The influence of different courtyard ratios in university buildings on their thermal performance during the hot period: (Faculties of Agriculture and Education, New Sohag University, Egypt as a case study).

Amr Sayed Hassan Abdallah 1,*, Dina Ahmed Mohammad 1, Abdel-Monteleb Mohammad Ali 1

1 Architectural Engineering Department, Faculty of Engineering, Assiut University, Egypt
* Corresponding author. Tel: +201002021565, Fax: +20882332553
E-mail: arch_amrsayed@yahoo.com, Dr.amrsayed@aun.edu.eg

Abstract. Due to the importance of courtyards in educational buildings, their role in improving climate and their impact on students' performance and learning. This paper aims to comparing the thermal performance of courtyards with different dimensions and ratios, with their impact on overlooking space in university buildings, as well as their impact on the thermal comfort of the students in such courtyards in "the Faculties of Agriculture and Education, New Sohag University" during the hot period of the academic year (March, April, May). It's worth noting that in order to achieve this aim, the research adopted the analytical and the applied methods; which included field measurements and questionnaire Furthermore, Parameters (such as indoor/outdoor temperatures, relative humidity, and airspeed) of the courtyards and spaces overlooking them were measured. In addition to 900 questionnaires forms that were distributed in the courtyards of the faculties of Agriculture and Education during the hot period which represent measurement months (March, April and May). Meanwhile, the findings indicated that the temperatures of "the Faculty of Agriculture courtyard" with a height/width ratio of (0.7) was higher than the temperature of "the Faculty of Education courtyard" with a height/width ratio of (1.2). The findings also revealed that the "Faculty of Education courtyards" with a H/W ratio of (1.2) achieved a sense of the thermal performance of overlooking spaces and Acceptable thermal comfort for students better than "the Faculty of Agriculture courtyards" with a H/W ratio of (0.7) during the hot period.

Keywords. Thermal Comfort; University Buildings; Courtyards; Thermal Performance; Sky view factors, (Height/width) ratio.

1. Introduction
Thermal comfort plays a major role in the building sector, particularly in hot dry regions, due to their impact on indoor temperature and energy consumption [1]. University buildings require a high level of internal environmental quality [2], as students spend long periods up to one third of the day in educational spaces [3]. Problems of thermal comfort in indoor environment of university buildings in hot dry regions include: High temperature [4], insufficient ventilation, and high student density [5]. Having a courtyard in the building certainly improves the indoor climate of spaces overlooking to such space. Studies showed that a building with a courtyard is the best type of buildings in terms of usage in desert dry regions [6, 7, 8, 9, 10]. The courtyard acts as a thermal regulator, the mitigating indoor temperature in the building [11], where large parts of the courtyard become shaded during day hours leading to reducing thermal loads on spaces overlooking such courtyard during the critical periods of the day [12]. It is worth noting that the design of a courtyard and its components have a great effect on the thermal performance of the courtyard, particularly the indoor temperature [13, 14]. A number of researchers studied the influence of a courtyard's shape on the shading ratio and the performance of the courtyard [15, 16, 17, 18, 19] using the simulation software (Design Builder) and (ENVI-met). Other studies addressed the influence of the H/W ratios on thermal performance in courtyards [20, 21, 22, 23] using the Ray Man simulation software to simulate the performance of thirty buildings with different ratios.
Results showed that a deep courtyard is thermally better [24, 25]. In addition, some studies addressed the influence of orientation on the thermal performance of the building [26, 27, 28, 29]. A number of studies focused on components of courtyards (shading devices, trees, water elements, finishing) and their influence on the thermal performance of a building [30, 31, 32, 33]. They found that shading is considered the best strategy for improving the thermal performance of courtyards in hot dry climates [34, 35, 36]. Nevertheless, a study addressed the influence of shading a court on the thermal performance of spaces overlooking such courtyard. It was found that shading a courtyard improves its thermal performance and that of overlooking spaces [37].

Despite the various studies on courtyards’ influence, most of which focused on the influence of courtyards on public buildings in general, or on residential buildings as a passive design strategy for improving the thermal performance of courtyards and space overlooking such courtyards, as well as their influence of the thermal comfort of students at the courtyard during the hot period. The main objective of this paper is to compare the thermal performance of courtyards with different dimensions, and their influence on overlooking space in university buildings during the hot period of the academic year.

2. Methodology
A courtyard's design affects its thermal performance and, consequently, indoor temperatures of spaces overlooking such space, as well as the thermal comfort of students at the courtyard, in university buildings in Upper Egypt, during the hot period. Thermal comfort was evaluated based on two approaches, objective measurement and subjective assessment using a questionnaire survey. Monitoring was done for (indoor/outdoor temperatures, relative humidity, and airspeed) of courtyards and space overlooking such courtyards, using the measurement devices shown in Table (1).

