Parametric assessment of a building active façade by means of a combined metallic sandwich panel with an unglazed solar collector

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Abstract. The building sector has a poor performance in terms of energy efficiency and is looking for alternatives to reduce the use of fossil fuels on building use stage. Renewables are unlimited and solar thermal energy is a technology with a demonstrated potential. The façade is a key element able to harness renewable energy coming from the sun becoming in an Active Solar Thermal Façade (ASTF). The main purpose of this study is the development of a parametric study using a numerical model to analyze the behavior of an unglazed solar collector. Thus, evaluating different design and meteorological parameters to show their influence on the heat transfer and the efficiency. The study shows that solar irradiation and mass flow are the most influential on thermal difference. However, for the efficiency ambient temperature and inlet temperature both are the most influencing ones. In brief, a set of parameters have a significant influence on the behavior of the ASTF that are fully governed by environmental conditions. Nevertheless, there are some other parameters that can be controlled during the operation. The challenge is to make a continuous configuration of this adaptable values depending on the external situation to achieve a higher performance for the ASTF.

1. Introduction

Being a sector with still a very poor performance in terms of energy efficiency, the building industry has recently been looking for several alternatives to improve the carbon footprint caused by the building's use stage. The development in the next years of new and modern buildings equipped with the latest technologies, should contribute to Nearly Zero Energy Buildings (NZEB). Nevertheless, the intervention in the current building stock should be one of the main priorities.

Solar thermal energy is a technology with demonstrated potential that is being widely developed, thanks to the pull of renewable industry. Highly significant and promising systems and technologies have been developed, focused into reducing the total amount of fossil fuels associated with energy consumption in buildings as well as minimizing the demand.

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The façade is a key element in this situation, linking indoor, where comfort is pursued, with outdoor under variable environmental conditions. Renewable energy coming from the sun is unlimited and the envelope could be able to harness it and therefore, becoming an active solar thermal façade (ASTF)

This research is focused on the behaviour of a low temperature active façade composed by an unglazed collector and a steel sandwich panel. The system was developed as part of a research project (BASSE) [1] concluded in 2016 and was tested at Tecnalia´s KUBIK® (experimental building in Derio).

2. Aims and Methodology

The main purpose of present study is the analysis of the unglazed solar collector as a progress over an assessment previously carried out [2]. Different alternatives for the dynamic design parameters will be evaluated even the influence of the external phenomena. Looking to analyse the behaviour of the active façade a parametric study will be performed, by means of a numerical model.

The study is focused on an active façade solution composed by four main components: (1) the sandwich panel with a polyurethane insulation core (k=0.025w/m^{2}k) combined with two slotted steel skins (k=50W/m^{2}k). Nylon pipes (k= 0.2 W/m^{2}k) (2) installed into the slots of the external skin to be later completed with the final steel cover (3) acting as solar absorber. Each panel has 6 parallel tubes and for interconnecting them modular header elements (4) are also provided inside the module. Dimensions of the standard panel are 3 m long, 1 m wide and 0.08 m thickness. A complete system was installed in a real building [3] and the preliminary tests demonstrated the potential of this solutions acting as a solar thermal collector. This geometry is commonly employed size in panel solution

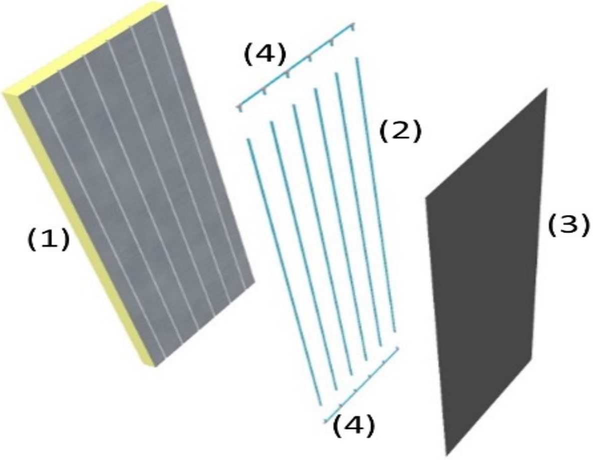

Fig. 1. Sandwich panel integrating an unglazed solar collector. Main components of the solution

As an extension of that previous study, where key design parameters for the panel and the circuit were performed highlighting the importance of the skin and pipe materials, an additional study for dynamic parameters is carried out in current research. These dynamic parameters are: inlet temperature, mass flow rate, ambient temperature, solar irradiation and wind speed.

