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# Daylight Illuminance in Classrooms Adjacent to Covered and Uncovered Courtyards Under The Clear Sky of Najran City, Saudi Arabia

Abdultawab M. Qahtan
*Najran University, Najran, Saudi Arabia*, tawab444@gmail.com

# DAYLIGHT ILLUMINANCE IN CLASSROOMS ADJACENT TO COVERED AND UNCOVERED COURTYARDS UNDER THE CLEAR SKY OF NAJRAN CITY, SAUDI ARABIA

**Abdultawab M. Qahtan**
*Department of Architectural Engineering, College of Engineering, Najran University, Najran, Saudi Arabia*
*tawab444@gmail.com*
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للإضاءة الطبيعية في الفصول الدراسية تأثير على فعالية وصحة الطلاب، كما تساهم في توفير الطاقة الكهربائية. في المناطق الحارة، يعد مفهوم الفناء في المباني من الحلول المستدامة التي تحقق الإضاءة الطبيعية للفراغات الداخلية المتاخمة له دون التأثير سلبًا على أحمال تبريد المبنى في فصل الصيف. احتوت مباني كليات جامعة نجران على عدد من الافنية المنغلقة. مؤخرا في كلية الهندسة تمت تغطية هذه الافنية باستخدام قماش PVC. تهدف هذه الدراسة إلى تحليل مستوى شدة الإضاءة الطبيعية في الفصول الدراسية ومدى تأثير الفناء (المغطى والغير مغطى) عليها. تم إجراء دراسة حالة لأربعة فصول دراسية في كلية الهندسة تحت سماء مدينة نجران الصافية. أظهرت النتائج أن مستوى شدة الإضاءة الطبيعية في الفصول الدراسية المجاورة للفناء المكشوف كانت منخفضة. حيث وجدت بحد أقصى 100 لوكس و30 لوكس بالقرب من النوافذ ومنتصف الفراغ على التوالي، عندما كان مستوى الإضاءة الخارجية 110 كلوكس. فيما يتعلق بالفصول الدراسية المتاخمة للفناء المغطى، كانت مستويات الإضاءة الطبيعية الداخلية 18 و10 و7 لوكس، بمسافة 1 و3 و5 أمتار من النافذة، على التوالي. بشكل عام فان الفصول الدراسية تعتمد بشكل أساسي على الإضاءة الكهربائية.

Daylight penetrating the classrooms makes students efficient, improves overall health and increases energy efficiency. In the hot regions, the concept of courtyards in buildings is deeply linked to the architecture as a sustainable solution to daylight indoors without negatively affecting the building cooling loads in the summer. Najran University has existing courtyards in college buildings. Recently, the university covered the courtyards using PVC canvas. This study aims to investigate and compare the daylight illuminance in classrooms adjacent to covered and uncovered courtyards. A case study of four classrooms in the College of Engineering was investigated under the clear sky of Najran City. Results showed that the daylight illuminance in the classrooms adjacent to the uncovered courtyard was low with a maximum of 100 lux close to the windows when outdoor illuminance was 110 Klux. However, the indoor daylight illuminance in the classrooms adjacent to the a covered courtyard was 18, 10 and 7 lux, with 1, 3 and 5 m distance from the window, respectively. These classrooms depend mainly on electrical lighting.

## 1. INTRODUCTION

Lighting design for buildings is important, particularly for educational buildings that should provide visual comfort to users. Artificial lighting is responsible for 17% of electricity use in Saudi Arabia compared with the global average of 15% [1]. In Saudi Arabia, artificial lighting is extensively used in educational buildings because the government covers the electrical bills and users lack awareness about energy saving. An important factor that leads to energy saving is the amount of daylight penetrating the educational spaces to reduce electrical lighting given that students often work during daylight hours.

In hot dry regions, such as Najran, allowing daylight into classrooms may permit excessive heat gain, which increases the use of air condition and, consequently, energy consumption. However, colleges at Najran University (NU) integrated courtyards in their design to increase the visual comfort of students and faculty members in classrooms for educational processes, without increasing indoor temperature. Recently, the construction management at NU constructed blind roofs to protect their courtyards from the rainwater that falls a few days per year, that is, a total of 29.6 days/year [3]. The present study aims to investigate and compare the performance of daylight in classrooms adjacent to an uncovered courtyard and a PVC-covered courtyard in the College of Engineering at NU.

