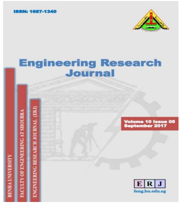
ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 49 Jul. 2021, pp 197-208

Journal Homepage: http://erj.bu.edu.eg



The Effect of Solar Chimney on the Thermal Performance of Hotel Room in Aswan, Upper Egypt

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Abstract. After the energy crisis during the 1970s, energy availability became questionable. Hospitality buildings consume large amounts of energy to provide comfort and several services for guests. Energy efficiency and renewable energy hold the key to sustainable energy provision and tourism development and represent the key for energy balance in the hospitality sector of Egypt. This paper aims to minimize energy usage and manage the effective use of natural resources as wind, to enhance environmental conditions. Employment of passive design techniques as natural ventilation techniques is proposed as a mitigating measure for the excessive energy use in hotel buildings. Solar chimney has proven scientifically as one of the effective passive solar-induced ventilation tools. This study investigates the impact of using different percentages of the glazing part on the indoor air velocity and indoor operative air temperature based on a number of CFD simulation results. Investigating a prototype of a five star hotel in Upper Egypt, a base case of three floors hotel building with repetitive hotel room 4m*8m is proposed with façade designed to include an open terrace and vertical solar chimney. Within the framework of this study, DesignBuilder software was used for CFD simulation. Investigating different options for the selected parameter, results show that indoor operative temperatures can be increased by increasing the glazing percentage, while the age of air can be reduced and the indoor air velocity can be increased, so it will enhance the ventilation rates.

Keywords: Hospitality Buildings, Thermal Performance, Passive Design, Natural Ventilation, Solar Chimney.

1. INTRODUCTION

Over the past six decades, tourism has steadily expanded and become one of the world's largest and fastest growing economic sectors. In addition, Hospitality buildings consume large amount of energy to provide comfort for guests [1]. Passive strategies should be applied on hospitality buildings to minimize energy consumption.

1.1. Tourism Industry in Egypt and Energy Consumption

Over the past 20 years, tourism in Egypt has grown rapidly and it is recognized to be one of the largest contributors to Egypt's economic growth. After the 2011 revolution and the current political instability in Egypt, the Egyptian hotel sector has been negatively affected, with a large, reducing the sector's income [1].

In addition, energy cut-offs due to demand exceeding supply in 2014 caused a decline in hotels' revenue of more than 20%. Moreover, electricity prices rose by 40% in 2014, representing a threat to the future of the hospitality sector in Egypt [2].

The hotel sector represents one of the most energy and resource consuming branches of the tourist industry. Figure 13 provides a typical breakdown of the energy consumption in a typical hotel [3].

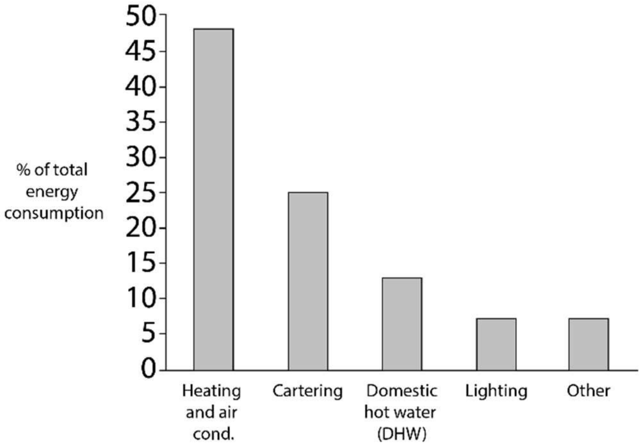

FIGURE 13. Energy consumption breakdown in a typical hotel [3].

The above data show that the outdoor climate has a major impact on the overall electricity use. About half the electrical energy is typically used for space conditioning. Therefore, the hospitality sector in Egypt requires a set of energy efficiency strategies in addition to using renewable resources to minimize energy consumption.

1.2. Passive Design Strategies

Passive design strategies respond to local climate and site conditions to minimize the energy used and maximize the comfort of building users. Natural ventilation as a cooling passive strategy, can lead to indoor thermal comfort and minimizing the operation hours of active cooling solutions. Natural ventilation systems depend on air pressure differences to circulate fresh air throughout buildings. Differences in pressure can be caused by wind or by the buoyancy effect.

