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Elements of influence for solar ventilated building facades: a review

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Elements of influence for solar ventilated building facades: a review

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Abstract. Climate change has become a fundamental concern for scientific researchers, architects and engineers, so it's required to improve the performance of sectors responsible for city and building infrastructure. Burning fossil fuels to produce electricity and heat is the biggest cause of climate change and emissions, and represents one third of total greenhouse gas emissions. Thus, buildings become responsible for improving the external environment, either by construction phase, rehabilitation process or by maintainability process. This work reviews and evaluates elements of influence for solar ventilated building facades in order to improve this field of research as this solution allows to achieve important energy savings

1. Introduction

Recent studies on global long-term energy consumption estimate that by 2040 total energy consumption will increase by 25% compared to 2014 [1], or even 48% compared to 2012 levels [2].

In addition, these estimates are anticipated in the context of an increase in energy efficiency for all energy-intensive sectors (construction, transport and industry). Practically, without the implementation of energy efficiency solutions in the short and medium term, global energy consumption estimates show that in 2040 an increase of more than 100% (110%) will be achieved over the 2014 values.This increase in energy consumption under these conditions is considered to reach even 140% compared to 2010.[2]

On the other hand, it relies on the fact that renewable energy sources will be more important to respond to this ever-expanding energy globalization. The analysis anticipated an average annual increase in the use of renewable energy sources of 2.6% between 2012 and 2040[1].

Also, an analysis of global climate change shows the achievement of a further increase in global average temperature on the basis of the 2016 values. Additionally, this is happening after other extremely high temperatures recently recorded on our planet, our previous maxims being in the years 2005, 2010, 2014 and 2015[3]. It is practically the third consecutive year in which we note a new record of average annual temperature on Earth, the main cause of which is undoubtedly the increase in the pollution of our planet's atmosphere.

In this context, there are a number of global and European actions to reduce energy consumption (which will also have an impact on the reduction of pollution) as well as increased use of renewable energy sources. Here is mentioned at the level of the European Union (EU) the "2030 Framework for Climate and Energy", endorsed by the European Council in 2014, which proposes to reach the following figures by 2030:

- reducing greenhouse gas emissions by at least 40% compared to 1990 levels;
- increasing the share of renewable energy sources to 27% of total EU energy demand;
- improving energy efficiency by at least 27%.[4]

On the other hand, it should be noted that the buildings sector is one of the main energy-consuming areas (example at EU level, buildings account for about 40% of total energy consumption [5]and 36% of total greenhouse gas emissions of the greenhouse [6]). For this reason, the construction sector enjoys a great interest in implementing solutions to increase energy efficiency and use of renewable energy sources.

As a consequence, there are also strategies for energy efficiency of buildings in Romania, which were developed even in the pre-accession period to the EU [7]. Also, national energy policies were adopted in Romania after the accession to the EU on 1 January 2007: "Romania's Energy Strategy for 2007-2020" [8], "National Strategy for Sustainable Development, Horizons 2013-2020-2030" [9], the "National Energy Efficiency Action Plan (NAPE III)" approved by the Government in 2015 [10],a document prepared on the basis of the requirements of Directive 2012/27 / EU [11] has been transposed into national law, Directive 2002/91/EC [12] has been fully taken up at national level by Law No 372/2005 [13] (which entered into force on 1 January 2007).

As part of solutions that can help reduce energy consumption of buildings, smart facades occupy an increasingly important place. This is mainly due to the fact that it has been demonstrated that the implementation of smart façades in building envelopes translates not only in reducing their energy consumption, but also in improving occupant comfort [14].

2. Classification of building facades

There are several definitions in the literature on the concept of smart facades[15], [16]. Synthetically, a smart façade is a complex product capable of reacting (self-adjusting) through its components (active or passive) to changes in the external and / or interior environment [17].

Also, several constructive solutions are included in the category of smart façades. The most common and equally applicable are the following: [18]: "double skin façades (DSFs)", "double glazed facades", "open joint ventilated facades (OJVFs)", "kinetic façades" and "solar façades". It should be noted that there is no clear delimitation between these different variants of smart facades, and a combination of two or even three of the solutions outlined above can be used.

In 1970, Zuk and Clark defined kinetic architecture as an architectural form that can be inherently displaceable, deformable, expandable, or capable of movement .[19] The term "kinetic" also indicates the body's response to a particular type of stimulus in biology (Wang et al) and an ability to modulate energy in its main forms: visible light and heat.

