Courtyard' Design as a Sustainable Tool for Classrooms' Lighting and Thermal Performance

Muna Salameh and Basim Touqan

Abstract Sustainable Architecture is capable of creating sustainable buildings with comfortable indoor spaces and less energy consumption. Courtyards as passive design concept is a sustainable design tool since many ages. Proper courtyards' ratios integration in school buildings can help in improving the thermal comfort and lighting in the classrooms with less energy consumption especially in the hot arid climates like UAE. This research used a qualitative methodology based on IESve software to evaluate the effect of variation in the proportions of the school courtyards on the thermal performance and lighting of classrooms, the models of the study were built according to Koch-Nielsen assumption courtyards' ratios for a school building as a case study. The results of this research confirmed that the ratios of closed courtyards affect the thermal performance of the buildings based on investigation rooms. The findings of this research showed that the 2X courtyards width to height ratio succeeded to reduce the inner investigation room's air temperature with about 4–6 °C compared to 3X and open X Courtyards' cases. Additionally, the simulation revealed that the investigation rooms in the open X and the 3X courtyards' cases had the highest daylight and lux levels, which was to be expected given that both cases featured fewer sheltered outside spaces with greater solar exposure than the 2X courtyard. Finally, the 2X courtyard case had the best threshold glare level for the investigation room at roughly 212.48 cd/m2, with significant difference from the other cases. This study can help in designing sustainable schools.

Keywords Courtyards · Hot arid climate · Lighting · Classrooms · Thermal performance

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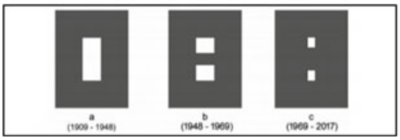
1 Introduction

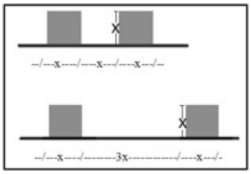
1.1 Courtyard Ratios and Thermal Performance

The ratios of the courtyard control the thermal properties, lighting and ventilation, [1–7] stated [8–12]. The courtyard ratio was calculated in different ways in relation to its height, width and length. Tayari and Nikpour [13] mentioned that the different ratios of the central courtyards affects directly the thermal performance of the building and should studied in the early stages of design. Chadalavada [14] stated that reducing the courtyard size, length and width as in Fig. 1a has a significant impact on the thermal performance of the building, as it reduces the inner temperature from7–9 °C, but unfortunately that produced a negative effect on the internal lighting. Rojas-Fernández et al. [15] stated that the efficient aspect ratio should differ according to the climate. The Maryland Department of Education [16], Reynolds [17] and Sthapak and Bandyopadhyay [18] stated that the aspect ratio (AR) can be measured by dividing the courtyard floor area by the square of the average wall height around the courtyard. The AR is clarified as “the range of openness to sky”. Thus, the higher the aspect ratio, the more visible the courtyard is to the sky. Koch-Nielsen [19] confirmed that the thermal characteristics for the courtyard and for the surrounding spaces are mainly determined by the courtyard proportions. He added that the best recommended ratios are related to the height of the building, if the height of the courtyard is X it is better to have a width that ranges from X to 3X (Fig. 1b). Moreover, the deep courtyard can expand the daytime interior shading time while a wide courtyard can improve the ventilation system.

Zamani et al. [20] investigated the thermal conditions inside and outside a typical Iranian courtyard home. According to the findings, the courtyard was on average 1.2 °C cooler than the outside. Additionally, it was noted that the courtyard’s exterior experienced greater temperature variations than its interior. In conclusion, the findings indicated that courtyards can create a cooler microclimate in the summer.



a- Site plan for a building illustration shows the transformation of the courtyard size and type (Chadalavada 2017)



b- The suggested proportions for the courtyard by Koch-Nielsen from X-3X where the height of the masses around the courtyard is X (Koch-Nielsen 2002).