Measurement is conducted from 9 a.m. to 3 p.m., 6 days per month, during the hot period (March, April, and May) for the academic year 2017-2018. Subjective assessment using questionnaire survey was used in distributing questionnaires from 1-2 p.m. in the measurements period during the hot period; representing the period when most students sit for a break inside "courtyard 2" which the main courtyard of the building of "the Faculty of Agriculture", and the courtyard at "the Faculty of Education". Questionnaires are 860 out of 900 (480 in the Faculty of Education and 420 in the Faculty of Agriculture). The remaining questionnaires were eliminated due to incomplete information.

Table 1. Devices used for measurements.

| measurements                  | Device used         | Precision      | Range                     |
|-------------------------------|---------------------|----------------|---------------------------|
| Temperature & humidity in courtyards | TR72Ui              | 1%, ±1°C       | (0 to 45°C) (10% to 90% RH) |
| Airspeed in courtyards   | EA3000 Standard Handheld Anemometer | ±5%, + 0.1 m/s | 0.2 m/s to 30 m/s |
| Temperature & humidity in spaces | TR-76Ui            | 1%, ±1°C±      | (0 to 45°C) (10% to 90% RH) |
| Temperature of earth surface | Infrared Thermometer 42515 | 2%, ±2°C±      | -50 to 800°C |

3. Case Study location and description
Sohag is located at a latitude of 26:56 °N, and a longitude of 31:69 °E, 67 meters above sea level, in
the southern part of Upper Egypt according to the Egyptian Code of Improving Energy Use, issued by the HBRC [46], as shown in Figure 1.

![Egyptian climatic map, HBRC classification, 2006 [46], and Location of New Sohag City relative to Sohag City.](image)

Outdoor temperatures in winter range from 7.3°C to 22°C, whereas the highest temperature average in summer is about 39.6°C during day, down to 23.1°C at night [47]. Relative humidity ranges from their lowest value of 30% in May and the highest value of 57% in January; (30% 45%) in summer, and (44%-57%) in winter [48]. Wind is North and Northwest in winter, and Northwest/North in summer [49]. The largest amount of rain is about 0.2 mm in (March, April, and May), followed by (January, February, and December) (0.1 mm). Other months of the year almost have no rainfall. In general, Sohag City is characterized by the scarcity of rainfall [49]. As for solar radiation, Sohag City is characterized by clear sky over the year, with direct strong solar radiation. Also, the highest value of solar radiation occurs during the months of June and July, and the lowest in February [49].

- **Analysis of Faculties of Agriculture and Education, New Sohag University as an applied example:**

The faculty of Education is located next to the main entrance of New Sohag University, New Sohag City, as shown in Figure 2. The building consists of four repeated floors and a ground floor with a total area of 4711 m². There are two courtyards in the building with a total area of 1531 m². The building consists of two wards with the two courtyards in between, with part of the classes and faculty members' offices overlooking the same. The building of “the Faculty of Agriculture” is located west of the main entrance of New Sohag University, New Sohag City, as shown in Figure 3. The building consists of five repeated floors and a ground floor with a total area of 7492 m². There are three floors in the building with a total area of 3147 m². The building consists of three wards with courtyards in between. Some of the classes, labs, and faculty members’ offices overlook the courtyards.
Measurement locations: A number of spaces overlooking courtyards with different orientations were selected; representing spaces with different functions (classes, labs, offices) at the buildings of the two faculties. Figure 3 shows the measurement locations at the faculties of Agriculture and Education buildings.

4. Results
4.1. Thermal performance of courtyards

Figure (4-a) shows that the temperatures of courtyards were higher than outdoor temperatures in hot-weather days. While, figure, (4-b) shows that the highest difference of the average temperatures of the three courtyards in the building of "the Faculty of Agriculture" were (1.1, 3.1, 1.3) °K respectively at 2 p.m., whereas the highest difference of the average temperatures of the two courtyards in the building...
of "the Faculty of Education" was (1.3, 0.7) °K, respectively, at 2 p.m., as illustrated in figure. (4-c).

Figure 4. Temperatures of courtyards in the two buildings of the two faculties (Agriculture & Education) during the measurement period (9 a.m. to 3 p.m.) in the hot period.

