behaviour in the two cases analysed, for each airflow step. The objective of our study was to evaluate the outlet temperature values and to determine which is the recommended air flow rate and plate distance for the solar collector analyzed.

Table 1: Temperature and velocity fields

30 mm	158m3/h	203m3/h	250m3/h	296m3/h	354m3/h	397m3/h
Temperature						
Velocity						

50 mm	158m3/h	203m3/h	250m3/h	296m3/h	354m3/h	397m3/h
Temperature						
Velocity						

Analyzing the temperature and velocity fields for the two cases we can see an evolution on the increase on outlet temperature for the case of 30 mm distance between the glazing and absorber. The velocity images show how for the lower airflows the air is flowing on the inferior part of the collector due to natural flow convection process, while for higher airflows, the air is flowing uniformly over the whole surface of the collector. While the highest increase in temperature is for the case of 158 m3/h at distance of 30 mm, we can see that the highest increase is for the case of 203 m3/h at the distance of 50 mm between the gazing and the solar absorber. The increase in temperature from inlet to outlet is between 34% to 78%.

Calculating the heat flux released by the solar collector, we see higher values for the case of a smaller distance between the glass and the absorber, indicating a higher efficiency.

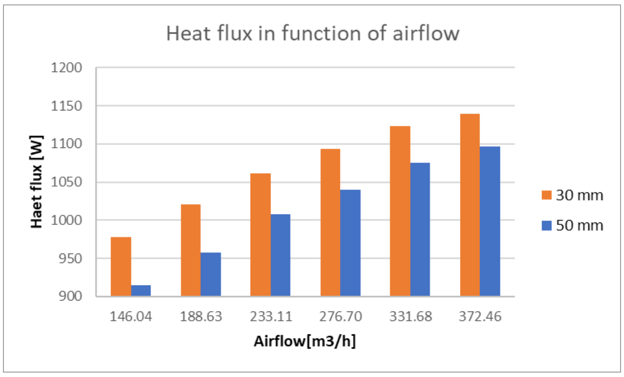


Figure 4. Heat flux released for the analyzed cases.

The heat exchange efficiency within an air solar collector can be expressed as the following formula [16]:

$$\varepsilon_{HX} = \frac{T_{air-out} - T_{amb}}{T_p - T_{amb}} \tag{1}$$

where $T_{air\text{-}out}$ is the air outlet temperature (K), T_{amb} is the ambient air temperature (K), and T_p is the absorber (plate) surface temperature.

The obtained values vary from 50% to 61% for the case of 30mm while for the case of 50 mm the efficiency varies from 41% to 54%, indicating that the better performances can be obtained when the collector is closer to the glazing sheet, where a heated zone is created.

However, observing the pressure loss for the two cases we see no significant differences between the cases. This fact has direct impact on the global energy consumption of the system, considering the fan for example.

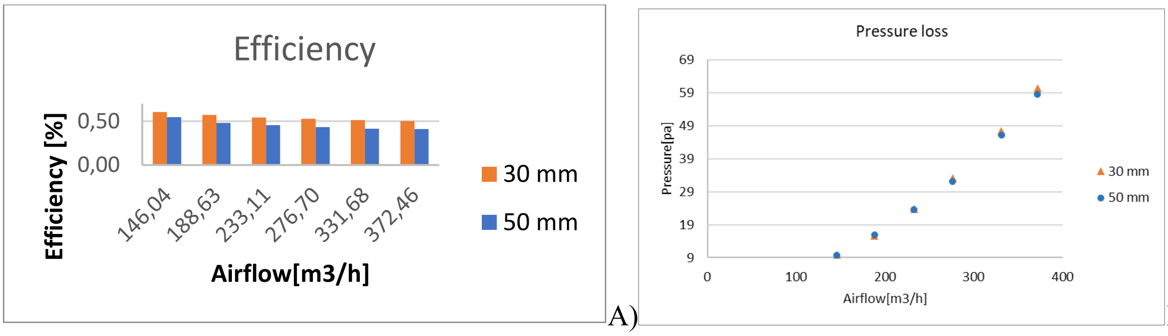


Figure 5. A) Heat transfer efficiency for the analyzed cases. B) Pressure loss

4. Discussion

Analyzing the results obtained, it can be concluded, that the configuration with a smaller distance between the glazing and the absorber is much more efficient, with a visible increase in the heat transfer, for all the air flow rates taken into account. For and airflow of 158 m3/h, the heat flux released was about 980 W, while for the case of 50 mm, the heat flux was 920 W, indicating 30 W/m2 increase for a solar collector which has the smaller distance between the glazing and the absorber.

The results achieved by analyzing the GTC proposed in this study, correlated to experimental findings from previous studies, show the potential of such solutions for preheating the air in the ventilation systems of the buildings. Moreover, the presence of the glazed surface significantly reduces the negative impact of wind velocity on the overall efficiency of air solar collectors, as indicated also by other studies[17, 18]. Thus, this structure of GTC can be used with promising results to space heating and ventilation in cold-temperate climate, as previously showed by Gao et al. [19]. Confirming the experimental findings, the results show that the best solution from the tested configurations is with 30 mm distance between the glazing and absorber, regardless what the air flow rate is. The validated CFD model can be further exploited for other passive or structural improvements in order to achieve even better results.

5 Conclusions

Nowadays the buildings sector is responsible for over one-third of the total energy consumption and CO_2 emissions, being the largest energy consuming sector in the world [20], while the requirements regarding energy use reduction and the CO_2 emissions are more and more strict [21]. Therefore, in order to reach these goals, it is necessary to implement highly efficient passive systems and solutions by using renewable energy sources to obtain the indoor comfort parameters with minimum energy consumption.

Thus, the studied GTC system provides promising results. The heat transfer between the air and the metal is intensified depending on the flow's characteristics and other external parameters which can have an important influence and can increase the overall heat transfer contributing to better efficiency of the GTC.

The GTC system taken into consideration in this work has allowed to determine the best configuration in order to be implemented in future studies regarding “active façades”. Starting from this configuration, inertial elements can be integrated within the GTC system in order to enhance its performance (e.g. phase change materials).

Acknowledgement
This study was financed by Romanian National Authority for Scientific Research, project CIA-CLIM "Smart buildings adaptable to the climate change effects" PN-III-P1-1.2-PCCDI-2017-0391.

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