Numerous studies have discussed the advantages of daylighting in educational buildings. They indicate that daylighting indoors has a direct effect on the energy saving of 15%–40% [4]. Daylighting, also has an improvement in student performance, promotion of better health, productivity and overall sense of satisfaction of users [4]. However, Classroom should be designed to have enough illuminance that is appropriate for activities like writing and reading on whiteboard and desks. The Saudi standard for indoor lighting, has recommended the Maintained values of illuminance in the classrooms ranges from 300-500 lux [5].

The classrooms in a hot arid climate are not designed with daylighting as a top priority due to problems of heat gain [6]. In such climate, courtyards are one of the sustainable concepts that have been used to enhance daylighting in buildings without exposing the windows to direct sunlight [7]. The influence of courtyard on daylight illuminance in adjacent spaces has been investigated by several studies. Guedouh and Zemmouri, investigated the hot and dry region of Algeria to assess the influence of courtyard on its adjacent spaces under clear sky conditions. The on-site measurements found that the courtyard offered a high potential for natural lighting and thermal control [7] . Cantón and Llano, examined courtyards as a passive strategy in educational buildings under the clear sky of Argentina [8]. The shade condition of the courtyard is the strategy that highly affects the thermal and energy consumption in classrooms with the presence of cool daylighting. Studies have also cited that courtyards form an effective shading to prevent direct solar radiation without sacrificing daylighting [9], [10]. Vaisman and Horvat, found that courtyards could improve the luminance hours between 9% and 20%, thereby providing a viable option when seeking an increase in the amount of light reaching the interior of buildings [11].

### 1.1. Daylight performance metrics

The assessment of daylighting performance is an important step in daylighting design because it indicates the extent daylight availability can replace artificial lighting. Software simulation and field measurement are mainly used to assess the performance of indoor daylighting. Daylight can be determined using two main metrics, namely, daylight factor (DF) and daylight autonomy (DA). DF is the ratio between indoor illuminance and outdoor illuminance under the same unobstructed overcast sky. DF is a conventional approach to assess internal daylight [12]. It is most useful for locations that have overcast sky as their primary condition. Meanwhile, DA is a climate-based daylight metrics represented as a percentage of the occupied hours of the year when the minimum illuminance threshold is met by daylight only [12]. Useful daylight illuminance (UDI) is a modification of DA and defined as the percentage of the working year when daylight illuminance on the work plane fall within a certain range (often 100–2000 lux). Below 100 lux, artificial light is needed, and visual discomfort will occur above 2000 lux [13]. UDI and DA are the two most common daylight assessment dynamic or climate-based metrics [12] and are achievable through simulation tools particularly in such climate of Najran city.

### 1.2. Predicting daylight illuminance from Najran sky

Saudi Arabia is amongst the sunniest place on Earth [14]. Najran City (southwestern Saudi Arabia) has the highest daily solar radiation in Saudi Arabia of approximately 10 h per day [15]. Figure 1 shows that the monthly sunshine hours vary on average between 357 h from April to August and 260 h on the remaining months of the year [16] and monthly average of more than 322 Wh/m2/day. Moreover, Najran City has an extremely low cloud cover with an average below 15% (Fig. 2). However, the CIE standard defines clear sky as a sky with less than 30% cloud cover, whereas a sky with more than 70% cloud cover is a cloudy sky [17]. Thus, Najran City has a clear sky throughout the year.

In summary, DF should be calculated only under the CIE overcast sky condition, which is relatively difficult to achieve under Najran climate. By contrast, daylight availability is assumed to represent well for sunny climate conditions, such as Najran City, as it is calculated under actual sky conditions, including a clear sky. However, daylight availability requires a complex and time-consuming calculation process, which is mainly achieved by computer software, which allow dynamic daylighting simulation.

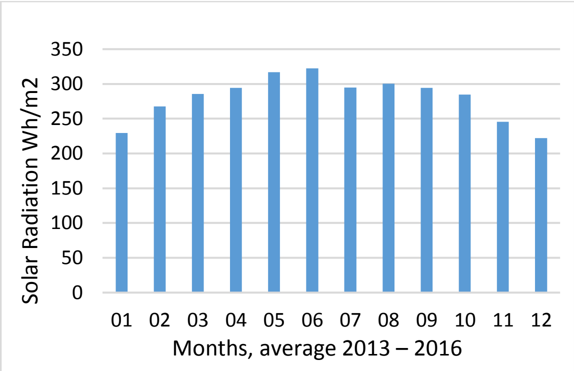



Fig. 1. Monthly global horizontal irradiance graph of Najran City averaged from 2013 to 2016 [18].