Fig. 1 Different ratios for the courtyard

1.2 Courtyard and Lighting

In the case of schools, the lighting in the classrooms should be adequate to provide a suitable environment for learning, as most of the tasks in the classrooms depend mainly on the visual understanding. According to the earliest study conducted by consultants in the architectural engineering field and under the supervision of the Ministry of Public Works in the UAE to assess school performance, [21] insisted on the importance of the use of natural lighting in schools when it is possible, to decrease the use of artificial lighting and decrease the energy consumption. Accordingly, when the natural light accessed inside the inner spaces provides suitable visual comfort for the occupiers and decreases the energy use for electrical lighting [22]. In daytime, both the visual comfort and the energy use for lighting depend on the autonomy of the daylight. Moreover Al-Sallal [21] insisted that the problem of limited daylight can be solved by galleries, atria and mostly he recommended the establishment of courtyards in the schools. He added that courtyards can be efficiently used for lighting the surrounding classrooms. Grün and Urlaub [4] highlighted the importance of natural lighting and natural features in schools, they proposed the courtyard as a solution for that [23] stated that the courtyard is an important strategy for lighting, as well as for ventilation and cooling. Furthermore, they insisted that the height to width ratio in the courtyard affects the level of the daylight factor. Muhaisen and Gadi [24] mentioned the importance of courtyards in improving the natural lighting for the surrounding spaces. Al-Sallal and Abu-Obeid [25] stated that in the schools the reduction of the penetrated natural lighting into the classrooms causes increases in the expected operative periods of artificial lighting. Maesano and Annesi-Maesano [26] stated that better lighting conditions in the classrooms lead to better results for the students.

This research tried to investigate the effect of the variation in the ratios for a case study (existing school) when expanded based on [19] assumptions for the ratios for the courtyards, and its effect on the thermal performance, energy consumption and lighting, mainly for an investigation room in the ground floor for the original school and two other models based on.

2 Methodology

This research followed qualitative method with comparative analysis for a case study which was a school building with different courtyards' ratios in Sharjah-UAE. To simulate the case study, Virtual Environment software (IES) was used to look into the school building's enclosed courtyard's environmental performance and classrooms lighting. According to Crawley et al. [27], the IES program accurately and rationally simulates the environmental performance of buildings.

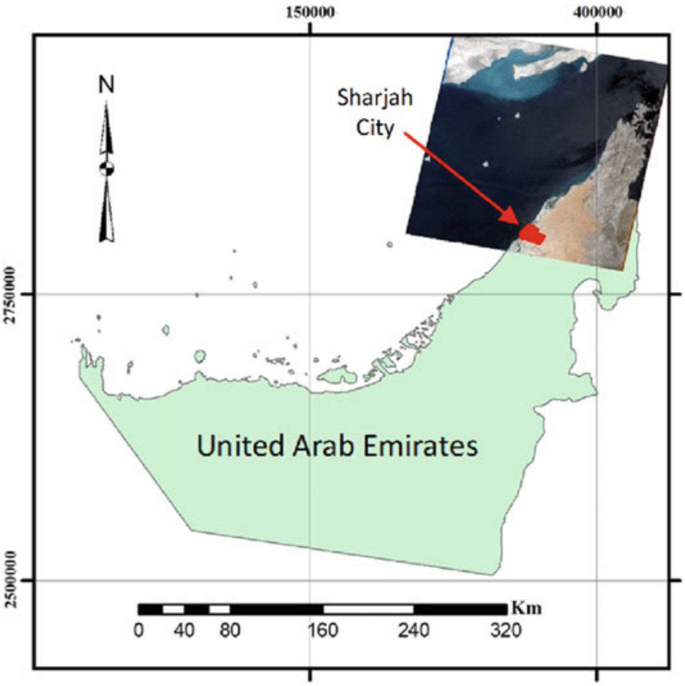


Fig. 2 Location of UAE to the right and location of Sharjah to the left [29]

2.1 Case Study Features and Climate

The case study for this research was the Al Murooj English School, which is situated in Sharjah-UAE (Fig. 2). All of the UAE's emirates, including Sharjah, have a mostly arid hot desert climate [28], with high curve for the average dry and wet bulb temperatures (Figs. 3 and 4).

