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To cite this article: Sameh Monna *et al* 2019 *J. Phys.: Conf. Ser.* **1343** 012190

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Improving thermal environment for school buildings in Palestine, the role of passive design

Sameh Monna¹, Mutasim Baba², Adel Juaidi³, Aline Barlet⁴ and Denis Bruneau⁴

¹ Architectural Engineering Department, An-Najah National University, Faculty of Engineering, 107 Nablus, Palestinian Territories

² Building Engineering Department, An-Najah National University, Nablus, Palestine

³ Mechanical Engineering Department, An-Najah National University, Nablus, Palestine

⁴ Ecole Nationale Supérieure d'Architecture et de Paysage de Bordeaux, Laboratoire GRECCAU, 740 cours de la Libération, CS 70109, 33405 Talence cedex, France

samehmona@najah.edu

Abstract. School buildings have an enormous impact on students' health, well-being and educational achievement; they also have an impact on energy consumption and other natural resources. Solar chimneys, solar walls, underground ducts for ventilation, shading, and building orientation were used to improve the indoor thermal environment in a pilot project school. A quantitative analysis was carried out based on field measurements by recording some thermal comfort parameters (mainly air temperature and relative humidity) for one year in the school. The aim was to evaluate the effects of the solar chimney, solar wall and underground duct used in selected classrooms on the indoor thermal environment and compare the results to base case classrooms in the same school. The study provided positive results confirming that the passive environment control system used in the pilot school is highly effective in providing indoor thermal comfort on hot and sunny days. The impact of ground ducts and solar chimneys on cold days was relatively small. Most of the classrooms tested on the three floors of the building were found to be thermally uncomfortable in winter.

1. Introduction

School buildings are important as they have an enormous impact on students' health, well-being and educational achievement. All over the world, governments put considerable effort into providing schools with thermal comfort and into achieving energy efficiency. The educational sector is growing dramatically as a result of the upward trend in population size. Recent studies [1], [2], [3], [4] have analysed the effects of the passive design solution for school buildings (such as natural ventilation, shading, thermal insulation, etc.) on students' thermal environment and building energy efficiency. These studies found that the passive design solution can improve thermal environment and energy efficiency, especially in the cool season.

Studies of school buildings have shown that environmental comfort parameters can greatly affect the learning process [5], [6]. Thermal environment is a significant factor in school design and operation, not only because of the comfort sensation that the occupants feel, but also because it is related to a building's energy consumption, which influences its sustainability [7], [8]. Proper design of school buildings requires a balance between thermal performance and an acceptable quality of the indoor climate



conditions [9], [10]. The importance of maintaining adequate indoor air quality and thermal comfort, especially in schools, is recognized as being a contributing factor to students' learning performance [11].

In many of the technologically and economically advanced countries, schools, occupant comfort, students and teacher performance are put as a first priority. However, in developing countries, many of the recent developments in ensuring high performance and quality in the school environment have not been applied to school design and construction. The evaluation of current design and construction of schools and the creation of pilot projects are the missing link towards improving the indoor environment in schools. In Palestine, the Ministry of Education and Higher Education started an initiative to improve thermal conditions in school buildings in Palestine by launching a few pilot projects to evaluate conditions and learn the lessons. In recent years, the Palestinian government has significantly reduced the number of students per school by increasing the number of schools in major towns and cities. However, design alternatives that will solve comfort problems are rarely generated or evaluated and environmental comfort conditions are not considered as a starting point in the design and construction process. Most buildings in Palestine are not thermally insulated [12]. Palestine suffers from a shortage of natural resources, particularly energy, and imports almost all of its energy needs from neighbouring countries. Furthermore, Palestine depends on other countries for 100% of its fossil fuel imports and for 87% of its electricity imports [13]. In the West Bank or Gaza no public school is equipped with heating or cooling systems, as the Ministry of Education budget does not allocate any support for capital investment and running costs of heating and cooling systems in schools. This lack of heating and cooling systems in classrooms has many negative impacts on students, especially those at elementary level.

One of the greatest challenges of modern design is to create thermally comfortable environments in schools through studying in detail all contributing factors, especially passive design solutions [14].

