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Research Article

Catching Daylight: Improving Natural Illumination Levels in Deep-Plan Drawing Studios at the University of Jordan

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Abstract: This paper investigates enhancing internal natural illumination levels of existing drawing studios in the Architecture Engineering Department at the University of Jordan for the purposes of securing a better learning environment and lowering energy costs. These studios are artificially lit all daytime despite the existence of large side windows. By using the daylight factor method, the daylight factor was measured inside a selected studio and then via a scale model in the Artificial Sky Lab under clear sky conditions. The scale model enabled us to study several elements or factors affecting daylighting. By using high transmittance glass, changing the windows' wide frames, adding reflective panels facing the studied studio's windows and using bright white paint for the studio's interior walls, the daylight factor increased by 6-13.5% in the studio model. These interventions can be applied on existing and other studios and labs in the University. Moreover, the method used can be replicated to improve daylighting in similar deep-plan rooms due to its easily applicable and simple low-cost tools.

Keywords: Daylight factor, daylighting, educational buildings, energy saving, students' productivity

INTRODUCTION

Daylighting is defined as [the "active" use and control of natural light to achieve a particular purpose, be it to save burning fossil energy or to improve building occupants' comfort and well-being or both.] (Boubekri, 2014, p. 54)

Different methods are used to measure internal natural illuminance; one of them is daylight factor (DF), which is the percentage of illuminance at certain internal point resulting from direct and diffused skylight -to external illuminance, excluding direct sunlight (Hammad, 2006). DF is also defined as [the ratio of interior to exterior illuminance under an evenly overcast sky.] (Müller and Schuster, 2003, p. 63)

Why daylighting? It has been proven that providing buildings with natural light is necessary for good vision (Ruck *et al*., 2000) and visual comfort (Das and Paul, 2015); it also offers comforting space for building occupants (Boubekri, 2014; Müller and Schuster, 2003).

Humans prefer natural illumination due to their preference of natural substances (Haans, 2014) and because it consists of a balanced spectrum of color (Liberman, 1991, cited in Edwards and Torcellini, 2002).

Daylighting is preferred by office workers due to its unpredictable changes over daytime, which make it interesting in comparison with constant artificial lighting (Müller and Schuster, 2003) and day-lit working spaces provide workers with less stress environment (Ruck *et al*., 2000).

Daylighting creates a healthy environment inside buildings (Das and Paul, 2015); it improves psychological health (Boubekri, 2014; Müller and Schuster, 2003; Veitch and Galasiu, 2012) and the general well-being of buildings' occupants (Boubekri *et al*., 2014; Mirrahimi *et al*., 2013; Veitch and Galasiu, 2012).

Studies have shown that school students' test scores increased significantly as natural lighting increased inside classrooms (Heschong *et al*., 2000; Mirrahimi *et al*., 2013).

Moreover, workers' performance and productivity increased in day-lit workplaces (Heschong and Oaks, 2003; Hwang and Kim, 2011) and absenteeism decreased (CECS, 2017).

Using daylighting to illuminate buildings is preferable due to its role in energy saving (Boubekri, 2014; Müller and Schuster, 2003); it is capable of

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reducing building energy costs by one-third (Gregg, 2016). Daylighting is available, free and more efficient than artificial lighting, while the latter consumes electricity, thereby raising the building's operating cost and radiating heat that raises cooling loads (Boubekri, 2014; Kaneda, 2007; Müller and Schuster, 2003).

Sustainability requirements: Natural illumination is one of the optional requirements for sustainable buildings and in Jordan it is one of the standards for healthy internal environment. This standard requires providing any building with daylighting in 80% of the occupied spaces in educational institutions (RSS, 2013).

Energy facts of Jordan: The cost of consumed primary energy in Jordan in 2016 was 7% of the Gross Domestic Product GDP (NEPCO, 2016).

Lacking traditional energy resources, Jordan imports about (97%) of its primary energy (NEPCO, 2015), on the other hand, there are 300 sunny days per year in Jordan (Etier *et al*., 2010) and that constitutes another motivation for moving from artificial lighting to employing daylighting to illuminate buildings' interior spaces in this country.

The study problem: One can easily observe that, in the Architecture Engineering drawing studios at the University of Jordan, artificial illumination is used all throughout the daytime hours- from 8:00 am to 5:00 pm- which means that the available natural illumination levels are not sufficient to illuminate these spaces (Fig. 1a and 1b).