Fig. 1. “Kinetic” architecture façade [19]

Fig. 2. Exemples of active façade [19]

Active facades are defined as integrated elements of the tire that adjust to the weather conditions in order to maintain the parameters of the comfort conditions.[19], [20]

These different types of smart facades can also use the same technical solution. For example, solar collectors with air can be mounted in the exterior walls of buildings provided with solar façades or ventilated facades [21]–[23]. Furthermore, these "transpired solar collectors" (TSC) can also be associated with other methods of increasing energy efficiency (photovoltaic panels, Phase Change Materials - PCM, etc.) [22].

3. Elements of influence

O'Hegarty et al [24] state that the façade is the image of the building and is the result of coordination between project specialties and this must be considered at the design stage. Thus, according to the studies in the specialized literature, among the most important operating parameters for a ventilated solar façade are the following:

- absorbent plate (features)

- the size, step and geometry of the holes
- air flow and wind
- glass layer

3.1 Absorbent plate

The first parameter that influences the efficiency of the ventilated solar façade is the absorbent plate, which is generally made of metals such as steel, copper, or aluminum but can also be made of plastic. The main characteristics that influence the absorbent plate are related to material porosity, plate geometry, plate thickness, plate transfer surface and, last but not least, specific properties.

Thus, Vaziri et al.[25] asserts that the most used solar air heaters are those using glass (trombe wall) and non-transparent (solar wall). Mainly the conventional solar heaters are made of an insulated plate / plate, the insulated air ducts and the fan if it is an active system.

The absorbent plate is thermally insulated at the bottom and side where a glass layer is applied to form an air passage. By placing the glass layer on the outside, the heat loss through convection decreases at the surface of the absorbent plate, as a result leading to an increase in the temperature of the absorbent plate.

To improve the efficiency of conventional solar heaters, researchers have suggested improvements to reduce heat loss to the collector and increase the convective coefficient between the air and the absorption plate.

To minimize heat loss, double glasses have been suggested by some researchers [25]. By creating a double duct the air circulation spreads on both sides of the absorbent plate, thus increasing the energy efficiency of the assembly. [26]

Yeh et al. [27] designed and built double-flow air heaters with attached fins and greatly improved the efficiency of the solar heater collector.

Experiments have been carried out to study a device for inserting an absorption plate into the double passageway into a recycling hot-air heating plate. Their results indicated that by using "double-pass" type "recycling" devices instead of conventional double heaters, a significant improvement in collector efficiency could be achieved [28].

An experimental investigation of the double-pass solar heater with 2, 4 and 6 attached fins used layers of steel wire mesh as the absorption plate and longitudinal gauges installed along the air passage at the bottom and top of the solar heater. Thus, the maximum efficiency achieved for the double-pass solar heater was 63.74% for a flow rate of 0.0325 m3/h [29].

Krishnananth and Murugavel have conducted an experiment in which they wanted to improve the thermal performance of an air heater by incorporating heat accumulators [30].

Another elements for solar collectors is the color of the absorbent board, which is usually black, which is generally not consistent with building aesthetics.

In 2000, Tripanagnostopoulos et al. have built and tested three solar collectors with different colors of black, blue, red and brown with and without the outer glass layer. The results indicated that there are small differences between black solar collectors and other colors (red, blue, brown) which led to their acceptance as integration into a building [31].

Van Decker et al. performed a mathematical and experimental study on the conditions of the heat exchange between the plate and the outside air, stating that 62% of the heat transfer is performed on the outside face of the perforated plate, 10% on the inside and the rest of 28% being performed on the air passage through the holes.[32]

S. J. Arulanadam et al. showed that for the same plate geometry, the change of plate conductivity from 0.196 W/mK to 15.121 W/mK can led to a 10-20% decrease in efficiency and reducing the overall thermal efficiency by 5%. The results of the study show that if a plate is made of material with a low thermal conductivity (plastics) thermal efficiency of the collector can still be obtained [33].

3.2 The size, step and geometry of the holes

Experimental tests performed by Wang et al. show that with the increase of the diameter of the infiltration hole the temperature of the surface increases by about 8°C, thus with the increase of the diameter there is a phenomenon of air uniformity on the surface of the plate. Increasing the gap between perforations and more precisely the increase from H (high of the absorber plate) * 0.3 to H * 0.6 leads to the improvement of thermal transfer and surface temperature increase up to 61.8 °C, which means a temperature increase of 14.9° C, and for H * 0.9 the increase in temperature is 3.7°C, so these studies show that an increase over this percentage does not cause any significant change in the surface temperature of the heat collection plate.[34]

The height of the infiltration hole affects the uniformity of the airflow near the surface of the heat collecting plate, thus affecting the heat exchange of the system. An increase in height ratio causes the difference in outlet air temperature, heat collection efficiency, and lead also to an improved heat exchange efficiency. As the height ratio increases from 0.3 to 0.9, the temperature difference at the outlet increases by 6.8°C, the heat collection efficiency increases by 25% and the heat exchange efficiency increases by 10%.[34]