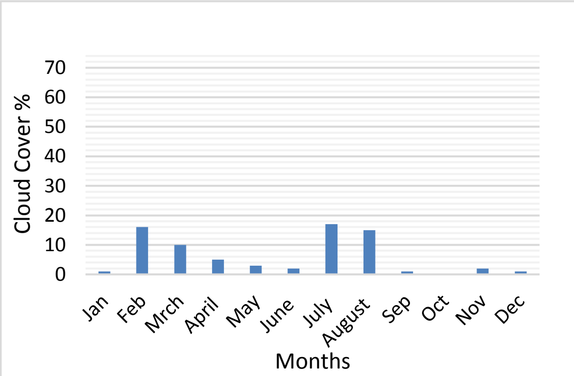



Fig. 2. Average cloud cover in Najran City in 2009–2017 [16].

## 2. METHODOLOGY

This study adopted a case study method to investigate the daylight illuminance level under clear sky condition in classrooms adjacent to the courtyard. Four classrooms were selected to represent different situations of classrooms adjacent to uncovered/covered courtyards. Before performing the field measurements, a site visit walkthrough to the selected classrooms was conducted. On the basis of the site visit, a case study field measurement would be sufficient at a particular time that has a high value of outdoor daylighting rather than the two main metrics, that is, DF (the worst case) and UDI. If the results were positive then further investigation needs to be conducted to confirm the daylight availability throughout the year.

### 2.1. Description of the case study

The College of Engineering at NU has a three-storey building with exterior dimensions of 202 m × 132 m (Fig. 3). The building was designed with six large courtyards in addition to six small courtyards to harvest daylight, enhance visual comfort and reduce the electric consumption by electrical lightings in the adjoining spaces. The courtyards are an enclosed type that has a square shape with a direct daylight source from the sky. The lower part of the courtyard from the ground floor consists of non-used space. The upper part, that is, first and second floors, contains classrooms and offices, respectively. The courtyard has diminutions of (11.7 * 11.70 m). Recently, the courtyards were incorporated with a PVC blind roof elevated at approximately 1.5 m to form a clearstory opening to daylight the courtyard; therefore, the measured height is 20 m, extending from the ground floor to the roof level of the courtyard. The monitored classrooms are highlighted by the shaded regions in Fig. 3. Table 1 presents the views of the investigated courtyards and classrooms. The classrooms have identical windows with diminutions of 170 × 110 cm, with green-tinted glass panel of a double low-e.

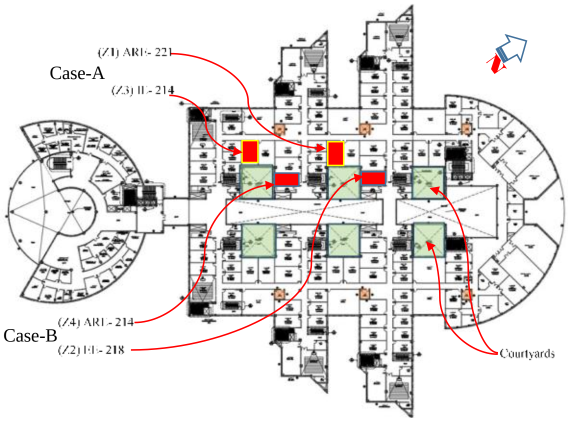
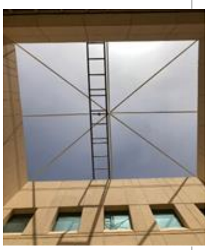



Fig. 3. First floor Plane of the case study building showing the courtyards and investigated classrooms.

Table 1. Case study that measures four different classrooms adjacent to two different courtyards.

| | | | | |
|---|---|---|---|---|
| **Courtyard roofing** |  |  |  |  |
| | **Uncovered courtyard** | | **PVC-covered courtyard** | |
| **Measured Zones - Classrooms** |  |  |  |  |
| | **Z1** | **Z2** | **Z3** | **Z4** |

### 2.2. Field measurements

Two courtyards, uncovered and PVC-covered, were selected. Measurements were conducted simultaneously in the four classrooms adjacent to the selected courtyards. The classrooms have different orientations and floor areas. Classrooms Z1 (52m2) and Z2 (42m2) were exposed to an uncovered courtyard and have two windows directed southeast and southwest, respectively. Meanwhile, Classrooms Z3 and Z4 were exposed to a courtyard with a PVC roofing.