There are various types of passive ventilation strategies for residential building applied since centuries, such as solar chimney, trombe wall, wind catcher, courtyard and air well. Solar chimney has proven as one of the effective passive ventilation tools that widely applied [4].

1.3. Solar Chimney as Natural Ventilation Technique

The solar chimney is a simple and effective tool that has been applied to enhance natural ventilation in spaces. A solar chimney is a natural draft device that uses solar radiation energy to build up stack pressure stimulating internal air to exit from its outlets, hence indirectly prompting outdoor air to replace internal exhausted air from other openings [5].

1.3.1. Solar Chimney Main Concept

The solar chimney is a vertical or inclined cavity with an outlet opening at the top of it to remove the hot air out. At least one of the chimney's walls is made transparent of glazing material, and its back wall is made of absorber material. The chimney has an inlet opening to transfer the indoor air to be heated by solar radiation enters the chimney through the glazed part. The air passed from the room through the chimney and exit from the top of chimney as shown in Fig. 14 [6].

The solar chimney is one of the technologies which working on the buoyancy principle. The airflow due to buoyancy effect is created by differences in temperature or pressure between the locations of inlet and outlet openings. Therefore, if there is high gradient difference between inlet and outlet positions, this will improve the airflow rate.

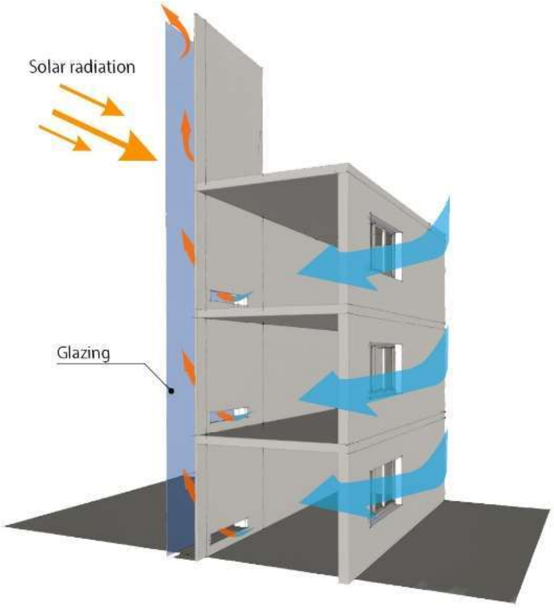

FIGURE 14. **Solar chimney working principle**

The geometry of the solar chimney channel is described by its height, length, cavity depth and width. The elements of the solar chimney are presented in Fig. 15.