Further, a validated Computer Fluid Dynamic (CFD) model was accomplished [2] and this will be the tool used to assess the dynamic parameters affecting the performance. For representing the fluid crossing an interior and an exterior wall are defined in the model, as well as a mass flow inlet and a pressure outlet. All these assumptions are displayed as boundary conditions for the different domains in Figure 2. T_{amb}, T_{in} and $\dot{m}$ are direct inputs to the model while the irradiation is transformed in a heat flux and the wind velocity is used to estimate the heat transfer coefficient (h_W).

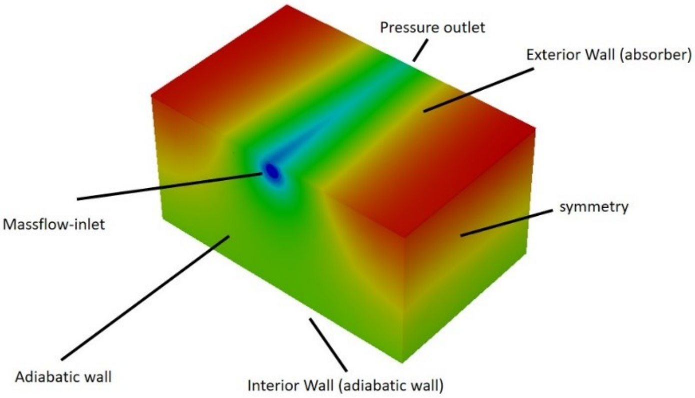

Fig.2. Representation of the 3D-CFD model, with boundary conditions.

The aim of the model is to calculate the heat transfer within solids and between solids and fluid, giving as a result the outlet temperature. Outlet temperature will allow to calculate the energy gained in the panel as the difference between inlet and outlet temperatures for certain mass flow rate (equation 1) as well as the efficiency (equation 2).

$$Q = \dot{m}\, C_w \,(T_{out} - T_{in}) \tag{1}$$

$$\eta = \frac{Q}{A_c\, I_{sol}}$$ (

The parametric study was developed within a realistic range with the aim of quantifying their influence on the collector performance as well as the thermal difference. A baseline has been selected for the set of parameters which gives an efficiency (η) of 0.43 and temperature difference (T_{out}-T_{in}) of 2.8 ºC.

Taking this baseline as reference (Table 1) the parametric study has been carried out. Making variable one parameter and fixing all the others for each studied case, the influence of that variation can be appreciated

Table 1. Baseline, maximum and minimum values for performed parameters.

Parameter	Baseline Values	Upper limit	Lower limit
Solar irradiation (l_{sol})	600 W/m^{2}K	100 W/m^{2}K	1000 W/m^{2}K
Wind speed (V_W)	1.5 m/s	1 m/s	6m/s
Inlet temperature (T_{in})	15 ºC	10 ºC	45 ºC
Ambient temperature (T_{amb})	14 ºC	5 ºC	40 ºC
Mass flow rate ($\dot{m}$)	0.13 kg/s	0,04 kg/s	0.2 kg/s

3. Results

The parametric study carried out shows the difference between inlet and outlet water temperature (T_{out}-T_{in}) together with collector's efficiency (η). Thermal difference also represents the heat transfer according to the equation 1. The results are provided for each variable parameter.

3.1 Dynamic design parameters

Dynamic design parameters are easily modifiable parameters when the definition of the complete assembly is fixed. Inlet temperature and mass flow rate are those parameters that can be varied under such approach.

3.1.1 Inlet temperature and mass flow inlet

As the inlet water temperature increases from 10 ºC to 45 ºC (Figure 3), the temperature difference between the outlet and the inlet decreases [6] whereas the efficiency of the collector also decreases. The temperature and efficiency drop down from 3.23 ºC to 0.49 ºC and 0.49 to 0.07 respectively. Thus, a linear trend between inlet temperatures, heat transfer as well as for the efficiency can be appreciated.