Table 2 summarises the two cases that will be studied in this paper. First is the Case A, where two identical classrooms adjacent to different courtyards are compared. Classroom Z1 is adjacent to an uncovered courtyard with two windows facing southeast. Classroom Z3 is adjacent to a PVC-covered courtyard with two windows facing southwest. Whereas, the second is the Case B with two classrooms. Classroom Z2 is adjacent to an uncovered courtyard with two windows facing southeast. Classroom Z4 is adjacent to a PVC-covered courtyard with two windows facing southwest.

Classrooms were monitored simultaneously at 12:30 pm (midday) on the 21st of March 2018 without electrical lighting. The work plane in the adjacent classrooms was defined as an ideal horizontal surface located 0.80 m above the floor. A grid space of 1.0 × 1.0 m on the work plane was measured. The measurements were taken over half an hour duration, starting at 12:30 pm and ending at 1:00 pm. Moreover, outdoor direct sunlight and diffused light were monitored at the rooftop of the building and the ground floor of the courtyards. The collected data samples were recorded using an Extech HD450 metre that measures from 0 lux to 400 Klux, with a basic accuracy of ±5% (Fig. 4).

Table 2. Investigated cases and zones (classrooms) in the College of Engineering.

| **Case A: Two identical classrooms facing southeast** | | |
|---|---|---|
| Zone (classrooms) | **Z1** Uncovered courtyard | **Z3** Covered courtyard |
| Floor area | 57 $m^2$ | 57 $m^2$ |
| WWR | 21% | 21% |
| Window glazing | Double low-e tinted glazing | |
| **Case B: Two classrooms facing southwest** | | |
| Zone | **Z2** Uncovered courtyard | **Z4** Covered courtyard |
| Floor area | 52.3 $m^2$ | 41.8 $m^2$ |
| WWR | 22.4% | 28% |
| Window glazing | Double low-e tinted glazing | |


Fig. 4. Light metre used for measuring daylighting (0 lux–400 Klux).

## 3. RESULTS AND DISCUSSION

Four classrooms adjoining two courtyards with different orientations and floor areas were investigated when the PVC roofing system was constructed for the six courtyards of the College of Engineering in NU. The results are illustrated in two sections. First is a distribution of daylighting on indoor work plane, whereas the second is the average daylight penetration indoors.

### 3.1. Distribution of daylight illuminance in the classrooms adjacent to the courtyard

Table 3 illustrates the layouts of the investigated classrooms that show the daylighting illuminance values at the measured points on the work plane of the four classrooms. Based on this measured points a daylighting contour maps have been drawn and illustrated in Table 4. These two tables present a summary of the measuring results for a clear sunny sky in Najran City on the 21st of March 2018. The contour maps clearly demonstrate the daylighting distribution on the work plane of the four investigated classrooms.

In Table 4, Case A compared Classrooms Z1 and Z3, which are adjacent to uncovered and covered courtyards, respectively, and windows facing southeast. For the contour map of Classroom Z1, although it is adjoining an uncovered courtyard, the daylighting level failed to meet the minimum threshold of classrooms (300-500 lux). The average indoor daylighting was approximately 42 lux on around 40% of the work plane, whereas the remaining ranged from 12 lux to 5 lux close to the wall opposite a window. Therefore, poor distribution of daylight was observed under a clear sky condition where outdoor illuminance was 110 Klux. The highest values were recorded in the areas close to the windows with a maximum of 90 lux. Thus, this classroom depends on electrical lighting to reach the recommended level of illumination. Meanwhile, for Classroom Z3, which adjoins a PVC-covered courtyard, the daylight illuminance value was nearly zero (darkness) with a maximum illumination level of 8 lux recorded close to the windows. This classroom depends entirely on electrical lighting to illuminate the whole work plane.