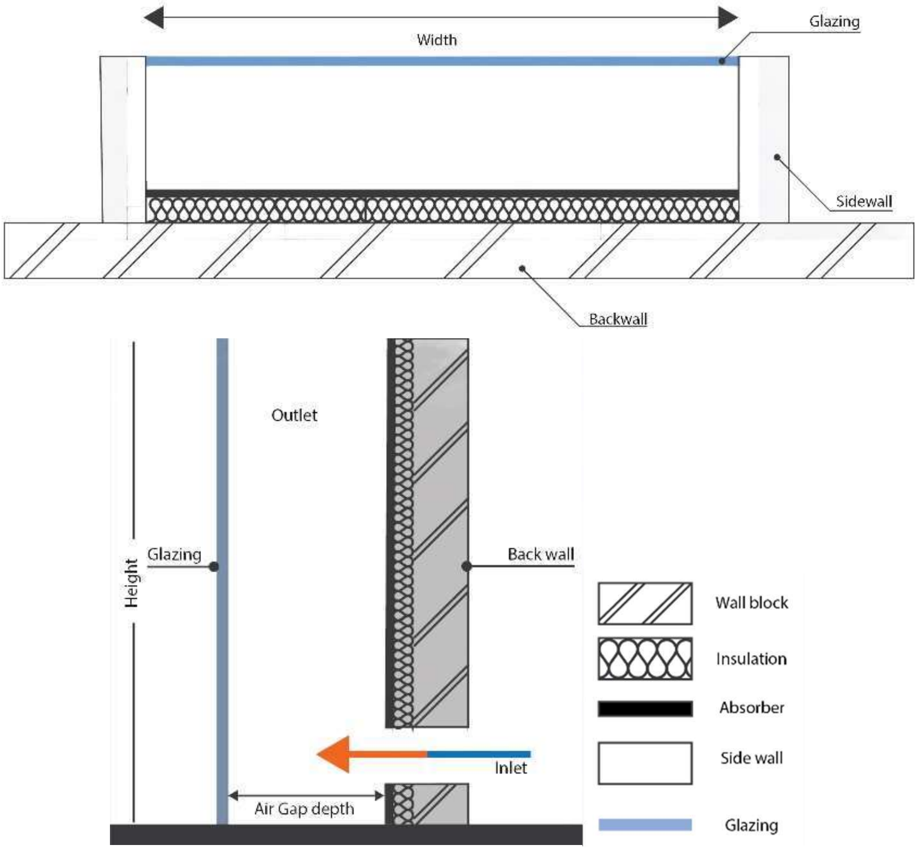

FIGURE 15. **Top view and cross-section of typical solar chimney**

1.3.2. Factors Impacting Solar Chimney Performance.

There are many factors with various parameters that can all impact solar chimney performance. Improving solar chimney performance depends mainly on the correct choice of height, width, cavity gap, angle of inclination of the chimney. In addition, the optimum design reflects on reaching the highest airflow rate [7].

Previous experimental studies analyzed many types of influencing factors on the solar chimney performance, including configuration, installation conditions, material usages, and environment and summarized these factors into thirteen type [8].

Regarding the factor of selecting the glazing material, studies proved that properties of transmissivity, reflectivity and absorptivity are important to the performance of a solar chimney. In addition, double-glazing shows its advantage in enhancing the performance of a solar chimney [8]. However, there are no studies conducted to investigate the impact of the glazing part percentage on the performance of solar chimney on hot desert climate as in Upper Egypt.

1.4. Upper Egypt Climate Conditions.

The predominant climate in Egypt is hot and arid, since the effects of water surface are restricted to a small area on the two banks of the Nile. According to Köppen climate classification, Upper Egypt has a hot desert climate like the rest of Egypt. Aswan has the hottest and driest summer days of any city in Egypt.

The summer weather is very hot and dry, making high temperatures a lot more bearable. Air temperature during the day can be about 42ºC and decreases to about 30ºC during the nighttime. According to the weather data reports exported from the software (Energy Plus) using EGY_Aswan.624140 weather data sheet, the hottest week lasts from June 29 to July 5. The hottest day of the year is 2nd of July as shown in Fig. 16 and Fig. 17.

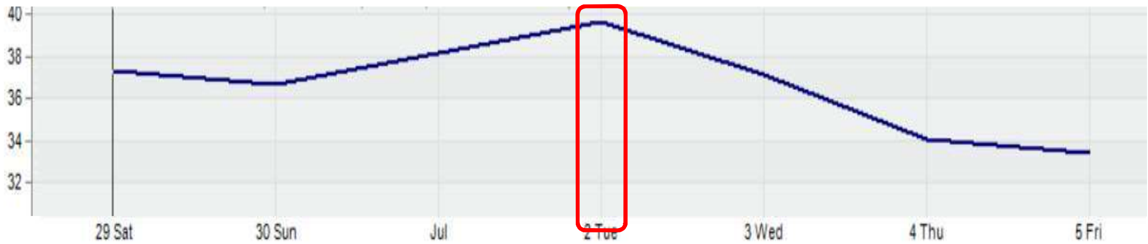

FIGURE 16. Typical outside temperatures (°C) of the hottest week from June 29 to July 5, determines the hottest day: 2^{nd} of July.

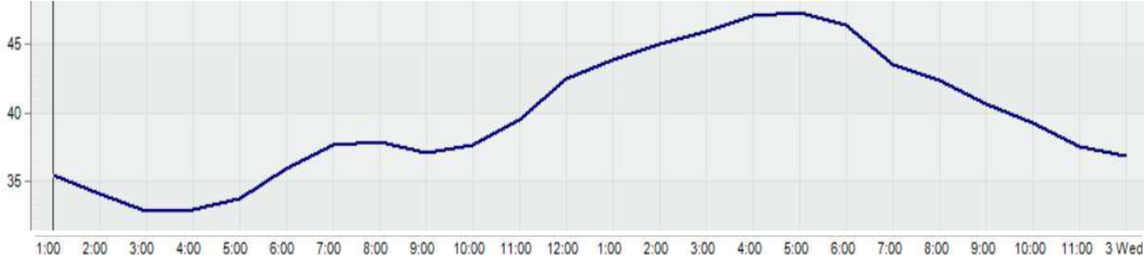

FIGURE 17. Hourly Outside temperature (°C) at the hottest day July 2.