On the other hand, (Figure 4) increasing mass flow rate from 0.04 kg/s to 0.2 kg/s represents a η increase from 0.34 to 0.46, while (T_{out}-T_{in}) is decreasing from 7.45 ºC to 1.99 ºC. An opposite trend for heat transfer and efficiency arises in this case as in similar studies performed by other authors [6, 7]. That means, for high mass flow rate the heat transfer is lower but the efficiency increases.

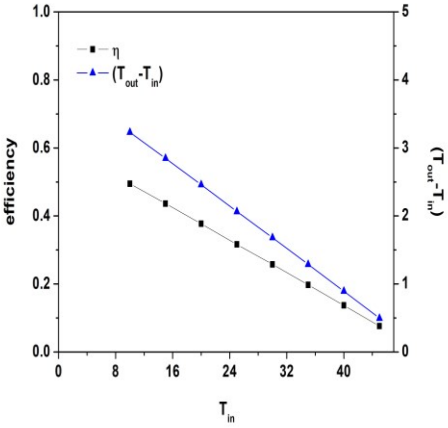

Fig. 3. Efficiency & temperature difference Vs inlet temperature

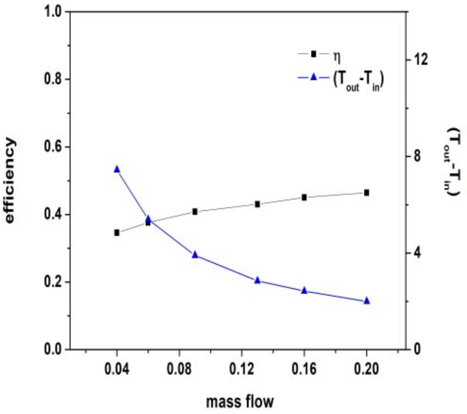

Fig. 4. Efficiency & temperature difference Vs mass flow rate

3.2 Dynamic Meteorological parameters

Although meteorological parameters could be predicted, these cannot be controlled as in the case of dynamic design parameters. Based on recorded values through the year, the collector behaviour has been predicted taking maximum and minimum values for ambient temperature, solar radiation and wind speed according to the case studied.

3.2.1 Ambient temperature

Figure 5 shows the variation of η and (T_{out}-T_{in}) due to ambient temperature. When the ambient temperatue variates from 5 ºC to 40 ºC, both paramters increase from 0.34 to 0.72 and from 2.22 ºC to 4.73 ºC respectively showing a linear tendency.

3.2.2 Solar irradiation

The solar irradiation apparently could be considered to be one of the most influencing parameters. This effect can be appreciated for the case of temperature difference (T_{out}-T_{in}) [4] and consequently to the energy output. But the impact is less significant on the efficiency change.

Even though solar radiation increases from 100 W/m^{2}K to 1000 W/m^{2}K, the efficiency barely increases from 0.40 to 0.43, while the (T_{out}-T_{in}) linearly raises up from 0.44 ºC to 4.71 ºC. The linear trend displayed for the temperature difference together with the irradiation, supposes a small variation in the efficiency.

3.2.3 Wind speed

The influence of the wind [5] has been carried out for velocities from 1m/s to 6m/s. As shown in figure 7, when the wind speed increases the efficiency and temperature difference both decrease. This trend is consequent with assessment made by other authors [8-9].

As the wind speed increases, the efficiency and temperature drop down from 0.46 to 0.27 0and 3.064 ºC to 1.802 ºC respectively, due to wind convective heat losses.