Likewise, Case B (Table 4) compares Classrooms Z2 and Z4, which are adjacent to different courtyards with windows facing southwest. Classroom Z2 adjoins an uncovered courtyard. The contour map of this space shows that the daylight illuminance level failed to meet the minimum standard requirements of classrooms (300-500 lux). The average illuminance was approximately 53.4 lux on approximately 40% of the work plane, whereas the remaining had daylight illuminance ranging from 21 lux in the middle of the space to 7.4 lux close to the wall opposite a window. A poor distribution of daylight illuminance was also observed compared with the recommended levels of classrooms. For Classroom Z4, which adjoins a PVC-covered courtyard, the daylight illuminance value was nearly zero with a maximum illumination value of 17 lux recorded close to the windows.

Figure 5 confirms the results of poor daylight illuminance level indoors of all the four measured spaces. Within an uncovered courtyard, Z2 had higher illuminance level than Z1 because of the differentiation in Window Wall Ratio (WWR) of the spaces. Meanwhile, the spaces adjoining the courtyard with a PVC roofing showed illumination of nearly zero. More analysis and discussion is discussed in following section.

### 3.2. Average daylight penetration into classrooms adjacent to uncovered/covered courtyards

This section compares the average daylight illuminance with respect to the distance from the windows. The comparison was performed between every two identical classrooms exposed to different courtyard configurations. Classrooms Z1 (adjacent to uncovered courtyard) compared with Z3 (adjacent to covered courtyard). Likewise, Classrooms Z2 (adjacent to uncovered courtyard) compared with Z4 (adjacent to covered courtyard).

Fig. 6 contains four curves represent the four investigated classrooms. The curve with blue short dashes in the figure illustrate that the daylight penetration levels in Classroom Z1 had the highest average of 50 lux close to the window (0.5 m away from the window). The daylighting penetration level started to gradually decrease, reaching a value of 20 lux at a distance of 2.5 m away from the windows and 5 lux at the end of the space. Meanwhile, Classroom Z3 that indicated by brown solid line in the figure had a low illumination level that is nearly zero lux. Low illumination level occurred because of the PVC roofing of the courtyard that has a serious negative influence on the visual environment of the adjacent spaces.

Furthermore, Fig. 6 illustrates a comparison between Classrooms Z2 and Z4. The curve with red solid dots in the figure refers to classroom Z2 that is exposed to an uncovered courtyard. It shows that the daylight penetration levels in Classroom Z2 had the highest average of 85 lux close to the window (0.5 m away from the window). The daylighting penetration level began to gradually decrease, reaching a value of 45 lux and 20 lux at distances of 2.5 m and 5.5 m, respectively, away from the windows. The value of 7 lux was found at the end of the space. Finally, the burble curve with square marker in Fig. 6 illustrates the daylighting penetration level on the work plane of the Classroom Z4, which has windows adjacent to a courtyard shielded with a PVC roofing. This classroom has a low daylight illuminance at nearly zero lux. However, the daylight penetration in Classroom Z2 had higher daylighting penetration level than Classroom Z1. The difference in the values were due to the difference in the WWR of spaces, where Z2 had higher WWR of 28% compared with 22% of Z1 (Table 2).

In summary, after installing the roofing system, the lighting levels were greatly reduced despite the high level of outdoor illumination, as shown by Classrooms Z3 and Z4 in the second column of Table 3. The PVC roofing material blocked the penetration of visible light; however, the entire work plane of these two classrooms depend on electrical lighting during the daytime. The glazing type of double low-e and tinted glazing also played a role in reducing daylighting indoors due to its low solar transmittance including the visible light.

Table 3 Classroom layouts showing the measured points on the work plane, 0.80 m above the floor with grid space of 1.0 × 1.0 m. (the area highlighted blue is a 2.5 x widow height).