Although the studios are equipped, on the long walls, with large side windows that are expected to increase natural illumination (Das and Paul, 2015), yet these windows do not deliver the required lighting level to the studios' required activities, which consist of detailed drawing work. In Jordan, The Jordanian National Building Code recommends (750 Lux) as minimum illuminance value for precise drawing tasks (Hammad, 2006).

Goals and objectives of the study: The goals of the study are the following:

- Improve students' mood and enhance their productivity, in order to secure a better learning environment inside the Architecture Engineering Department studios.
- Reduce daytime artificial illumination use in order to lower energy costs.

The objective is simply to increase natural illuminance levels inside the studios.

LITERATURE REVIEW

DF is affected by many factors:

Building orientation: Affects the incidence of daylight inside (Müller and Schuster, 2003). Northeast and south external facades can provide the best uniform natural illumination to the daytime activity spaces (Das and Paul, 2015; Hammad, 2006).

Room depth: Affects the natural illumination level inside (Müller and Schuster, 2003). Daylight illuminance levels drop after three meters away from side windows (Boubekri, 2014) and increasing room depth will decrease DF (Das and Paul, 2015). It is difficult to obtain sufficient daylighting by side windows if the room depth exceeds 2.5 times the window height (Boubekri, 2014; Müller and Schuster, 2003).

- **Current practices to improve daylighting inside deep-plans:** Planned courtyards are used to illuminate fulltime work stations at the lower levels (Müller and Schuster, 2003). Light shafts can be installed in buildings to transfer daylight to enhance natural light inside deep-plans (LL, 2016; Müller and Schuster, 2003).

Fiber optics can transform light to deep-plan rooms with high efficiency, but with higher cost (Garcia, Hansen and Edmonds, 2003). Moreover, light pipes channel daylight inside deep-plan rooms and into the lower floors (Boubekri, 2014).

Many experiences were held to improve light pipes' efficiency: hollow mirrored light pipes combined with laser cut panels increased daylighting with an overall efficiency of 32% under sunny conditions (Garcia Hansen and Edmonds, 2003). Meanwhile, combining prismatic light pipes, fiber optics with Laser Cut Panel light deflector -as a sunlight collector- transferred daylight into deep-plans, during working hours; theoretically, this can work in both clear and overcast sky conditions (Wong and Yang, 2012). In addition, multiple aperture light-pipes can provide natural light at different floor levels for multiple work spaces (Kennedy and O'Rourke, 2015).

Shading elements: Have a negative impact on daylight utilization, decreasing natural illumination inside buildings (Müller and Schuster, 2003).

Windows' height and windows' sill level: Both the windows' width and height are important to increase daylighting inside the room (Boubekri, 2014). The lower the window sills level, the higher DF (Das and Paul, 2015); this makes the window taller and will thereby provide better internal illumination (Müller and Schuster, 2003) and deeper daylight penetration (Boubekri, 2014).

The effect of opposite close buildings and the floor level: Dense urban fabric decreases internal daylighting to a considerable degree, at lower floors in particular (Li *et al*., 2011), due to shading from neighboring buildings that decreases natural illumination inside the room (Müller and Schuster, 2003). If the external surface reflectance of the opposite close building is low, internal daylighting levels decrease (Boubekri, 2014) and increasing the reflectance of the opposite building's exterior surfaces will increase DF inside the rooms with side windows, especially at lower floors (Aly and Nassar, 2013; Boubekri, 2014).

Large trees adjacent to the building: Obscure daylight and reduce DF inside the building (Müller and Schuster, 2003). A study conducted in Shanghai, developed a formula to determine the appropriate tree type to be planted between buildings and suggested an optimal way to placing trees in right places in order not to reduce natural illumination inside the adjacent building interiors (Hongbing *et al*., 2010).

Windows area: An effective factor in DF and in the level of internal illumination (Das and Paul, 2015). Window-frame factor influences DF (Hammad, 2006). So, increasing windows' glass area can help in increasing DF.

Dirt accumulation over glass panes: Decreases glass's transmissivity and then DF (Das and Paul, 2015; Hammad, 2006). Applying regular cleaning on glass panes can increase glass transmissivity and the resulting DF (Das and Paul, 2015).

Low reflection coefficient of the inner surfaces' finishes: Increasing reflection coefficients of surfaces will increase DF (Baker and Steemers, 2014; Das and Paul, 2015) and will also decrease glare (WWWS, 2010). Using white colored paint inside the room is the most efficient color for visual and non-visual human purposes compared to other colors (Hartman *et al*., 2014).