2. Methodology

This study used Wadi al Mughair School to evaluate the effects of passive design strategies on a classroom's indoor thermal environment. The strategies used were a solar chimney, an earth duct and a solar wall. The Ministry of Education wanted to create this school as a pilot project in the West Bank. Transsolar KlimaEngineering served as a consultant to design the above-mentioned passive systems. The building is located in the city of Hebron (latitude 31.53 N, longitude 35.09 E, and altitude of 900 m) in the southern West Bank, which is considered representative of a climatic zone characterized by cold winters, relatively low precipitation and high temperatures during summer [15]. This zone is one of six climatic zones in the West Bank and Gaza Strip and contains the highest population intensity in the West Bank [16]. The building consists of 3 floors in a total built-up area of 2780 m². Passive design strategies have been used to increase temperatures in winter, provide fresh air, and avoid overheating in summer including: orientation, shading, earth duct, solar chimneys and solar walls. An 80 m long earth duct has been constructed under the ground and connected with duct leads to vertical and horizontal solar chimneys at the top of the building. The solar chimney has been sized so that it has an exposed area of 5 m² with a south-east orientation and the horizontal chimney has a cross-section of 0.7 m². The solar wall has a surface area of 12 m² on each floor. Four classrooms on each floor were selected to monitor the indoor thermal environment, mainly indoor air temperature and relative humidity, for one year. The classrooms were south-east facing, with an occupancy of 30 students per classroom, and a floor area of 55 m². Classroom 1 (R1) on each floor is a reference classroom which has no connection to the earth duct, solar chimney or solar wall. Classrooms 2 and 3 (R2, R3) on each floor are connected to the underground duct and solar chimney. Classroom 4 (R4) on each floor has a connection to a solar wall and solar chimney, as shown in Figure 1 and Figure 2.

To supply sufficient fresh air on winter mornings and to reduce the classroom temperatures in summer, the earth duct system works in combination with the solar chimneys to drive the air and increase its velocity to improve air supply temperatures. The earth duct has to be controlled with a bypass system operated by teachers only if the outside air temperature is lower than the underground temperature in winter, and when the indoor temperature is higher than the underground temperature in summer. South-

east oriented solar walls capture solar energy on the façade and can preheat the air before it enters the classroom, and the air flow will be driven through the solar chimneys.

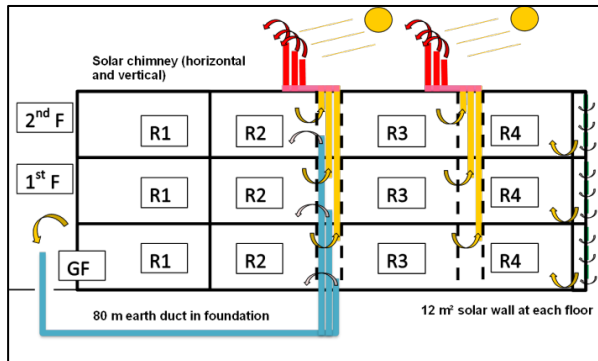


Figure 1. Vertical section shows the earth duct, horizontal and vertical solar chimneys and solar wall connection to the selected classrooms.

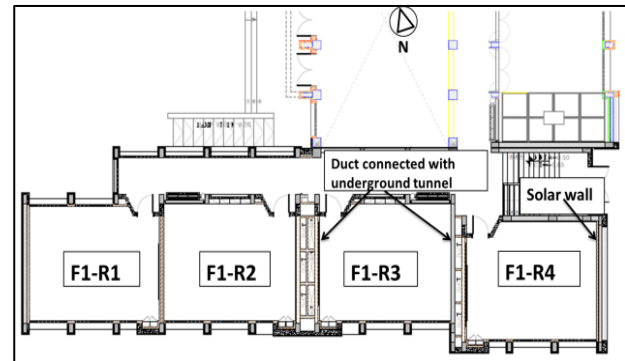


Figure 2. Floor plan shows selected classrooms, and the connection between underground ducts solar wall and solar chimneys.