2.2 Case Study Simulation Characteristics and Scenarios

Because the study focused on the impact of the courtyard on the school building, the fundamental building materials that were utilized in the actual school building–which was built in 1995–are those that were used for the simulation. These materials are listed in Table 1, which are the same mentioned in Dubai building standards for structures constructed prior to 2002, the materials were identified as standard materials [31, 32].

The study compared two suggested scenarios of the school building with closed courtyards in two different proportions to the thermal efficiency and ventilation

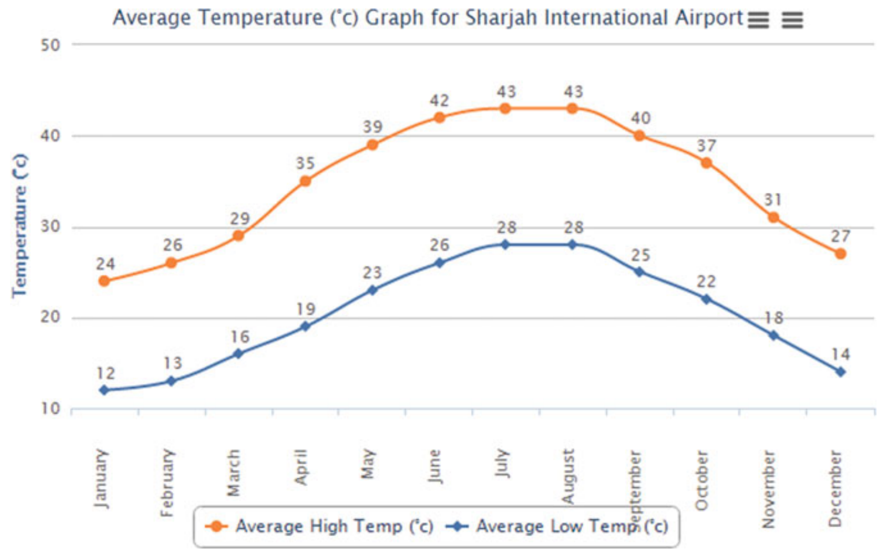


Fig. 3 Average temperature in Sharjah-UAE (IES)

Fig. 4 Wind rose [30]

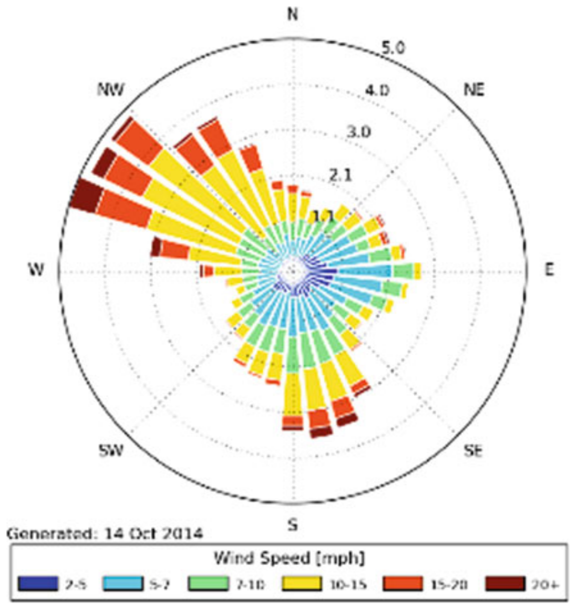


Table 1 Building materials of the school that were used in the IES simulation [31, 32]

Building component	Floor/Internal ceiling	Walls	Roof	Glazing
Material type	4 In. light weight concrete deck with false ceiling	Brick wall with 4 In. concrete block	6 In. heavy weight concrete with 2 In. insulation	Small Single-glazed windows
UV (Wm^2/K)	1.0411	1.8709	0.6819	5.2298