2. OBJECTIVES

The objective of this study is to assess the impact of changing the area percentage of the chimney glazed part, whether to be only one wall made of glazing material, three walls or a part of one wall and impact on the indoor operative temperature and air velocity in a typical hotel room in the hot dry climate of Upper Egypt. Simulations measure indoor air velocity, indoor operative temperature and age of air as they are the most representing factors of solar chimney performance.

3. METHODOLOGY

Computational Fluid Dynamic (CFD) has been identified as the most sophisticated airflow modeling techniques for generating the prediction analysis of airflow, and heat transfer around and inside the buildings [9]. Within the framework of this study, Design builder version 6.1.0.006 is chosen as the CFD simulation software, incorporating the Energy Plus calculation engine version 8.9.

3.1. Description for Hospitality Sector in Upper Egypt

Aswan includes large number of hotels, resorts and floatels. Hotels classified as five stars generally use more energy per visitor compared with other types of hospitality buildings. By investigating the hospitality sector on Upper Egypt focusing on 5-star hotels and resorts, a base case model for three floors hotel building with repetitive hotel room 4m*8m is proposed with façade designed to include an open terrace and vertical solar chimney as shown in Fig. 18 and Fig. 19.

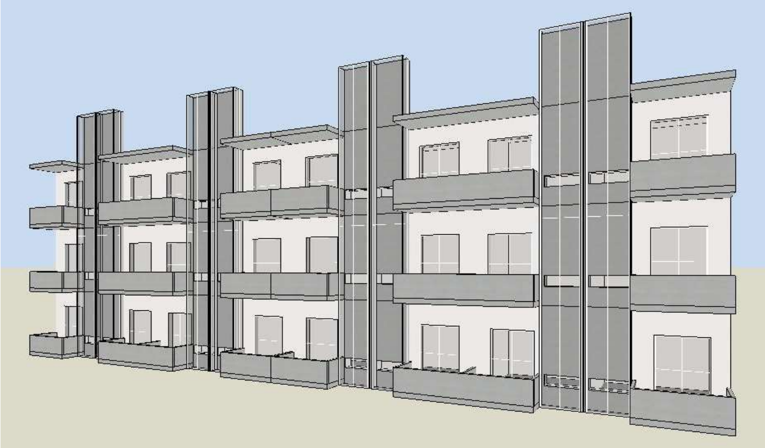

FIGURE 18. **Hotel building 3D model.**

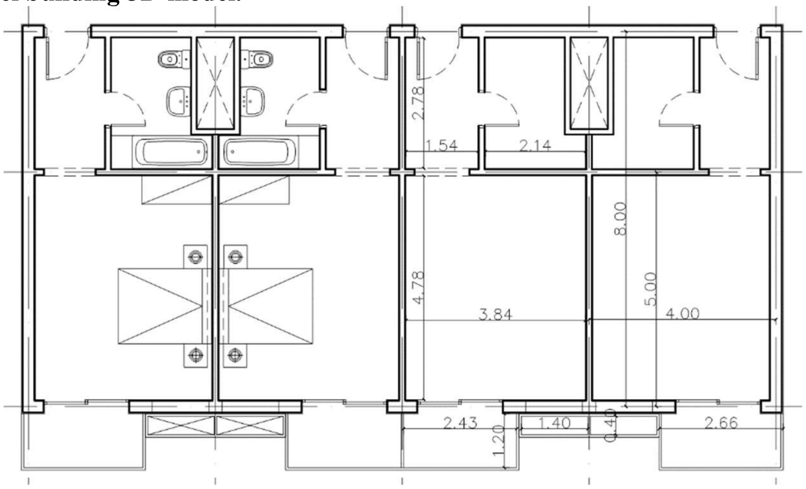

FIGURE 19. **Hotel building model plan.**

3.2. Hotel room and SCH model

A hotel building of three floor levels is modeled, with floor height 3.50m (FFL-FFL). A repetitive hotel room (4m*8m), with bedroom area (4m*5m), is designed with terrace door opening (1.60m*2.20), the door is with operation 50%. Figure 20 shows the hotel building cross section passes through building typical rooms and their connection with solar chimney.