To evaluate the effects of the underground duct, solar walls and solar chimneys on the thermal environment, field measurements for the selected classrooms were taken from 1 September 2016 to 31 August 2017. Onset HOBO data logger devices were installed in the selected classrooms and inside the duct on each floor to measure the indoor air temperature and relative humidity every 30 minutes. To exclude the effect of uncontrolled conditions for ventilation, the results were presented for working hours 7:00 am to 3:00 pm. For the outdoor climatic conditions, a mini weather station was installed on the top of the building. A comparison was made between the reference rooms (R1) and the classrooms connected to the earth duct and solar chimneys (R2, R3), and with classrooms connected to solar walls and solar chimneys (R4) on each floor and between floors.

3. Results and Discussion

The results show that the average indoor air temperature for the whole year ranges from 8 to 29°C for the ground floor, 6 to 30°C for the first floor and 5 to 31°C for the second floor. Comparing air temperatures for the second floor with the ground and first floors, these temperatures are slightly lower in winter and slightly higher in summer, which can be explained by the exposed roof. On cold days, with outdoor air temperatures $< 10^{\circ}\text{C}$, all rooms have average temperatures that are at least 5°C higher than the outside temperatures, but they are still below 18°C which makes all rooms uncomfortable in winter. On hot days, with outdoor temperatures $> 25^{\circ}\text{C}$, all rooms –except room 4– have average temperatures that are at least 5°C less than the outside temperatures. Outside temperatures fluctuate [ΔT swing (for 2 months) around 23°C], meanwhile indoor air temperature swings do not exceed 10°C for the same period. This can be related to the stabilizing effect of the underground duct and the building thermal mass.

For the winter season during working hours, the room temperature in the reference room (R1), which has no connection to the earth duct, solar chimneys or solar wall, has more fluctuation than the other rooms. On colder days at $< 10^{\circ}\text{C}$, only R1 has lower temperatures than R2, R3 and R4, due to the effect of the earth ducts and solar chimneys which play a major role in maintaining temperatures in these rooms at a higher level. Temperatures in R2 and R3 are stable with minor swings between day and night. R4, with the solar wall, has an unstable performance as the solar wall depends on the sun's availability. When the sun is not available, R4 on the ground, first and second floors has lower indoor air temperatures (1 to 4°C) than other rooms, as shown in Figure 3. When the sun is available, R4 has higher indoor air temperatures (1 to 3°C) than other rooms, as shown in Figure 4. All the rooms tested have a

temperature range of 5-18°C most of the time in winter, which means that using the passive design solutions tested here was not enough to maintain thermal comfort.

For the early and late summer seasons (May - June and September – October; schools are closed from mid-June till the end of August) during working hours, R4 with its solar wall on the ground, first and second floors has the highest temperatures (+1 to +8°C) compared to other rooms. Also, R3 which is attached to R4 and connected to the earth duct and solar chimney, has a relatively high and stable temperature during working hours ($\approx 25^\circ\text{C}$). Rooms 1 and 2 on the ground, first and second floors have lower temperatures. R2, which is connected to the earth duct and solar chimney, has the lowest air temperatures on hot days (ranges from 20 to 25°C) compared with other rooms, as shown in Figure 5 and Figure 6.

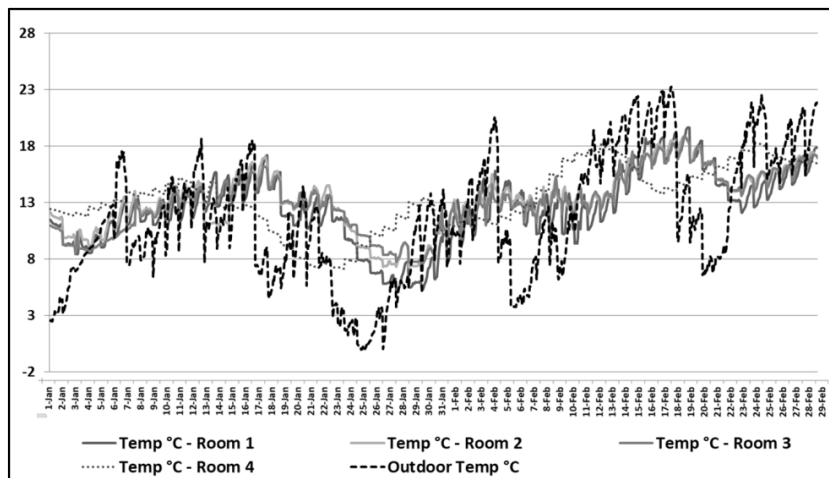


Figure 3. Two-month comparison (January and February 2016) of indoor and outdoor air temperatures for classrooms 1-4 on first floor.