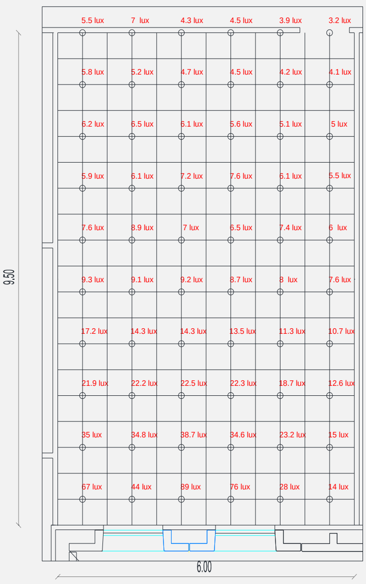
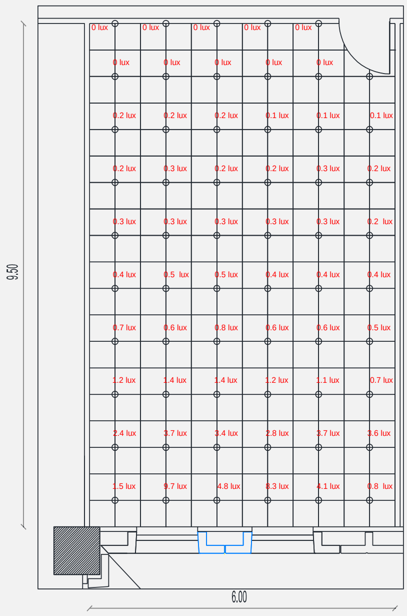
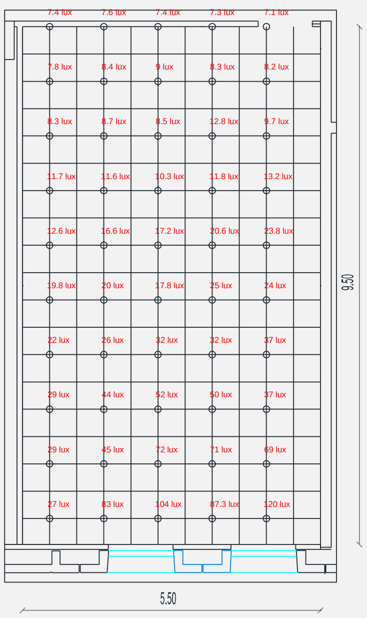
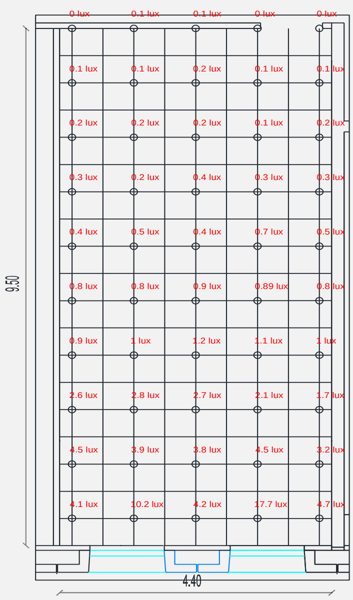
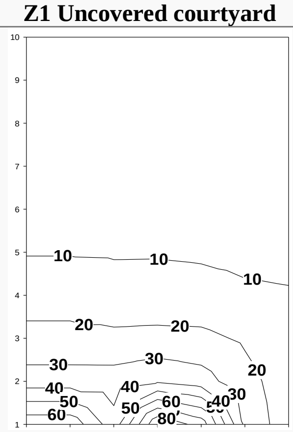
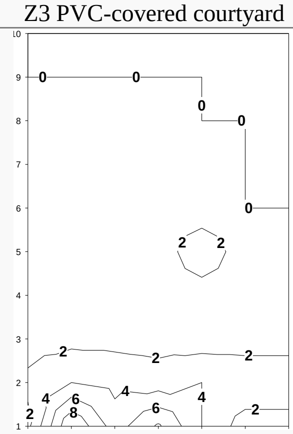
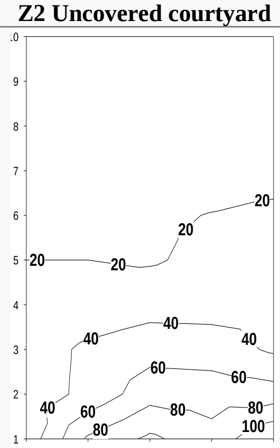
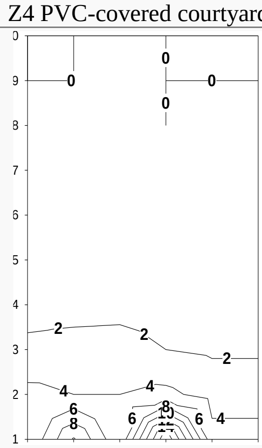
| **Case A: Measured points of two identical classrooms facing southeast** | |
|---|---|
| **Z1 Uncovered courtyard** | Z3- Covered courtyard |
|  |  |
| **Case B: Comparison of two classrooms facing southwest** | |
| **Z2 Uncovered courtyard** | Z4 Covered courtyard |
|  |  |