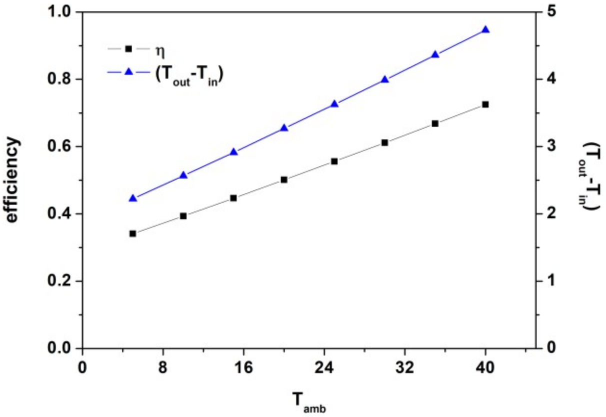

Fig. 5. Efficiency & temperature difference Vs ambient temperature

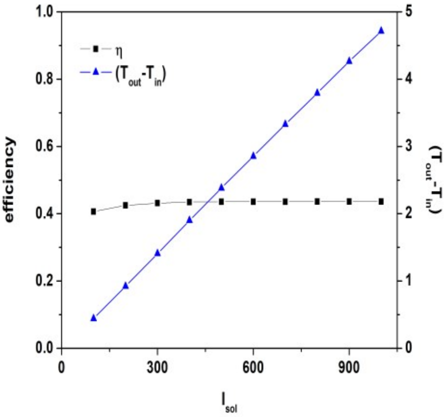

Fig. 6. Efficiency & temperature difference Vs solar irradiation

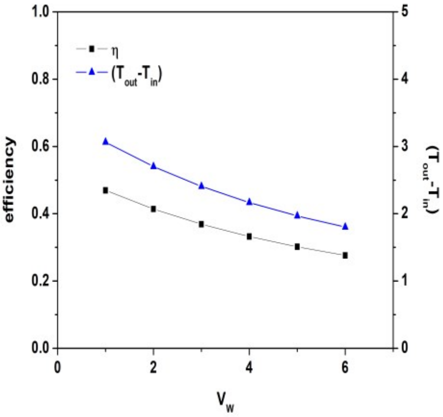

Fig. 7. Efficiency & temperature difference Vs wind speed

4. Analysis and discussion

Parameters with highest effect on the heat transfer are the solar irradiation and mass flow, giving temperature differences of up to 4.27 ºC and 5.44ºC respectively between the limit values considered. Other parameters affecting the temperature with less influence are, inlet temperature (2.77 ºC), ambient temperature (2.5 ºC) and the wind speed (1.262 ºC).

Regarding the efficiency, inlet temperature and ambient temperature display the greatest variance, giving a maximum variation of 0.41 and 0.38 respectively, followed by wind speed (0.19), mass flow (0.11) and solar irradiation (0.03).

As a consequence the temperature difference and the energy collected will be maximized when, solar irradiation an ambient temperature are high while mass flow, inlet temperature and wind speed are minimum.

It's worth noticing that those parameters with highest impact in the temperature difference (mass flow and solar irradiation) represent the lowest impact on the efficiency.

Figure 8 and 9 displays the performance of the maximum and minimum values for each of the 5 dynamic variables assessed, thus displaying the most influential.

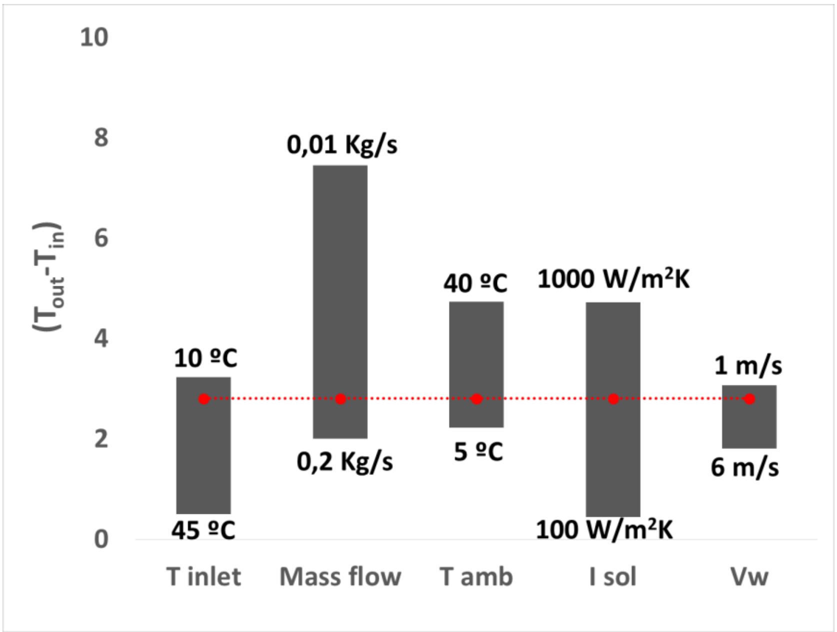

Fig. 8. Summary of the parametric study representing the maximum and minimum achievable (T_{out}-T_{in}) values