Comparing rooms R2 and R3 with the earth duct and solar chimney to reference room R1, the indoor air temperatures are slightly better in winter and much better in summer. On certain days of the year, the difference can be noticeable, as can be seen in Figure 4 and Figure 6. Daily diurnal temperature variations ($\Delta T_{\text{day.swing}} = T_{\text{day.max}} - T_{\text{day.min}}$), also known as fluctuation, inside all the rooms were very small (less than 4°C) for the whole year, meanwhile daily swings for outdoor temperatures range from 5 to 15°C for the same period. Comparing rooms connected to the solar wall and solar chimney R4, with reference rooms R1 and with R2 and R3, the indoor air temperatures for R4 are not stable in winter and are uncomfortably high in summer.

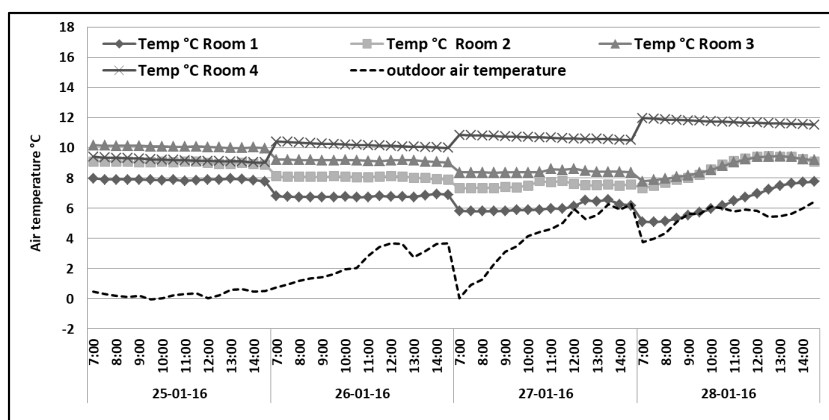


Figure 4. Four working days during working hours in winter show the difference between outdoor temperature and indoor air temperature for the selected classrooms on the first floor.

Comparing air temperatures on the second floor to those on the ground and first floors, the second-floor temperatures are slightly lower in winter and slightly higher in summer, which is due to the exposed roof on the second floor. For this reason, the paper shows the results for the first floor.

Indoor relative humidity (RH) for the ground and first floors ranges from 30% to 70% on most days of the year, which can be considered as comfortable according to ASHRAE 55. On the second floor, RH in all rooms in winter time and in the following weeks is higher than on other floors of the building. This can be related to the roof exposed to the outdoors, and lack of waterproofing in the roof.

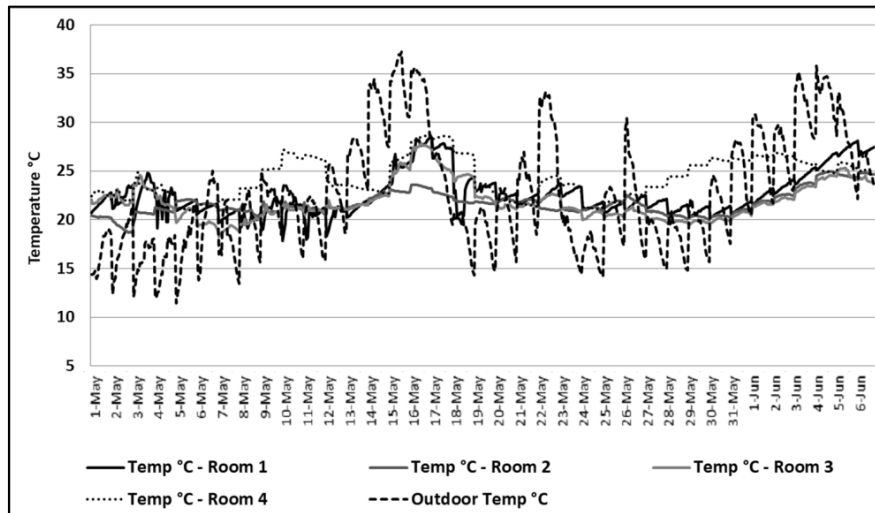


Figure 5. May and part of June 2016, comparison of indoor and outdoor air temperatures for the selected classrooms on the first floor.