Table 4. Distribution of Daylight illuminance (lux) in the investigated classrooms adjacent to the courtyards in NU.

| **Case A: Comparison of two identical classrooms facing southeast** | |
| --- | --- |
| **Z1 Uncovered courtyard** | Z3 PVC-covered courtyard |
|  |  |
| **Case B: Comparison of two classrooms facing southwest** | |
| **Z2 Uncovered courtyard** | Z4 PVC-covered courtyard |
|  |  |

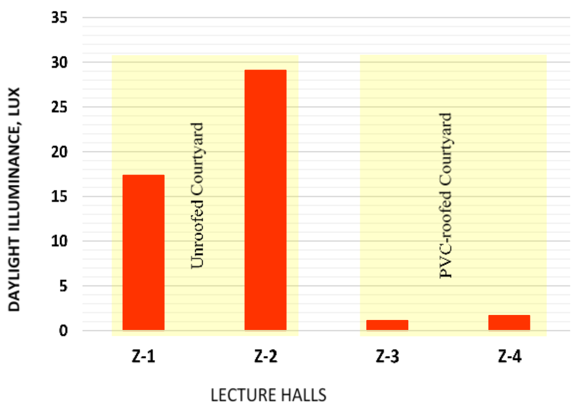



Fig. 5. Average daylight illuminance of the four zones.

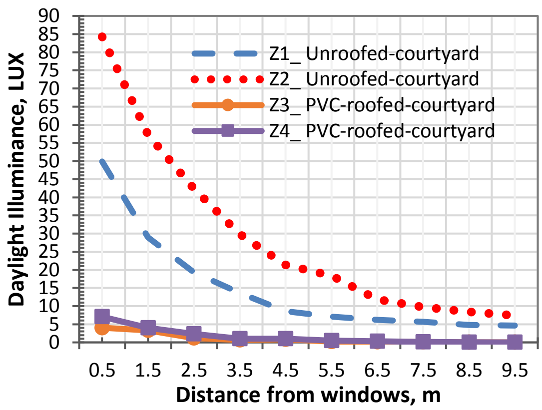



Fig. 6. Average daylight penetration (lux) into four classrooms.

### 3.3. Further discussion

Table 5 below summarizes the daylight illuminance in the investigated classrooms, on the ground floor of the courtyards and on the rooftop of the college building. The measurements were taken at two different times of the day. The first is in the early morning of 8 a.m. (Sunrise 6:25 a.m.) where outdoor illuminance was found 60 Klux. This time represents a college start time and a low value of outdoor illuminance of the sunny day. The second is at midday that represents the highest outdoor illuminance value of the day and the sun is directly overhead the courtyard. The outdoor illuminance was found 110-118 Klux and 84 Klux on the rooftop and ground floor of the uncovered courtyard respectively. However, table 5 illustrates that the PVC roofing extremely reduced the daylight illuminance on the courtyard ground floor from 84 Klux to 821 Lux.

The indoor daylight illuminance values that illustrated in column 4 of Table 5 are an average of 5-6 measured points at distance of 4.25m. This distance is a 2.5H guideline, which assumes that ample daylight for the workplane is delivered at a depth of 2.5 times the height of the window above the workplane [19]. The indoor illuminance at this distance was found ranging from 24 lux to 1 lux at 8.a.m. in the classrooms adjacent to uncovered and covered courtyards respectively. Whereas at midday, the indoor illuminance was ranged from 30 lux to 1 lux. These results in general show that the daylight illuminance in both cases is not sufficient and does not even come close to the classrooms requirements of 300-500 lux. This result of a low daylight illuminance in the four investigated classrooms needs more investigation, particularly the unexpected low values in the two classrooms adjacent to the uncovered courtyards.

This study has made an initial assessment to the role of glazing type (even though the glazing type is beyond the scope of this study) in reducing the daylight illuminance indoors. Table 6 summarizes the measured and factory light transmittance of the window glazing of the investigated classrooms. It shows that the factory light transmittance of a chosen window glazing was 6%. The measured light transmittance was found ranging from 2.8% – 3.5%. The decrease was due to the impact of dust on the window glazing surfaces.

