Experimental Investigation of a Window Solar Air Collector with Circular-Perforated Moveable Absorber Plates

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Abstract Window solar air collector is a significant instrument for heating residential buildings in cold regions. This paper presents an experimental investigation of the thermal performance of a window solar air collector with seven moveable absorber plates, as each plate contains 28 circular perforations. The 7 plates opened and closed at different angles in unison manually by a specific mechanical mechanism. The effect of changing the plate angles have been tested, alongside the effect of mass flow rates and the intensity of solar radiation. Experimental results shows that the highest air temperature difference is gained at vertical plates position (angle 0°) at mass flow rate 0.0097 kg/s and irradiance 730 W/m², and the maximum thermal efficiency were 71% at mass flow rate 0.0224 kg/s. In addition, the temperature difference between inlet and outlet air has increased by 24% in case of angle 0° than in angle 45°. In contrast, a flexibility between sunlight penetrating into the room and hot air from the collector will be gained when the plates set on angle 45°.

1. Introduction

Today, energy consider as one of the significant needs of society. As energy, environment and economic evolution of a country are closely related [1]. One of the appropriate technologies to utilize thermal energy coming from the sun is solar air collector (SAC), which is employed in many applications including drying agricultural food, ventilation application and residential heating [2] Nowadays SAC applications are much required especially in cold and severe cold regions. As solar air collectors are quite inexpensive and easy to install. In addition, they require little maintenance.

Various designs of SAC have been applied; Kutscher 1994 [3] investigated the convective heat transfer effectiveness for low-speed air flow through thin, isothermal perforated plates in unglazed solar collector by using a low-porosity perforated plates as absorbers for heating ambient air. The main factors affecting heat transfer have been shown to be suction flow rate, crosswind speed, hole pitch and hole diameter. Onur 1996 et al. [4] employed a number of vertical plates, indicated that the slat angle, the separation distance between glass panes and the air mass flow influences the performance of the collector, they showed that as the slat angle increases, the temperature difference decreases at any given time provided that mass flux and separation distance remain constant. While Nowzari 2014 et al. [5] tested SAC (Solar Air Collector) with two different perforated covers in which the holes made on one cover had the center-to-center distance of 20D (6cm) and on the other cover it is 10D (3cm), they have shown that increasing the number of holes on the cover increases the maximum temperature difference.
Li 2016 et al. [6] investigated the heat transfer and air flow characteristics of a glazed transpired solar air collector with slit-like perforations. Compared to circular holes, the local resistance loss through the slit-like perforated plate at constant porosity and Re$_h$ is smaller. As a result, effective efficiency increases with increases in the perforations diameter and ambient temperature. And decrease in the pitch, plenum thickness and inlet air temperature. Also, Croitoru 2016 et al. [7] performed an experimental campaign on an innovative solar collector. As perforated solar walls pre-heat the fresh air introduced in the building when the air is forced to pass through this solar heated perforated façade. They showed theoretically that heat exchange between metal plate and air can only be optimal for a certain type of geometry perforation called “lobed”. Zheng 2017 et al. [8] experimentally studied the thermal performance of three novel solar air collectors with perforating corrugated plate, slit-perforated plate, and corrugated packing. They indicated that the thermal efficiency of the three collectors in severe cold regions could be much higher than 50% and the collector with perforating corrugated plate had the highest thermal efficiency. Yu 2019 et al. [9] investigated a heating system combining SAC with hollow ventilated interior wall for residential building. Results shows that compared with other typical systems, this system increase the minimum indoor air temperature by 6.5°C and 3.2°C compared with the case without any system and the case with warm air from the SAC directly supplied to the room. Gao 2020 et al. [10] proposed a novel glazed transpired collector system with non-uniform perforation. The system consists of suction and supply ventilation installed beneath the structure and a black perforated corrugated plate. They concluded that the primary factors affecting secondary heating in the system were the hole diameter and height ratio. The results showed that the collector provided 6 °C higher temperature rise than a traditional collector. Hu 2020 et al. [11] experimentally and numerically examined the thermodynamic behavior of a PCM solar air heater exchanger. The system was designed to improve the indoor air quality and thermal comfort by continuous pre-heated air supply at a reduced energy use through the capturing and storing of solar energy.

The majority of the researchers concentrated on the improvement of the thermal efficiency of solar air collectors. Thus, a compromising between hot air gain and sunlight penetration to the desired room is needed. Therefore, window solar air collector is presented as it can be used in public buildings and at home to provide part of the heating load during winter time. This will reduce the number of traditional heaters used in cold climates as well. This paper aims to investigate the performance of window solar air collector with circular perforated absorber plates. The mechanism of combining circular perforations and flat plate is put forward. Alongside with moveable absorber plates. And glass on both sides. The experiment will be studied indoor. Mass flow rates and irradiances will be employed.