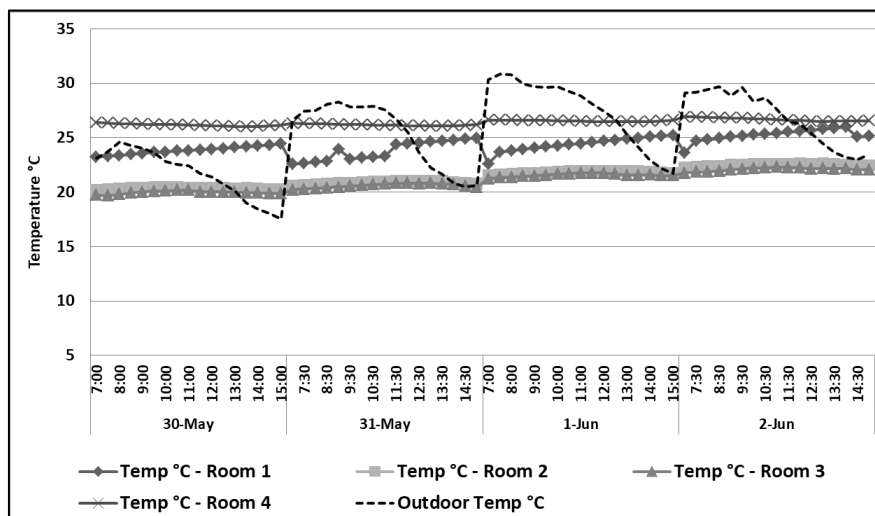


Figure 6. Four working days during working hours in early summer show the difference between outdoor temperature and indoor air temperature for the selected classrooms on the first floor.

4. Conclusions

Data analysis for passive design solutions in the selected school building has shown that there is a clear positive impact by the ground duct and solar chimneys on hot and sunny days. The chimneys act as good ventilators on these days and they could stabilize room temperatures in the classrooms at comfortable temperatures and humidity rates. However, the impact of ground ducts and solar chimneys on cold days was relatively small. The indoor air temperatures were higher than outdoor temperatures but much lower than the required comfort air temperatures. As the underground temperature in Palestine is stable (14 to 17°C), it is not expected that rooms are heated in winter to the comfort level (18 to 22°C). On relatively very cold days, most classrooms were measured at 10°C or less. For such cold days without sunshine,

the effect of solar chimneys and solar walls for withdrawing air from ground ducts was very limited. The reasons for this discomfort are: relatively low temperatures in the ducts, high ventilation rate in winter created by solar chimneys and the large thermal mass of the building, which is not thermally insulated.

For the three rooms with solar walls installed on their south-east wall, it was clear that they have the highest temperature throughout the year, higher than other rooms on sunny days. In winter, solar walls assist to a certain limit in warming the attached classrooms on sunny days only, but temperatures are still far from comfort level. In summer, these classrooms are uncomfortably hot on several working days. As no insulation was added to the solar wall, heat is transferred to the room by circulation through the grill and by radiation from the wall. The analysis of relative humidity levels shows that RH in the upper floor is higher than in the other two floors.

Air flow and air speed in solar chimneys depend on chimney height (the distance between inlet and outlet). In this case, the ground floor gives the highest values and best performance. On the upper floor the roof was not insulated from inside or outside which negatively affects heat loss in winter and heat gain in summer. The lack of insulation in air shafts transferring air from ground ducts to classrooms in this case, means that air moving to the rooms will lose some of its heat to the surrounding ground and shaft walls.

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