of the original school building with semi-opened courtyard (the basic case study). The closed courtyards were created in accordance with [19] recommendations, who claimed that the thermal characteristics of the courtyard and its surroundings are substantially influenced by the size and height of the courtyard. According to Koch, the ideal width for the courtyard is between X and 3X if the altitude of the courtyard sidewalls is X. The research employed the 2X and 3X instances (proportions) for the courtyard, ignoring the 1X proportion because it provides a tiny courtyard that is better suited to homes rather than public buildings. The inquiry will focus on the three examples listed in Table 2 to determine the ideal courtyard size for the case study school building in order to provide the optimal ventilation and thermal performance for potential future growth. The investigation room, which will be included in the energy simulation, is a classroom with 20 pupils that is located on the first floor and has a view of the courtyard. It is approximately 42 m^2 in size. The investigation room was presumptively full every day from 8 in the morning until 6 in the afternoon. 20 °C is the cooling set point. The investigation room's internal heat gain increased due to the presence of people and fluorescent lights.

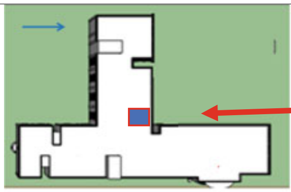
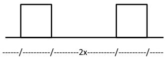
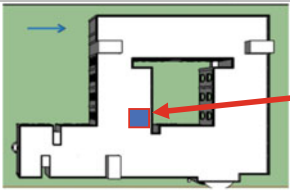
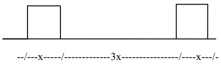
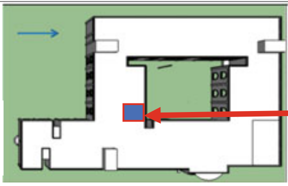
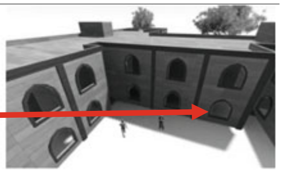
3 Discussion and Results

The IES VE software was used to simulate the three scenarios of the school building: the original school without a closed courtyard (open X), the 2X courtyard school, and the 3X courtyard school. The simulations were done for the assessment room in each of the three cases to look into the thermal behavior, illuminance.

3.1 Illuminance Analysis

The illuminance analysis for the investigation room was conducted on Sep21st _1200_cie.sky, the analyses in the simulation included the day light factor, glare and the lux. The simulation Showed that the higher daylight and lux levels were in the no courtyard case and in the 3X courtyard case (Table 3), and that was expected as those cases have less shaded areas outside the investigation room and more sun exposure than the 2X courtyard as what was shown in previous thermal analysis.

Table 2 The three simulation cases of the study

Cases of the analyses	Top view of the simulation cases with investigation room in the ground floor	Perspective for the simulation cases
First case: The original First case is the Basic case - School deprived of the closed courtyard- **Open X**		
Second case: The school with closed courtyard that has width 2X, where X is the courtyard height- **2X** 		
Third case: The school with closed courtyard that has width 3X, where X is the courtyard height-**3X** 		

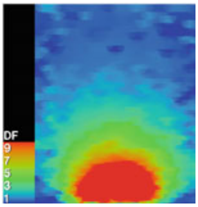
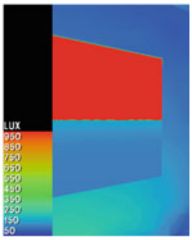
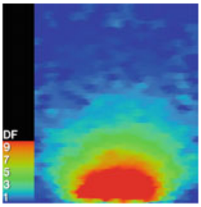
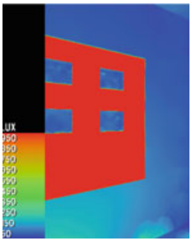
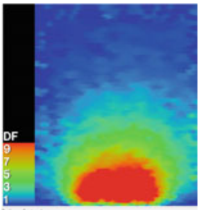
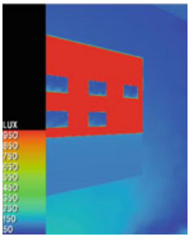
Because the investigation room is a classroom, and it is better to avoid glare in the classrooms (Lighting of the classroom 2015) the analysis indicated that the least glare was in the 2X courtyard case with threshold 212.48 cd/m2 and with significant difference from the other two cases (Fig. 5) and (Table 3).