METHODS AND MATERIALS

The methodology of this study consists of the following:

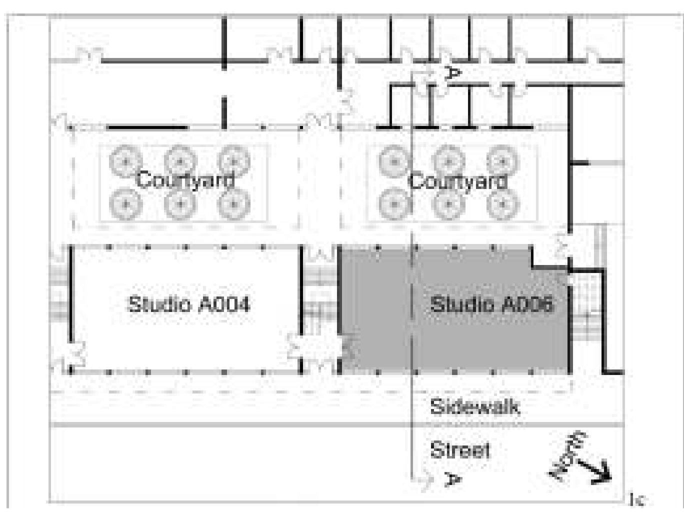
Measuring the natural illumination levels inside a selected studio: Natural illumination level was measured at 12:30 pm on a sunny day, using Megatrone device in the middle of a selected studio (Studio A006) and was found to be (200 Lux), which is much lower than the required illumination level.

Describing the current situation of studio (A006):

- **Building orientation:** The studied studio has the proper layout to enhance the incidence of daylight; the building layout is angular and its main façade is oriented northeast (Fig. 1c).

1a: Using artificial lighting during daytime inside the studio A006.

1b: The natural lighting inside studio A006.



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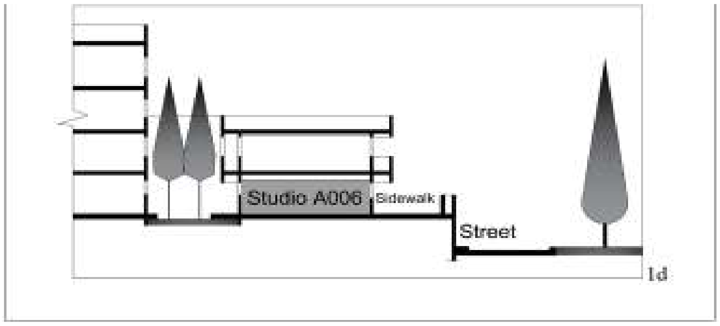

1e: The south-west façade, facing the inner courtyard.

1f: The north-east façade.

Fig. 1: The studied studio (Studio A006) / 1a & 1b: interior shots/1c: plan/1d: section/1e & 1f: exterior shots

- **Deep-plan studio with side windows:** The studied studio is deep-plan (10.5 m. depth) and equipped merely with side windows, as natural lighting utilities, at the external north-eastern façade with 2 m. high and at the internal south-western façade looking towards the inner courtyard (Fig. 1d) with 1.4-meter high. The studio's depth exceeds 2.5 times the window height:

  $(1.4x2.5) + (2x2.5) = 8.5$ m

  i.e., 8.5 m is the maximum studio depth to be enlightened naturally by the existing windows. The side windows are not fit enough to obtain sufficient daylighting for the studio due to the deep plan.
- **The presence of upper balconies:** With 1.5m deep- is shading the external facades containing the windows (Fig. 1e and 1f).
- **High sill level of the openings:** The southwest façade of the studio has openings with high sill level (1.6 m above floor level), while the north-east façade windows' sill height is (1 m) above floor level.
- **Low floor level of the studio combined with the adjacent narrow courtyard:** The studied studio is located at the ground floor level and the presence of a narrow courtyard (10 m width) with high walls (17 m) -adjacent to the southwest façade of the studied studio- with rough finishing materials on the courtyard walls (ashlars and rough stucco).
- **Large trees in the adjacent courtyard:** Obscure daylight off the southwest façade of the studio (Fig. 1e).
- **Windows area:** The studio's windows are wide-framed, which decreases the area of clear glass. There is also a dense steel guard before the north-eastern façade's windows obscuring natural lighting (Fig. 1f).
- **Dirt accumulation over windows' glass panes:** As a result of not applying regular cleaning, also decreases daylight penetration inside the studio.
- **There is a low reflection coefficient of the inner surfaces' finishes:** Due to the used paint and the colored posters hung up the studio walls most of the time.