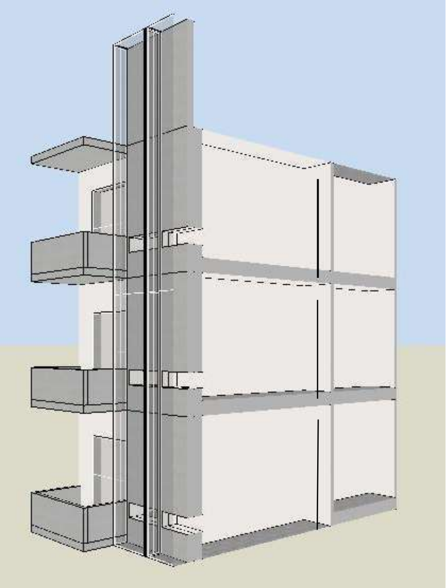

FIGURE 20. **3D sectional through the hotel building.**

A south facing solar chimney of cross section (1.4m*0.4m) is modeled with height exceeding building height by 2.5 meters. Inlet and outlet openings are of area (1.4m* 0.4m). The solar chimney's back wall consists of ESP Expanded Polystyrene layer of 0.05m thick as insulation material and Aluminum layer of 0.001m thick as absorber material. The glazing part will be double-glazing using two layers of clear glass of 0.006m thick with air gap of 0.01m thick. The simulations occur on the highlighted part of the room and its connection with solar chimney shown in Fig. 21.

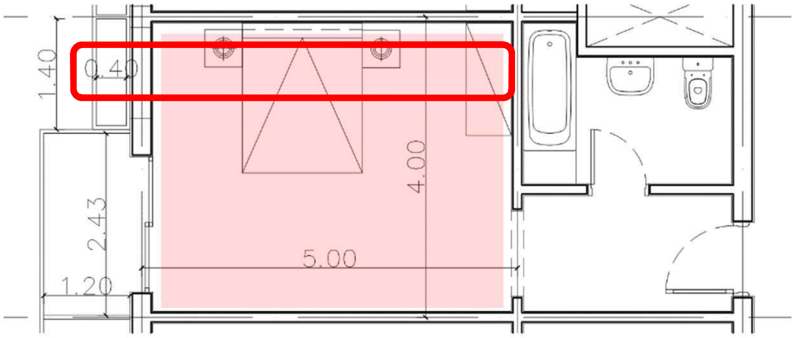

FIGURE 21. **Designed hotel room plan, showing CFD slice location.**

3.3. Solar Chimney CFD Simulation

CFD simulations are performed to investigate the impact of changing the percentage of the solar chimney's glazed part on the indoor operative temperature, air velocity and age of air on a hotel room. Three Cases of solar chimneys are developed as follows:

- Case 1 (C1): the front wall and the 2 side walls are all glazed.
- Case 2 (C2): Only the front wall is glazed.
- Case 3 (C3): the front wall is opaque with a glazed area at the top (1.40m*2.5m).

Simulations are done on the hottest summer day 2nd of July, on Aswan dry climate, on different hours along the day as follows: 6AM, 12PM, 6PM as shown in Fig. 22.

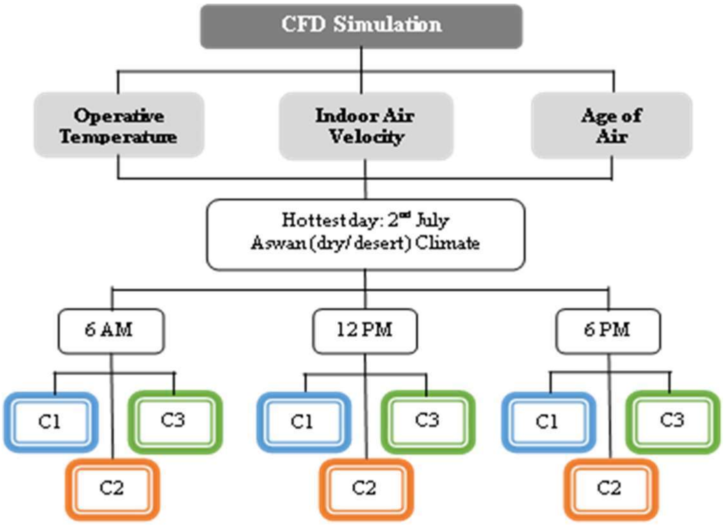

FIGURE 22. **CFD simulation diagram for the 3 cases**

Figure 23 shows the solar chimney model on each case and the following three figures show the CFD simulations for the three cases.