By changing the step (12 mm to 24 mm) and the diameter (0,80 mm to 1,55 mm) of the perforations in a solar collector, for high solar radiation (900 W/m2) and low air flows (72 m3/h,m2) Leon and Kumar have observed an increase in air temperature by 5.5°C. Furthermore, in the design, a solar wall must take into account the application in which it will be used and the need for the output temperature that can be adjusted by alternating the step between the perforations and the diameter of the perforations .[35]

The distribution of perforations on the surface has a significant influence on the fresh air preheating and implicitly on the efficiency of the system. On the other hand, the influence of perforation diameter and speed in the solar collector is slightly lower. An increase in the uniformity of the perforations in the upper and lower parts increases the efficiency of heat collection and the efficiency of heat exchange by approximately 25% and 10% respectively, which leads to an improvement in the outlet temperature to 15°C .[34]

The mathematical study by Biona et al. showed a decrease of the energy efficiency of the collector with the increase of the diameter of the holes with small distances between them.[36]

3.3 Air flow and wind

The wind is an important parameter in obtaining high efficiency solar collectors, this having a pronounced effect on the speed distribution on the collector plate, so to reduce its effect it is important to increase the air flow. The wind has particularly important consequences in the case of high buildings where the air speeds are high, so a wind speed of 5 m/s has been identified the maximum limit of the wind speed that affect the unglazed collector.[37]

An important strategy for increasing the efficiency of the solar collector would be to monitor its speed and to adjust the air flow according to the wind speed, thus avoiding a reverse flow inside the solar collector and a loss of heat.[37]

In the experiment of Chan et. al, the air temperature values were analysed in two directions, the air temperature passing through the holes and the air temperature running through the back of the absorbent plate, more precisely the air temperature in the plenum. They observed a temperature difference of 10% greater when passing through the air through the holes with the air temperature in the vertical direction under reduced solar radiation. For high solar radiation above 800 W/m2, they observed that the air temperature in the plenum box (vertical) is higher than the normal one (through the holes), so that an efficiency between 68-96% can be achieved.[38]

According to Leon and Kumar, a high temperature at the exit of the plenum box indicates a decrease of the efficiency of the collector solar.[35]

For high speeds, the efficiency of heat exchange is 15% and the efficiency increases to 69%, the explanation being given by the increase of the suction speed of the fan reducing the temperature of the exit air, but at the same time the infiltration rate increases, increasing the amount of air which goes into the collector.[34]

Gunnewiek et al [37] determined the minimum suction speeds of the solar collector so that the influence of the wind is canceled:

- over 0.0125 m / s the wind acts from the side with speeds higher than 5m / s
- over 0.017 m / s the wind acts frontally
- over 0.039 m / s for the action of the wind in a 45 ° plane

By applying the glass layer Gunnewiek et al [39] showed that it can increase the efficiency of the solar collector.

3.4 Glass layer

Bohumil Nabilek et al [40] states that TSCs(Traspired Solar Collectors) are sensitive to weather conditions his study of two solar collectors, one TSC(Traspired Solar Collector) and one GTC (Glazed Traspired Collector) type shows that GTC for temperatures between 22 ºC and 31.5 ºC the efficiency of the two collectors is approximately equal, but for low temperature weather conditions between 10 ºC and 23 ºC the efficiency of the GTC collector was about 40% higher than efficiency of the TSC collector.

Zhang et al. [41] finds the utility of the glass layer by describing 4 solutions for using GTC (figure 3):

- Complete air supply from outside (A);
- Mixture of indoor air with outdoor air supply (B);
- Heating the indoor air with the help of the GTC (C);
- Role of thermal insulator (D).

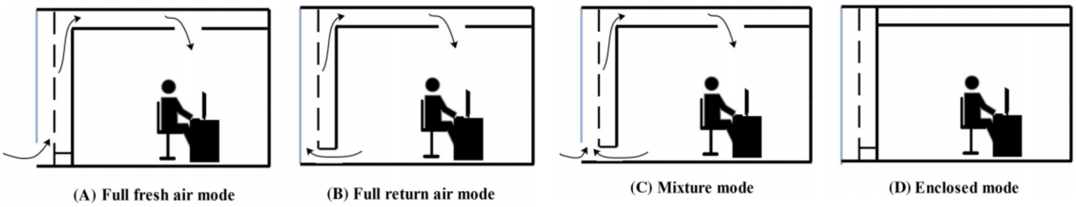


Fig. 3. GTC solutions [41]

Studies in the literature show that the use of the glass layer helps to increase the performance of the solar collector by increasing the air temperature in the collector. [42] Collins et al. conducts a numerical study showing that the performance of the solar collector decreases with increasing convective transfer at the plate, so this problem can be solved by using glass and transforming the TSC into GTC especially for cold climates. [43]

The economic study performed by Zhang et al [44] shows the importance of using a layer of glass over the absorbent plate to reduce convective exchange. The experimental study was conducted on a room with a volume of about 100 m^3 comparing different GTC solutions with conventional coal heating , the results being illustrated in Table 1 below.