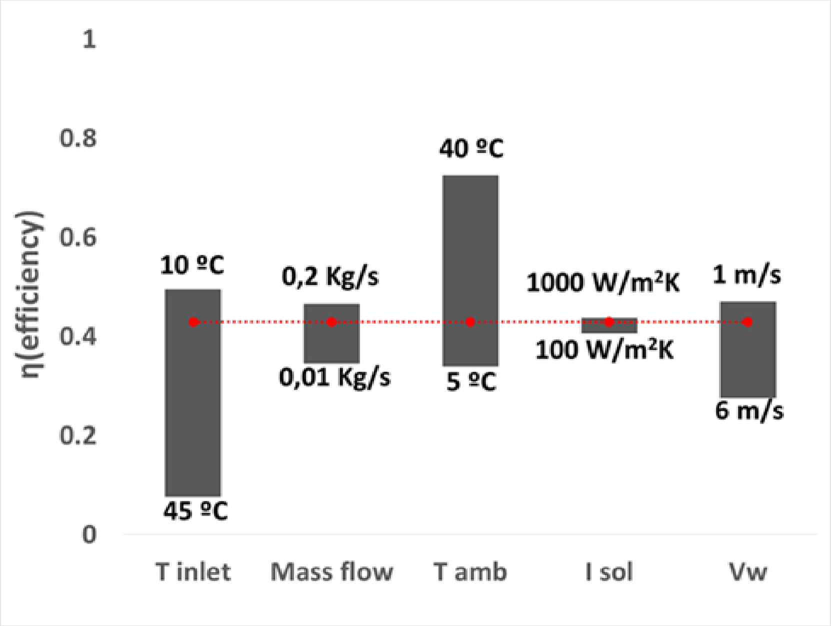

Fig. 9. Summary of the parametric study representing the maximum and minimum achievable efficiency values

5. Conclusions

The research developed, has carried out a parametric assessment for an active façade application. Based on previously made and validated numerical model, dynamic design and external meteorological parameters have been assessed, to show their influence in the heat transfer (T_{out}-T_{in}) and in the efficiency.

Five dynamic parameters have been studied. Two modifiable dynamic design parameters (inlet temperature and mass flow rate) and three dynamic meteorological parameters (ambient temperature, solar irradiation and wind speed.). A reference baseline has been established representing an efficiency of 0.43 and temperature difference of 2.8 ºC.

For three of the five parameters studied, inlet temperature, ambient temperature and wind speed the progression of the temperature difference and the efficiency evolve together. For the other two, mass flow rate and solar irradiation there's a crossed progression.

Moreover, the study shows that solar irradiation and mass flow are the most influential parameters for thermal difference but not for the efficiency. Increasing solar irradiation from 100 W/m^2K to 1000 W/m^2K the temperature difference reaches up to 4.3 ºC. Decreasing mass flow rate from 0.2 kg/s to 0.04 kg/s the temperature difference can reach up to 5.4 ºC, thus becoming the mass flow rate the most influential parameter for the heat collected.

However, ambient temperature and inlet temperature both are the most influencing parameters on the efficiency. That means that, decreasing inlet temperature from 45 ºC to 10 ºC the efficiency of the collector improves up to 0.41. And increasing ambient temperature from 5 ºC to 40 ºC, the efficiency also increases in 0.38.

To summarize, there are set of parameters that are fully governed by environmental conditions that have a significant influence on the behavior of the ASTF. On the other hand there are some other parameters that can be controlled during the operation of the ASTF. The challenge of a continuous configuration of this adaptable values depending on the external situation could strongly contribute to achieve a higher performance for the ASTF.

The benefits of this type of solutions are directly linked to energy saving in buildings. The system's efficiency can be improved based on the different set up of the studied parameters representing a higher solar contribution that, if properly combined with heating systems, represent a lower dependency on fossil fuels. Furthermore, the synergic interaction of these solutions with other devices such as a heat pumps or gas boilers can also increase the potential of active façades, thus improving the efficiency of both the façade and the heating system.

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