FIGURE 23. **3D model for solar chimney on each case**

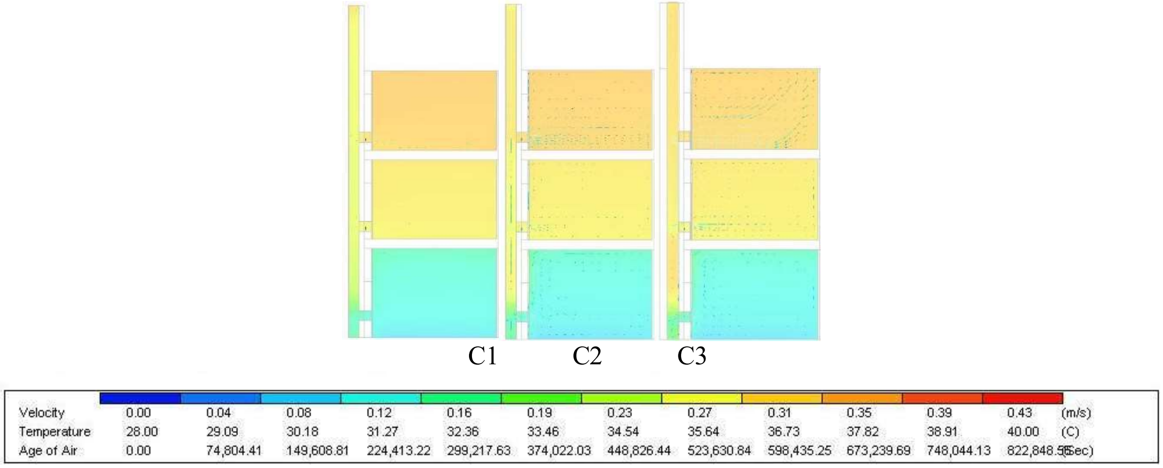

FIGURE 24. **CFD slices showing the operative temperature (°C), air velocity (m/s) and age of air (s)**

pattern of the room at 6 AM on three cases.

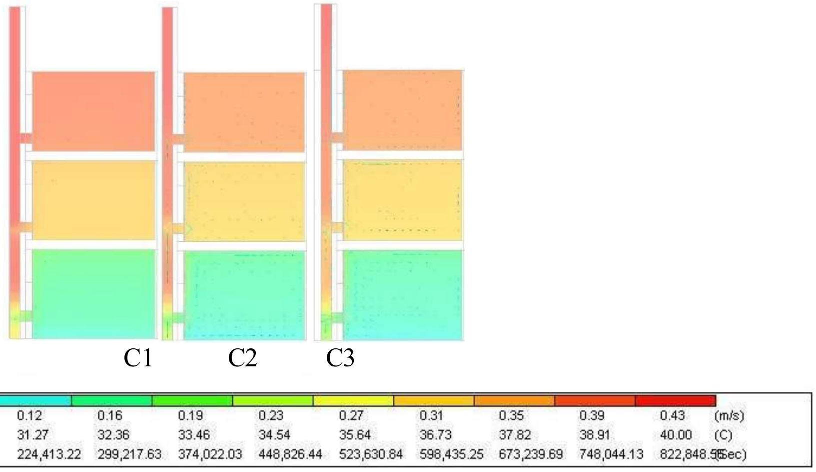

FIGURE 25. CFD slices showing the operative temperature (°C), air velocity (m/s) and age of air (s) pattern of the room at 12 PM on three cases.