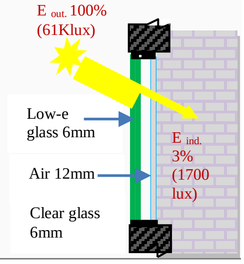
However, the selected visible light transmittance of 6% is very low to permit an adequate daylight illuminance in the classrooms, particularly those that open to the courtyard because there is no direct sunlight hits the windows glazing. In general, window design in Najran University gives a priority to prevent a heat gain. It is essential to note that in such climate of Najran city the ideal alternative solution for glazing is the one that enhances the efficiency of the glazing through the factor of “Light to Solar gain (LSG)” instead of SHGC. It measures the ability of glazing to admit light without the overload of solar heat gain.

Table -5 The daylight illuminance indoors, on the ground floor of the courtyards and outdoor.

| Case | Zone | Time | Illuminance level | | |
|---|---|---|---|---|---|
| | | | *Average indoor daylight illuminance at (2.5 H)*, Lux* | *G. Floor courtyard Lux* | *Outdoor Lux* |
| **Case A: Two identical classrooms facing southeast** | $Z_1$ **Uncovered** courtyard | 8am | 9 | 30 000 | 61 000 |
| | | 12pm | 13 | 84 000 | 118 000 |
| | $Z_3$ **Covered** courtyard | 8am | 1 | 135 | 61 000 |
| | | 12pm | 1 | 681 | 118 000 |
| **Case B: Two classrooms facing southwest** | $Z_2$ **Uncovered** courtyard | 8am | 24 | 30 000 | 61 000 |
| | | 12pm | 30 | 84 000 | 110 000 |
| | $Z_4$ **Covered** courtyard | 8am | 1 | 143 | 61 000 |
| | | 12pm | 1 | 821 | 110 000 |

**The 2.5H guideline, which assumes that enough daylight for the desk plane will be delivered at a depth 2.5 times the height of the window above the desk plan, which is in this study equal to (1.7h X 2.5 = 4.25m) [19].*

Table 6. The light transmittance of window glazing system of the investigated classrooms.

| Measured situation | Outdoor Illuminance, (Lux) | Indoor Illuminance (close to the window), (Lux) | Measured light transmittance (%) | Transmittance, Factory SAG [20] (%) | Window section |
|---|---|---|---|---|---|
| **Direct sunlight** | **61900** | **1710** | **2.8** | **6** |  |
| **Diffused light** | **6064** | **210** | **3.5** | | |

## 4. CONCLUSIONS AND RECOMMENDATIONS

This study investigated the daylight illumination level in four classrooms adjacent to uncovered and covered courtyards. A case study was investigated under clear sky with direct outdoor daylight illuminance of 110 Klux.

Field measurements were conducted at noontime under a clear sky of Najran city on the 21st of March 2018. Outdoor daylight illuminance exceeded 100 Klux. The measurements indicated that the daylight illuminance levels were low in the two classrooms (Z1 and Z2) adjacent to an uncovered courtyard. The daylight illuminance level on the work plane hardly exceeded 100 lux near windows, which is insufficient light levels in classrooms (300–500 lux). Meanwhile, the daylight illuminance levels in the other two classrooms (Z3 and Z4) adjacent to a courtyard with a PVC roofing varies from 10lux close to the window and nearly zero closed to the opposite wall at 12:30 pm when outdoor sunlight was 110Klux. These two classrooms depend totally on electrical lighting.

Although the glazing type was beyond the scope of this study, but investigation of the case study shows essential effect of glazing type on the daylight illuminance indoors. The glazing system used in Najran University has an average measured transmittance of 2.8% and 3.5% under direct sunlight and diffused light respectively.

### RECOMMENDATIONS

On the basis of this study, Najran University may consider replacing the courtyards' PVC blind roofing materials with transparent ones to protect the courtyards from rain and dust and allow daylighting to penetrate into the adjacent spaces. When designing educational buildings with courtyards, the window glazing type should not be high reflected to the visible light to get more daylighting indoors.

For future studies, in such climate of Najran city and such design of classrooms adjacent to the courtyards with Double low-e glazing, it is recommended to investigate the suitability of the low-e clear glass-layers for blocking heat gain and allowing natural light into the classrooms. It is also recommended to investigate the influence of certain variables of the courtyard in balancing between allowing daylighting and blocking heat gain in the classrooms. The variables are materials and shapes of the courtyard roof.

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