2. Experimental Study
Window solar air collector with circular perforations was conducted and tested indoor. Experiments were performed by utilizing 4 tungsten halogen projectors (a solar simulator), each of which has 1000 Watt of rated capacity. As dimmers were employed to monitor the amount of radiations from the projectors as well as monitoring the blower speed. Glass on both side of the collector were used, each thickness is 0.004 m. The dimensions of the collector are 1.2 m in height and 0.45 m in width and 0.15 m in thickness. The size of each absorber plate is 0.13 m in height and 0.43 m in width and 0.0013 m in thickness. Each one of the 7 absorber plates has 28 circular perforations with equivalent diameter of 0.01 m. The distance between each plate is 0.01 m. The absorber plate is iron with black coated material. Besides, Controlling the absorber plates angles is done manually by a mechanic mechanism. The outlet duct of the collector was employed to connect the WSAC to the blower to draw the air from the collector channel. Iron frame were used to manage all the 4 halogen projectors which function as natural sunlight. The distance between the projectors and the collector is 0.8 m, to make a uniform distribution of the light on the collector surface.

Solar radiation intensity from the projectors on the collector was measured by a solar meter (SM206-SOLAR), The instrument has a reaction time of 1 second and tests the strength of radiation within the range (0 to 2000 W/m$^2$). Inlet and outlet air temperature of WSAC, and absorber plate temperature, all
were measured. Inlet air velocity was also measured by the use of a fan type thermo-anemometer (BENETECH-GM816). The temperature of air flow, absorber plates, the collector inlet and outlet temperature and glass covers temperature were measured by using of thermometer with 9 channels using 9 copper-constant (K-type) thermocouples. All thermocouples are first calibrated to be within ± 1°C at 0°C and 100°C. Solar intensity error range: ± (10%R+2dgt) R: readings. Temperature error: ± 0.38 W/m² °C, [±0.12 Btu/(ft²-h)/°C] deviation at 25°C. Flow rate error: ±5%.

![Figure (1): A front view of WSAC absorber plates opens at angles 45° and 0°](image1)

![Figure (2): Window solar air collector with the blower and the halogen projectors](image2)

As shown in the Figure (2) above, the present window solar air collector (WSAC) designed with a particular mechanic-mechanism that allow us to control the angles of the absorber plates. In this paper two angles were concluded, which are 0° and 45°.
Four mass flow rates alongside with three irradiations were tested. Mass flow rates 0.0113, 0.0176, 0.0261, 0.0347 kg/s. And, irradiations in the range of 330, 530, 730 W/m². A total of 12 experiments for each angle were taken. Solar radiation generally penetrates the upper glass-cover layer and reflects on the solar collector's absorber plates. The absorbent layer receives heat from solar rays and convectively passes power to the airflow. Heat loss to the air from the collector's side walls is minimized by strong insulation.

3. Theory
The thermal efficiency of the current design of window solar air collector will be calculated for evaluation. The estimation of the output parameters uses the calculated average air temperatures. In addition, the performance parameters also depend on the properties of the air which change with increasing or decreasing flux of solar radiation.

The useful heat gain, \( Q_u \) (W) is indicated as

\[
Q_u = \dot{m} C_p (T_{out} - T_{in}) \tag{1}
\]

And \( \dot{m} = \rho u A \tag{2} \)

The solar air heaters thermal efficiency is measured as
\[
\eta_{th} = \frac{Q_u}{I A_C}
\]  
(3)

Where,

\(\dot{m}\) mass flow rate of air,

\(C_p\) specific heat of air,

\(T_{in}\) and \(T_{out}\) inlet and outlet air temperatures, respectively,

\(\rho\) density of the air,

\(u\) velocity of the air,

\(A\) area of channel of flow

\(I\) intensity of solar radiation

And \(A_C\) the area of solar collector

4. Results and discussions

Window solar air collector with 7 moveable absorber plates was tested with two angles 0° and 45°. A total of 24 cases with different air flow and irradiance were studied. Therefore, the following comparison was made between the two angles results. Plates position at angle 45° allow sunlight penetrating to the room, as well as supplying hot fresh air. Nonetheless, angle 0° will provide sunlight to the room only through the circular perforations on the plates surface, however, temperature difference will be higher compared to that with angle 45°. Owing to the reduction of incident solar radiation on the plates at angle 45°.