Suggesting solutions to improve DF inside the studied studio: Referring to the DF affecting factors, one can suggest many solutions to enhance DF inside the studied studio:

- Light shafts, light pipes and fiber optics: Although light shafts, light pipes and fiber optics proved their efficiency in improving daylighting inside deep-plans (Garcia Hansen and Edmonds, 2003), yet these solutions were excluded due to high cost and the difficulty of installing these tools in existing buildings.
- Lowering windows' sill: This solution was excluded due to the existence of heating radiators next to the windows.
- Redesigning the landscape inside the courtyard: Removing courtyard trees and placing them in other places, then planting other trees or shrubs and placing them optimally to increase DF. This solution was excluded for reasons that had to do

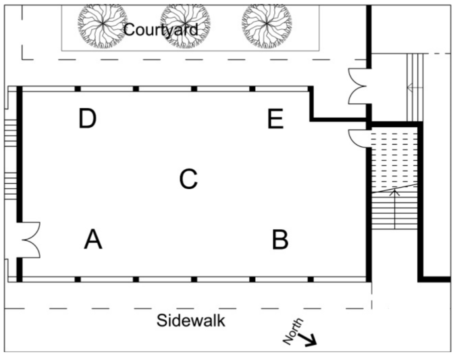

Fig. 2: Points of inspection distribution inside the studio A006

Fig. 3: Measuring DF inside the studio model in the Artificial Sky lab

with saving natural environment and for sustainability purposes.

- Using light guiding systems by reflecting sunlight into the building, then diffusing it into the studio (Garcia Hansen and Edmonds, 2003):
  - o Applying reflective white paint on the studio walls and on the courtyard walls.
  - o Installing reflective panels: Smooth metal sheets to be used in two locations: on the walls of the courtyard facing the southwest façade and opposite the northeast façade of the studio.
- Increasing windows' glass area: Changing the windows' framing type to increase glass area and changing the design of the steel guard to thin steel bars.
- Increasing glass transmissivity by applying regular cleaning on glass panes.

Testing the effect of the suggested solutions on DF through an experiment inside an Artificial Sky lab. The suggested applicable solutions were tested on a scale model to measure their effect on DF:

- Applying DF method; DF inside the existing studio was measured on a sunny day at 12:30 pm, using DF meter (Megatrone), at 5 points of inspection: points (A & B) next to the northeast façade, point (C) at the middle of the studio and points (D & E) near the southwest façade (Fig. 2). The illuminance on the street side and inside the courtyard was 4.000 and 380 Lux, respectively.
- Measuring DF inside the studio model with configurations similar to the existing studied studio, with scale 1:50, inside the Artificial Sky Lab., under uniform clear sky condition, with sky illuminance (10.000 Lux) to simulate Amman sky illuminance at the University of Jordan (Hammad, 2006). Five points of inspection were distributed inside the model the same way they were distributed inside the existing studio.
  - o Studio model details: trees at the courtyard, with low surface reflectance of the courtyard walls and colored posters on the walls inside the studio, grainy transparent sheets to simulate the unclean glass and dark lines to simulate wide-framed windows and dense steel guard (Fig. 3a to c).
- Measuring DF inside the model at the five points of inspection after changing some factors: decreasing windows' frames width, cleaning glass panes and adding white reflective paint to the inner surfaces of the studio and to the courtyard walls.
  - o Application in the model: Removing the colored posters, revealing the white boards inside the studio and off the courtyard walls and removing the grainy transparent sheets with its dark lines (Fig. 3d):
- Measuring DF inside the model, at the five points, after making other interventions: covering courtyard walls with reflective aluminum foil on courtyard walls (Fig. 3e) to simulate the metal reflective panels and other panels covered with aluminum foil opposite the north-east façade, the distance between these panels and the studio windows was tested to get maximum DF inside the model.