Figure 5 shows the temperature distribution in courtyards during the periods (from 10 a.m. to 12 p.m.), (12 p.m. to 2 p.m.), and (2 p.m. to 4 p.m.) during the hot-weather days. It can be seen that shading ratios in "the three courtyards of the Faculty of Agriculture" reduced during the period (from 10 a.m. to 2 p.m.) despite of being surrounded by buildings with H/W ratios of (1.2, 0.7, 1.2), respectively.

On the contrary, shading ratios increased in courtyards 1 and 3 after 2 p.m., whereas the shading ratios decreased in courtyard 2 due to the reduced containment temperature (the total area of walls specifying the courtyard and ground area) to (2), compared to a value of 4 for courtyards 1 and 3. The reduced containment temperature means increased solar radiation reception [49]. Therefore, the shading ratios decreased due to the lack of green areas. Meanwhile, the shading ratios of the two courtyards "in the Faculty of Education" due to the shade caused by surrounding buildings with a H/W ratio of (1.2).

On the other hand, the shading ratios of the two courtyards for the period (12 p.m. to 4 p.m.) decreased, despite the fact that a containment temperature was (4.1), but without shades.
Figure 6 demonstrated the ground surface temperature in courtyards during the periods (10 a.m. to 12 p.m.), (12 p.m. to 2 p.m.), and (2 p.m. to 4 p.m.) in hot-weather days. It can be seen that the ground surface temperature was reduced in "the three courtyards of the building of "the Faculty of Agriculture" during the period (10 a.m. to 12 p.m.) due to shade caused by the surrounding buildings. Yet, the temperature increased (from 12 p.m. to 4 p.m.) as a result of poor shading in courtyard 2, the lack of green areas in courtyards, and the using of dark-coloured floor tiles. Yet, surface temperature decreased in the two courtyards of "the Faculty of Education" for the period (10 a.m. to 12 p.m.) due to shade caused by surrounding buildings, trees in both courtyards, and light-coloured floor tiles. Meanwhile, the temperature increased from (12 p.m. to 4 p.m.) due to poor shading.
Airspeed in the "three courtyards of "the Faculty of Agriculture" decreased during the hot period, as shown in figure 7 a result of not opening the common entrances in such courtyards. Air speed increased for the middle courtyard compared to courtyards 1 and 3; the outer street works as a major space through which air is transferred from the high-pressure zone to the low-pressure zone. On the other hand, airspeed increased for the three courtyards when common entrances were opened.

Figure 8 shows that the air moves with high speed from the middle courtyard passing through the public entranceways of courtyards through courtyard 1 and courtyard 3 by openings from inside to the outside and vice versa; causing airspeed to increase and temperature to decrease by 1.5°C.

* Surfer Software was used to determine the thermal distribution. The court was divided into various points making a mesh, and temperature values were measured in the said mesh.
However, airspeed increased in both buildings of the Faculty of Education, as shown in Figure 9. As a result of air entering through the main entrance opening facing both courtyards, and passing by the shaded part in both courtyards “courtyard 1 and courtyard 2”, (due to pressure difference, and the difference between temperatures of the exterior and the two courtyards) through small openings at the corners of the building as shown in Figure 10.

Figure 7. Plan of points where airspeed was measured in courtyards of the building of “the Faculty of Agriculture”, as well as airspeed upon opening and closing common doors of courtyards during the hot period.

Figure 8. Plan, showing airspeed in courtyards due to pressure difference, photos of openings and entrances in the building of “the Faculty of Agriculture” which contribute to airspeed in courtyards.
Courtyard 2 at the building of "the Faculty of Agriculture" scored higher temperature values during the hot period, due to design of the courtyard; with the SVF (Sky View Factor)* increasing to 0.84. Yet, SVF decreased for both courtyards at the "Faculty of Education" to 0.69 and 0.67, respectively, as shown in in figure 11. Increase SVF means increasing solar radiation received as is strongly related to temperatures in courtyards and, consequently, internal temperature values, [50, 51].

*Inner courts were shut using Fisheye Lens. The SVF was calculated using Rayman software.
From the above, it can be seen that the building of "the Faculty of Agriculture" with a H/W ratio of 0.7 scored higher temperature values compared to the "Faculty of Education" courtyard with a H/W ratio of 1.2, due to reduction of the SVF value and the confinement degree compared to the "Faculty of Education: courtyard, causing less shading ratios, as well as an elevated ground surface "Faculty of Agriculture courtyard" (as a result of using dark floor tiles, no trees, and hollow shades), with airspeed reduced as a result of not opening common doors of courtyards.