3.2 *Thermal Analysis*

According to Muhaisen and Gadi [11], the thermal performance of buildings may be studied using field measurements or computer modeling.

The investigation room's exposure to the sun varied in each of the three scenarios when the school building was involved. According to the sun's route around the school, the investigation room's north external wall received the most of the sun's effects. The 2X courtyard school had the least amount of sun exposure for the investigation room, while the open X courtyard had the most. As a consequence, the north wall of the investigation room had the most solar exposure in the case of the

Table 3 Daylight and lux analysis in the investigation rooms for the three cases of the courtyards

Cases	Daylight on investigation room plan	Lux on the investigation room perspective	Glare
Case 1: Open X			
Case 2: 2X courtyard			
Case 3: 3X courtyard			

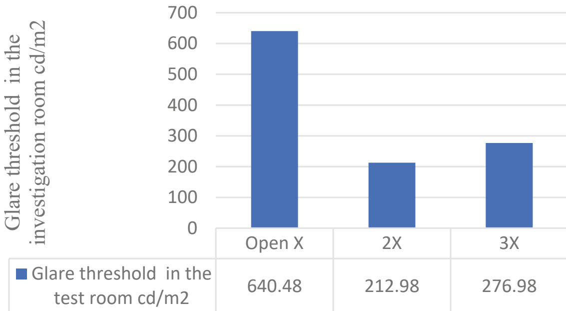
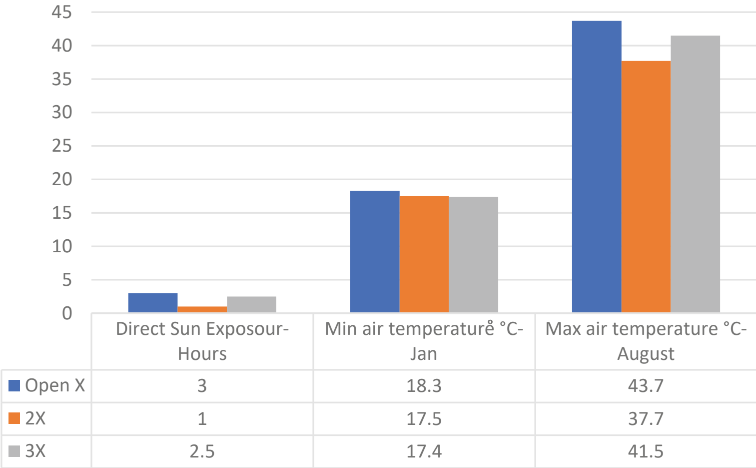


Fig. 5 Comparison for the glare in the investigation rooms for the three cases of the courtyards



	Direct Sun Exposour-Hours	Min air temperature °C-Jan	Max air temperature °C-August
Open X	3	18.3	43.7
2X	1	17.5	37.7
3X	2.5	17.4	41.5

Fig. 6 Sun exposure, min and max air temperatures on specific dates for the investigation rooms in the three cases of the courtyards