![Figure (5): Variation of temperature difference of air flow with mass flow rate at various irradiance values for angle 45°](image)

**Figure (5):** Variation of temperature difference of air flow with mass flow rate at various irradiance values for angle 45°
Figure (6): Variation of temperature difference of air flow with mass flow rate at various irradiance values for angle 0°.

Figure (5) shows the effect of mass flow rate on temperature difference of air flow at different values of solar radiations.

As can be seen above, temperature difference slightly decreases with increasing the mass flow rate for different solar radiation intensity. Increasing the air velocity will reduce the contact time of air with the absorber plates, resulting a reduction in the air temperature difference. Results were similar trend when the plates set on angle 0°, as shown in Figure (6).

Figure (7): Variation of temperature difference with irradiance at different values of airflow for angle 45°.
Figures 7 and 8, shows the relation between the air flow temperature difference and the solar radiation intensity for different mass flow rate for both angles 0° and 45°. Obviously, the temperature difference has increased with increasing the solar radiation. And the highest the solar radiation intensity the highest the air flow temperature difference.

According to Figures (7) and (8), higher temperature difference will be gained in angle 0° than in 45°. The particular reason for this circumstance is the amount of solar radiation falling directly on the plates while being close at angle 0°.

Figure (9): Shows the temperature of the first, fourth and last plate with irradiance at specific air flow at angle 45°.
Figure (10): Shows the temperature of the first, fourth and last plate with irradiance at specific air flow at angle $0^\circ$.

Figures (9) and (10), shows the temperature of the first, fourth and last plate for angles $45^\circ$ and $0^\circ$ respectively at mass flow rate equal $0.0261$ kg/s.

As plate four has the highest temperature among the other plates for the two angles, considering the high heat transfer between the inlet airflow and the first plate due to the temperature difference, therefore, less heat transfer will occur between the airflow and plate four, resulting in rising its temperature. For plate 7, which is the last plate, it is quite obvious that its temperature is less than plate 4, owing to the effect of the external environment at the exit.

Figure (11): Shows a comparison between the temperature difference of both angles with irradiance at a specific value of airflow ($\dot{m}=0.0261$ kg/s).

As shown in Figure (11), temperature difference for angle $0^\circ$ is higher than that for angle $45^\circ$, due to the amount of the incident solar radiation on the plates. however, when the plates position sets on angle $45^\circ$, the amount of the incident solar radiation will be lower, resulting in the reduction on the temperature difference between the two angles.
Figure (12): A comparison between the thermal efficiency of both angles with mass flow rates at a specific value of irradiance (Q=530 W/m²)

Figure 12 illustrate the variation of thermal efficiency for both angles with mass flow rate. It is noticeable that thermal efficiency, increase with mass flow rate for both angles. Moreover, angle 0° thermal efficiency is by far larger than that of angle 45°. It is contributed to the perforations effect that arises when the plates set on angle 45°, that lead to a decrease in the air flow rate as well as decreasing in the collector thermal efficiency.

5. Comparison between the Present Work and other Research

The present work doesn’t conform with previous works, so the results were compared with the closest research which is flat plate solar collector with vacuum glass. it is actually different than WSAC, but it is the closest suitable research. Figure (13) illustrate the comparison between the present work and the FPSC with vacuum glass of Ref. [12] for thermal efficiency at irradiance 330 W/m². It is noticeable that the higher thermal efficiency for WSAC at angle 0° is 71%, and the highest thermal efficiency for angle 45° is 56%, both at irradiance 330 W/m², and that for FPSC with vacuum glass is 81%.

Figure (13): Comparison between the thermal efficiency of the present work and FPSC with vacuum glass of Ref. [12] at irradiance 330W/m²
6. Conclusion

A window solar air collector with circular-perforated, moveable absorber plates that can supply residential building with preheated fresh air and a sunlight penetration, was designed and conducted in this paper. The main conclusions of the present study can be summarized as:

1) The present window solar air collector is a new type of solar collectors that provide both hot air and sunlight to the residential building, by controlling the movement of the absorber plates manually to be opened in different angles, two angles were taken into consideration, which are 0° and 45°.
2) When the plates positioned vertically at angle 0°, it represents the usual shape of a solar air collector, and provide hot air only with a penetration of sunlight through the circular perforations on the plate surface to the room.
3) Maximum thermal efficiency was gained at angle 0° which is equal 71%, on the other hand maximum thermal efficiency for angle 45° where 56%.
4) As the plates are sets at angle 45°, the sunlight will be penetrating through the collector with less amount of heated air than at angle 0°.
5) In conclusion, angle 45° compromise between hot air gain and sunlight penetrating into the desired place.

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