Table 1 – Economical study [44]

Heating type	Life cycle cost	Saved energy	GHG reduction
GTC with corrugate plate	1376 euro	1.34 tce	73.56 tce
GTC with slots	1501 euro	1.57 tce	86.18 tce
Classic charcoal heating	2127 euro	-	-

Zhang [44] points out that GTC improves indoor air quality, reduces energy consumption and the corrugated plate of GTC helps improve heat collection due to the movement of air near the plate.

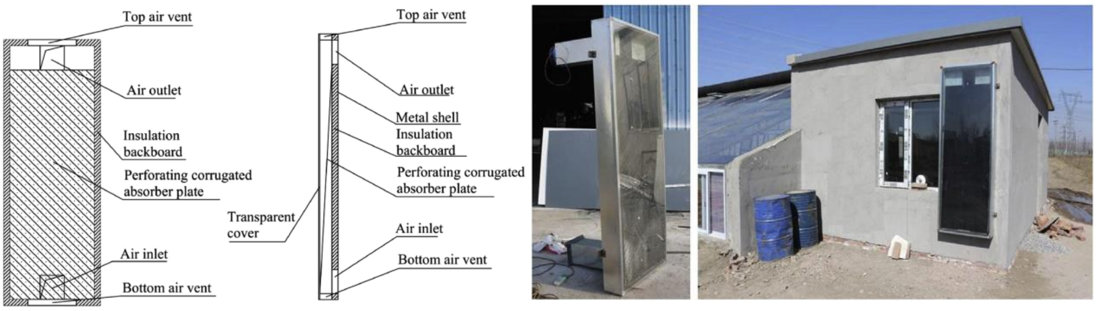
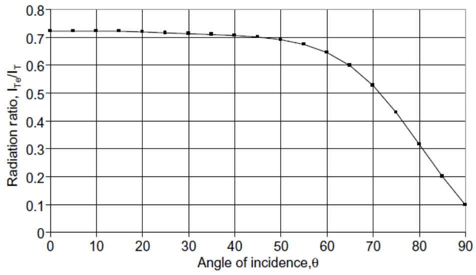


Fig. 4. Zhang experimental setup [44]

The numerical study conducted by M. Belusko et al. presents the comparison of two solar collectors with and without glass integrated in the roof, thus proving that the GTC performance is higher than TSC collector. (figure 6) [45]



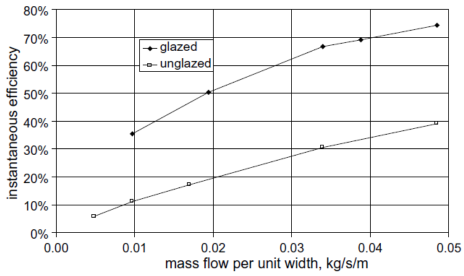


Fig. 5. Influence of incidence angle [45] **Fig. 6.** Efficiency of the GTC and TSC collectors[45]

Besides of the comparison between the two collectors, Belusko et al made a study showing the influence of the incidence angle on the radiation received by the GTC (figure 5), the interval 0-60^o represents the optimal interval in which the ratio between radiation absorbed by GTC and total radiation remains close. constant.[45]

The optimal distance between the absorbent plate and the glass was determined by Nahar and Garg in 1980 through an experimental study. They determined that the minimum distance is in the range of 4-5 cm so that the heat loss by convection is minimal and the shading of the absorbent plate due to constructive considerations. [46]

4. Conclusion

Larger perforations can improve the efficiency of heat collection, but they reduce the effects of air preheating, reducing the temperature difference between the introduced and exhausted air between 3-6°C. Consequently, we propose to fulfil a parametric study on this area which will lead to the determination of the optimum diameter that would enhance the efficiency of the solar collector.

Increasing fan speed and diameter leads to a progressive increase in heat exchange while the efficiency of the solar collector decreases gradually.

The distance between perforations and how these are arranged, have an important impact on the heat transfer and the efficiency of the solar collector. Subsequently, further investigations on this subject are needed in order to better quantify the best geometry under given conditions.

In conclusion, for solving the problems introduced by the cold climate of Romania and problems introduced by the high wind speeds on the perforated solar collectors, a viable and easy solution is the introduction of a glass layer in front of the solar collector.

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