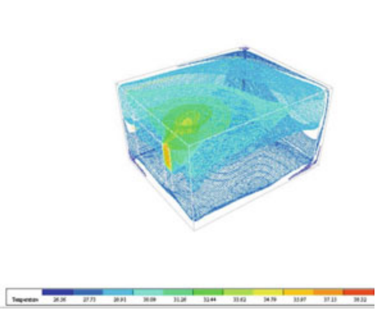
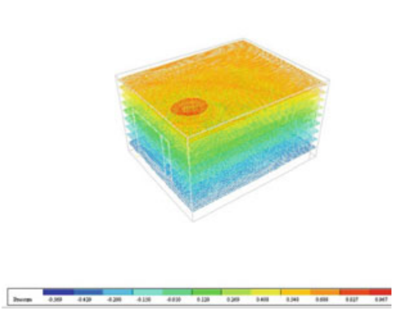
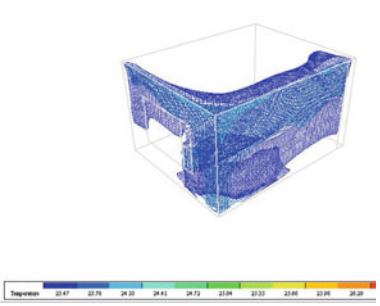
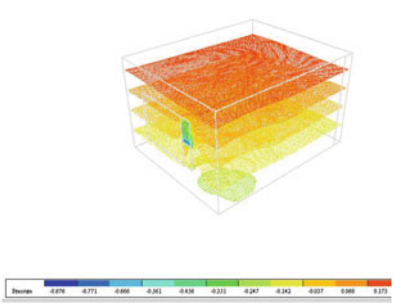
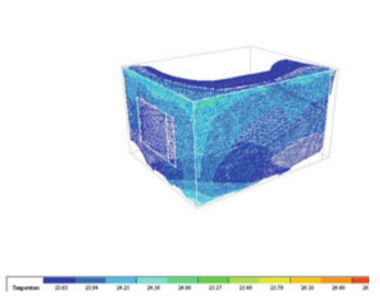
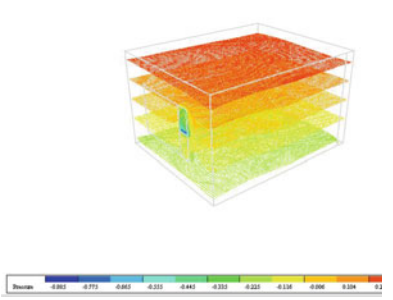
2X courtyard, the investigation room will be less heated, making the interior of the investigation room colder compared to the other two situations.

The simulation showed that the 2X courtyard school had the lowest air temperature in the investigation room, and that this was significantly different from both the school without a courtyard and the one with a 3X courtyard (Fig. 6). The temperature at 2X Courtyard School is around 23% cooler than that at open X Courtyard School and 19% cooler than that at 3X Courtyard School. Because the 2X courtyard school had less solar gain and exposure, as previously mentioned, the variation in temperature in the three situations may be explained. Thus, the 2X courtyard school has the lowest energy need for cooling the investigation room.

3.3 Temperature and Air Pressure Inside the Investigation Room–Natural Ventilation

Microflow CFD the Computational Fluid Dynamics (CFD) in the IES software was used to check the Temperature of the air in the investigation room and related Pressure contour inside it on the 27th of April at 7:30 at the macro flow external vent in the IES. Table 4 shows the temperature and the pressure contour inside the investigation room and the results were as the following: The least temperature for the investigation room was in the case of 2 X courtyard on 27th of April the simulation date and it was around 23.47c, which means less energy for cooling, on the other hand the least pressure on the surfaces was in the case of 2X courtyard on the simulation date with maximum reading around 0.277 ps.when the temperature is low the pressure on the surfaces is low (Anon—air pressure 2015), and that prove that the investigation room has the least temperature when the pressure inside it is the least when it depends on the natural ventilation, though the temperature is the least in the case of 2X courtyard comparing with the other two cases.

Table 4 Temperature and air pressure in the investigation rooms for the three cases of the courtyards

Cases	Temperature of the air in the investigation room	Pressure contour inside the investigation room
Case 1: Open X courtyard		
Case 2: 2X courtyard		
Case 3: 3X courtyard		

4 Conclusion

Courtyards are an important passive design solution for the sustainable buildings including schools. The findings of this study supported the hypothesis that the ratios of a closed courtyard had an impact on the building's thermal performance. The results of this study revealed that the 2X Courtyards width to height ratio succeeded to reduce the inner investigation room's air temperature with about 4–6 °C compared to 3X and open X Courtyards' cases. Additionally, the simulation revealed that the investigation rooms in the open X and the 3X courtyards' cases had the highest daylight and lux levels, which was to be expected given that both cases featured fewer sheltered outside spaces with greater solar exposure than the 2X courtyard. Finally, the 2X courtyard case had the best threshold glare level for the investigation room at roughly 212.48 cd/m^2, which represented a substantial improvement over the other two cases open X and 3X courtyards. The study confirmed that courtyards with proper ratios can be a sustainable tool that can help in designing sustainable schools.

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