4.2. Thermal performance of spaces overlooking courtyards

It is important to take into consideration that in hot period courtyards have a great effect on indoor temperature of the spaces overlooking them during the measurement period (from 9 a.m. to 3 p.m.). As illustrated in Figure. 12 Indoor temperature of spaces overlooking "the courtyards of the Faculty of Agriculture" is lower than the temperature of the three courtyards with degrees (3.0, 3.3, 2.9 °C) respectively in hot period.

It’s noteworthy that indoor temperature of spaces overlooking both courtyards of "the Faculty of Education" have decreased compared to the temperatures of both courtyards with degrees not exceeding (3.9 and 4.4 °C) respectively in hot period as illustrated in Figure.13. This is primarily due to the increased shading ratios caused by the surrounding buildings in both courtyards of "the Faculty of Education" and increased airspeed within; causing a fall in Indoor temperatures of spaces overlooking both courtyards.

Furthermore, the measured Indoor temperature of spaces overlooking the courtyards were most of the time beyond the range of acceptable temperatures in hot period which represent (90% of acceptable temperatures) according to the "Adaptive Comfort Standard" (ACS) [51].

Figure 12. Temperature values for the three courtyards and spaces overlooking both, the building of "the Faculty of Education" in the measurement period (9 a.m. to 3 p.m.), during the hot period.

Figure 13. Temperature values for both courtyards and spaces overlooking both at the building of the Faculty of Education in the measurement period (9 a.m. to 3 p.m.) during the hot period.
From Figure 14, it is noted that spaces overlooking the exterior façade scored higher temperatures compared to those of spaces overlooking courtyards at the both faculties’ buildings in the measurement period (9 a.m. to 3 p.m.) during the hot period. Moreover, the findings revealed that the courtyard with a H/W ratio of (0.7) has a higher impact on the temperatures of the spaces overlooking such courtyards than the courtyard with a H/W ratio of (1.2).

Meanwhile, there was an increase in the indoor temperatures compared to outdoor temperatures of the spaces (Office 1, Office 2, Office 3, and the classroom overlooking the facade) with degrees not exceeding (1.6, 1.2, 1.9, 3.0 °C) respectively in the building of the Faculty of Agriculture. While the indoor temperatures of the spaces in the building of the Faculty of Education (classroom 1, classroom 2, classroom 3, and the office overlooking the facade) increased up to (0.8, 0.9, 1.0, 2.2 °C) respectively.

In the light of Figure. 15 We could see the regression lines among the courtyard’s temperatures and the indoor temperatures of the spaces overlooking the building of "the Faculty of Agriculture" during the measurement period (from 9 a.m. to 3 p.m.) in the hot period. Since the correlation factor was calculated; with temperatures ranged between (0.5, 0.7), it’s denoted that there is a moderate relation of proportionality, despite the fact that the impact of "court yard 1 and courtyard 3” is higher than the impact of "court yard 2” on the spaces overlooking it. This could be attributed to the design of the courtyard and thus on its shading.
On the other hand, we found that there is a strong relation of proportionality between the temperatures of the two courtyards in "the Faculty of Education building" and the spaces overlooking them as illustrated in figure. 16, where the temperatures ranged from (0.8 and 0.9). Hence, the impact of both courtyards in the building of "the Faculty of Education" on the temperatures of the spaces overlooking them is higher than the impact of the courtyards in "the Faculty of Agriculture" on the temperature of the spaces overlooking them.

4.3. Evaluation of relative humidity of spaces overlooking courtyards

The relationship, among indoor temperature values and the relative humidity of courtyards and spaces overlooking them, was studied using the psychometric chart. It was found that courtyards and spaces overlooking the buildings of the Faculties of Agriculture and Education fall within the acceptable limit of relative humidity (40-60%) \(^{(52)(53)}\) According to ASHRAE 2004 Standard \(^{(54)}\)