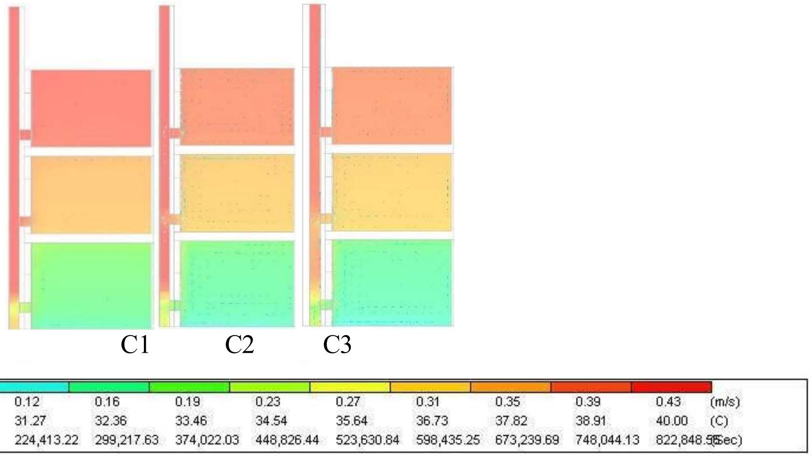

FIGURE 26. CFD slices showing the operative temperature (°C), air velocity (m/s) and age of air (s) pattern of the room at 6 PM on three cases.

Figure 24 shows CFD slices of the operative temperature, air velocity and age of air pattern on the hotel room at 6 AM on each case at outside temperature 35.9 °C and wind velocity 6.02 m/s. While in Fig. 25 the CFD slices occurs at 12 PM for each case at outside temperature 42.55 °C and wind velocity 9.55 m/s and for Fig. 26 at 6 PM the outside temperature is 46.47 °C and wind velocity 7.33 m/s.

4. RESULTS AND FINDINGS

The airflow velocities, the operative temperature and age of air are measured for ground floor room from the mentioned monitor point shown in Fig. 27.

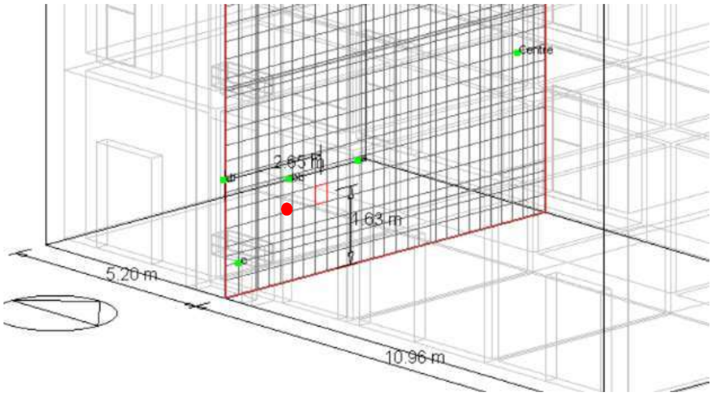

FIGURE 27. **Monitor point for ground floor room**

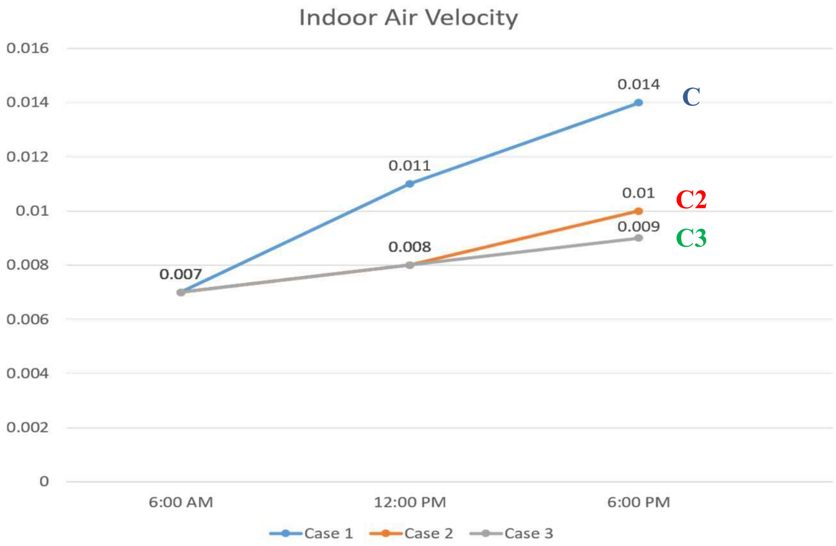

FIGURE 28. **Indoor Air Velocity (m/s) measured for solar chimney 3 cases**

As shown in Fig. 28, Case 1 of the maximum glazing area has the maximum velocity and by reducing the glazing area, the velocity reduced. The three glazed wall solar chimney may increase the indoor air velocity by 1.6 times more than the half wall glazed solar chimney.