Table 1: DF at the points of inspection with added interventions

Item	The situation details	Points of inspection (Fig. 2)				
		A	B	C	D	E
DF inside the existing studio (A006)[1]	The existing situation of the studio	9%	9%	5%	3%	3%
DF inside the scale model in the Artificial Sky lab, under clear sky conditions. – sky illuminace 10.000 Lux	• The same configuration as the existing studio	15%	15%	10%	5.5%	5.5%
	• Making windows' frames thinner ones, clean glass panes, white paint inside the studio and on courtyard walls.	18%	18%	14.5%	12%	12%
	• Adding reflective metal panels on the courtyard walls and 8 m. aside from the north-eastern façade.	21%	21%	17%	19%	19%

[1]On a sunny day at 12:30 pm, the illuminance outside was 4.000 Lux, and the illuminance in the courtyard was 380

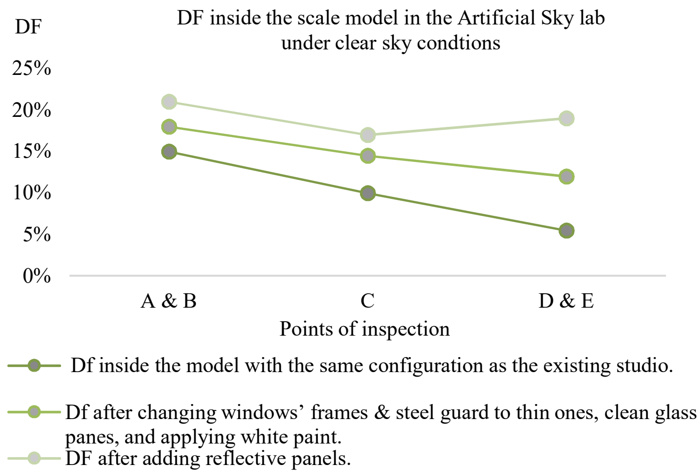

Fig. 4: DF change at the points of inspection inside the scale model in the Artificial Sky lab

RESULTS

Findings of the experiment are listed in Table 1, which illustrates that points (A & B) -located near the external façade- have the highest DF inside the existing studied studio and inside the studio model with similar conditions, followed by point (C) in the middle of the studio and finally by points (D & E) located near the southeast façade next to the courtyard.

The findings revealed that replacing the wide frames and steel guard of the windows with thin ones, cleaning glass panes and adding white paint to the inner walls of the studio and to the courtyard walls, increased DF by 3-6.5%. These changes raised DF inside the studio model, but there was a difference between the values of each point; yet, the ranking of DF at the five points was still the same.

The effect of adding reflective panels opposite the northeast façade was small (3% at points A & B), while placing metal panels on courtyard walls increased DF significantly (7% at points D & E).

The findings' patterns, shown in Fig. 4, illustrate that adding reflective panels made DF values almost uniform inside the studied studio, i.e. the dark side of the studio next to the courtyard became as bright as the street side points (A & B).

After applying the interventions, the highest change in DF was at the points next to the courtyard (D & E), then at the middle of the studio (point C) and last at the points next to the external façade (A & B).

DISCUSSION

The existing courtyard does not improve natural illumination in the studios at the lower floor as planned courtyards are supposed to do. The narrowness of the adjacent courtyard and the low reflectance coefficient of the opposite walls negatively affect the illumination levels inside the studio. This is clear from the DF values at the points next to the courtyard (D & E) that have the least DF values inside the existing studio and inside the studio model with similar conditions.

Decreasing the width of windows' frames, cleaning glass panes and adding reflective white paint can increase internal illuminance by 300 to 650 Lux, if applied on the existing studied studio.

Moreover, adding reflective metal panels to the courtyard walls enhanced the role of the courtyard in improving daylighting in lower floors. It can also increase internal natural illuminance by 300 to 700 Lux, if applied on the existing studied studio.

The whole interventions increased the overall DF by 6% at points (A & B), by7% at (C) and by 13.5% at

(D & E), which means that internal natural illuminance can increase at points (A & B) by 600 Lux, at (C) by 700 Lux and at (D & E) by 1350 Lux in the studied studio after applying the suggested interventions.

CONCLUSION

By using simple, applicable and low-cost materials, bright white paint on the studio's inside walls and on the adjacent courtyard walls, thin steel guard and windows' frames and high transmittance glass, DF increased by 3% to 6.5%. Then, adding reflective metal panels to the adjacent courtyard walls increased DF again by 3% to 6% in the studio model.

The cumulative result of applying the suggested interventions was that DF increased by 6% to 13.5% in the studio model. This means that the natural illumination levels at the existing studio -after applying the suggested interventions- can be increased to exceed the minimum illumination level required.

The suggested solutions allowed daylight to penetrate from the top down to the ground floor without removing the existing trees, which is good for sustainability purposes.

The same interventions can be applied on other existing studios and deep-plans in the University of Jordan and other universities. Besides, the methodology used in this study can be replicated in the redevelopment of existing buildings with deep-plan rooms due to its applicable low-cost tools.

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CONFLICT OF INTEREST

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