4.4. Influence of inner courtyards on students thermal comfort using questionnaire

Upon analyzing the findings of the questionnaires on "the courtyard 2" of "the building of the Faculty of Agriculture", the main courtyard in which the students sit for recreation after finishing their lectures, in hot period as shown in Figure.17. the findings revealed that 20% of the students felt that the temperature in the courtyard was "comfortable", while 73% felt that the temperature ranged from "slightly hot to very hot". Consequently, it’s denoted that "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) didn’t achieve the sensation of thermal comfort among the majority of the students in the hot period. This is mainly due to the reduced SVF, as well as the containment temperature of the "Faculty of Agriculture courtyard"; implying an increase in the solar radiation, and a reduction in the shading ratio with a rise in the temperature of the courtyards floor surface; (due to the use of dark-colored floor tiles, the lack of green areas, and a reduced airspeed as a result of not opening the public entranceways of the courtyards). As for humidity, the findings demonstrated that 30% of the students felt that the humidity in the courtyard was "natural". Whereas 23% felt that it was "slightly dry". On the other hand, 30% of the students felt that the airspeed to be "low", and 23% felt it was "enough", as a result of not opening the public entranceways of the courtyards which reduced the airspeed.
Meanwhile, the figure, 18 suggested that 30% of the students felt that the temperature in "the Faculty of Education courtyard" was "comfortable", while 65% of the students felt that it ranged from "slightly hot to very hot". This is mainly due to the decreased shading ratio of the courtyard after 12 p.m. as a result of poor shading at the courtyard. The findings also revealed that 35% of the students felt the humidity in the courtyard to be "natural", while 22% felt it was "slightly dry". Meanwhile, 42% of the students felt airspeed to be "enough", while 20% felt it was "low", this could be attributed to the high airspeed in the courtyard as air went in and out through air vents due to the pressure difference. Given the findings of the measurements and questionnaires, they implied that "the Faculty of Education courtyard" with a H/W ratio of (1.2) achieved a sense of thermal comfort for students more than "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) in the hot period. This is mainly attributed to the increased SVF and the containment temperature of "the Faculty of Agriculture courtyard", which causes an increase in the shading ratio, and reduced the floor temperature of "the Faculty of Education courtyard" due to using light-colored floor tiles and having green areas.

It is worth noting that the airspeed in "the Faculty of Education courtyard" was higher than that of "Faculty of Agriculture courtyard" due to air exchange through the air vents which resulted in a pressure difference inside and outside the courtyard, ensuring natural ventilation and optimizing the thermal behavior, thus, achieving an environment which thermally and environmentally appropriate for students’ activities in "the Faculty of Education courtyard".

![Figure 17](image17.png)

**Figure 17.** Results of questionnaires on temperature, humidity, and airspeed satisfaction at the "Faculty of Agriculture courtyard."

![Figure 18](image18.png)

**Figure 18.** Results of questionnaires on temperature, humidity, and airspeed satisfaction at the "Faculty of Education courtyard."
5. Conclusion
A comparative study was conducted in the Faculties of Agriculture and Education, New Sohag University to examine the thermal performance of the internal courtyards with different dimensions, and their impact on the performance of the overlooking spaces in the university buildings, as well as achieving the thermal comfort among the students in the hot period of the academic year.

- The findings of this Study ascertained that in the hot period the temperatures of "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) tend to be higher than the temperatures of "the Faculty of Education courtyard" with a H/W ratio of (1.2). This is mainly due to the impact of the courtyard’s geometric dimensions on the amount of the solar radiation incident on such courtyard, and consequently on its shading. As well as the reduced airspeed inside the courtyard of the Faculty of Agriculture.

- It is worth noting that the shading ratio of "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) has decreased during the critical noon time (from 10 a.m. to 4 p.m.). Meanwhile, the shading ratio of "the Faculty of Education courtyard" with a H/W ratio of (1.2) has increased (from 10 a.m. to 12 p.m.), owing to the rise of containment temperature up to 4.1 in comparison to "the Faculty of Agriculture courtyard" that amounts to (2).

- The findings have also revealed that the impact of "the Faculty of Education courtyard" with a H/W ratio of (1.2) on thermal performance of the spaces overlooking such courtyards was higher than the impact of "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) on the performance of its relevant spaces, mainly due to the courtyard design and (H/W) ratios.

- Likewise, the SVF for the courtyards has affected their relevant temperatures, and subsequently the thermal comfort level among the students. On the other hand, "the Faculty of Education courtyard" with a H/W ratio of (1.2) achieved more thermal comfort level among the students than "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) in hot-weather days. This is particularly noteworthy as it revealed that 73% of the students in "the Faculty of Agriculture courtyard" felt that the temperatures ranged from "slightly hot to very hot", while 30% of the students in "the Faculty of Education courtyard" felt that the temperature was "neutral".

- In this regard, it is important to take into consideration that "the Faculty of Agriculture courtyard" with a H/W ratio of (0.7) has not achieved the thermal comfort level among most of the students. This could be attributed to the poor design of the courtyard and the high temperature of the courtyards floor (due to the use of dark-colored floor tiles, the lack of green areas, and poor shading), not to mention the reduced airspeed as a result of not opening the public entranceways of such courtyards.

- Finally, due to the importance of courtyards and their impact on university buildings, there should be more studies conducted to search the ways of enhancing their thermal performance and achieving the optimum ratios in university buildings during the hot period to provide the thermal comfort for students.

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