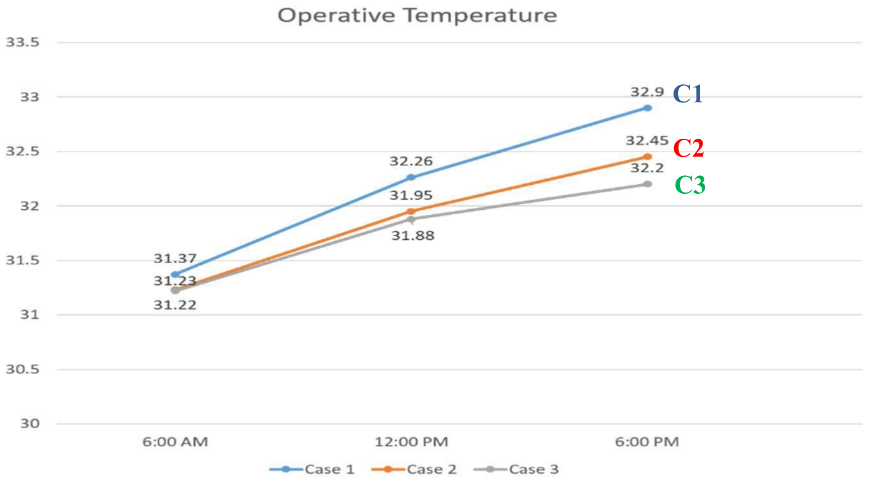

FIGURE 29. **Indoor Operative temperature (°C) measured for solar chimney 3 cases**

As shown in Fig. 29, Case 1 of three glazed walls has the maximum indoor temperature followed by case 2 then case 3 of the minimum indoor temperature and minimum glazing percentage. The temperature difference between case 1 and case 3 may reach 0.7 °C.

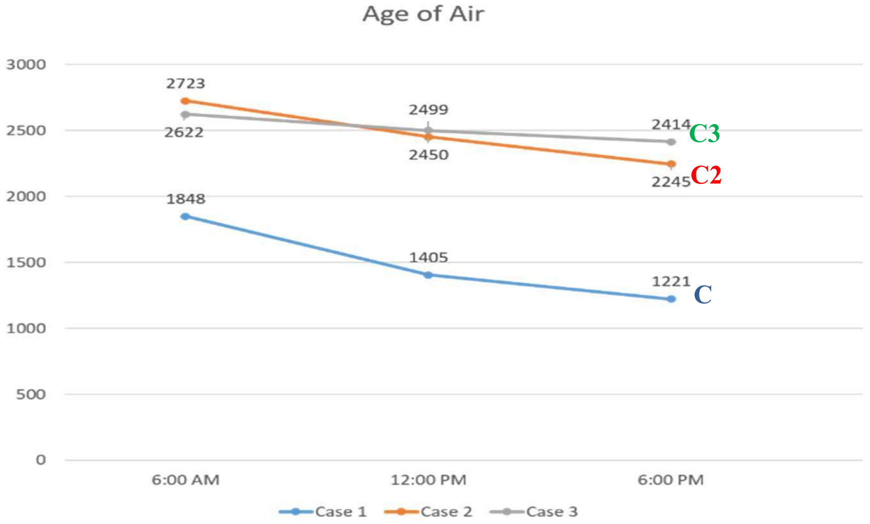

FIGURE 30. **Age of Air (s) measured for solar chimney 3 cases**

As shown in Fig. 30, Case 1 has the least age of air. When using three glazed wall solar chimney the age of air could reduce by 50%.

5. DISCUSSION AND CONCLUSION

CFD simulations have the potential to investigate the buildings indoor climate. The aim of this study is to investigate the impact of using different percentages of the solar chimney glazed part on the ventilation velocity and indoor operative air temperature by developing three different cases of solar chimney.

By comparing the three cases, the findings show that case 1 with maximum glazing percentage has age of air less than the other cases by 50%. In addition, the indoor velocity measured on case 1 is greater than that on the other cases by 1.6. However, the temperature measured on case 1 is higher than the other cases by maximum 0.7 °C. Therefore, increasing the glazing percentages will enhance the ventilation rates but would also increase indoor operative temperature.

Further experiments are required to determine the optimum configurations of solar chimney to enhance the natural ventilation. solar chimney orientation and outlet opening orientation can affect the exit velocity of a solar chimney, they may have great effect on solar chimney performance on hot and dry climate.

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