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Improving student performance by proper utilization of daylight in educational environments (Case study: IUST[1] School of Architecture)

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Abstract

Considering the significant impact of lighting on visual activities and human performance and wellbeing, the appropriate level of illuminance must be provided in educational environments. In this field, it is important to pay attention to the effects of natural and artificial lighting on student performance, also the architectural factors affecting appropriate utilization of daylight in educational spaces.In this paper, the effect of daylight on student performance was investigated and architectural factors of providing adequate daylight for classrooms were evaluated by computer simulations and in-situ measurements in classrooms and ateliers of the case study of this article. Then, strategies were provided for improving quality of daylight in this building and appropriate daylight illuminance was expressed for students in classrooms and training ateliers. The research method of this article is descriptive-analytic and computer simulations were used in the case study. This particular building (IUST School of Architecture) is chosen as a case study because, incidence of tiredness and drowsiness conditions among students was alternately reported in some classrooms and ateliers of this building. The information of performance and satisfaction of students with daylight, was collected through questionnaires from 82 students. Also, the performance of students in different ateliers is evaluated by investigating student academic scores.
The findings of this study can be used as guidelines for promoting sufficient illumination via daylighting in classrooms and ateliers in new designs.

Keywords: Daylight, student performance, Computer modeling, educational environments, School of Architecture.

1. Introduction

It is very important to consider lighting while designing architectural spaces. In educational spaces, it is more important to pay attention to light, especially natural light, due to high level of visual activities (which are done during the day in most cases). Activities in dark classrooms cause physical and psychological problems for users in educational spaces. Also, artificial lighting is one of the highest consumers of electrical energy. Therefore, electric lighting is an area in which it is possible to significantly save energy consumption.

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The present research aims to compare student performance in classrooms and ateliers with artificial lighting and day lighting, and investigate the effects of architectural factors on providing adequate daylight for classrooms.

1.1 Impact of daylight on human Performance in educational classrooms

Students' performance is significantly correlated with satisfaction with academic environment [1]. One of the most important environmental factors in educational classrooms is lighting. Daylight controls the body's circadian rhythm by hitting the retina, impacting the hypothalamus gland and controlling melatonin secretion. Melatonin (as sleep hormone) levels are reduced in the light and it is secreted in the dark [2]. One study has shown that there is not enough daylight in educational classrooms and blood melatonin levels of students in these classrooms are so much higher than those in classrooms with good lighting. This factor causes sleepiness among students and undermines their performance [3]. On the other research, studies have demonstrated that melatonin suppression values calculated for the electric light compared with natural light are the lower and so this lighting system does not seem to provide sufficient stimulus to the circadian system [4]. In this research, the obtained results showed that not only the illuminance but also light spectral power distribution of the light received by eyes played a significant role in circadian response and spectral characteristics of internal and external surfaces influenced light spectral power distribution [4]. Incidence of drowsiness conditions in classrooms and ateliers caused by low-light was reported in the measured spaces of this article.

Also, other studies have shown positive effects of daylight on improving human perception and mood and also comfortable feeling [5, 6]. Some studies have also suggested that daylight may have a positive impact on student performance. The result of a case study in three schools (located in Orange County, CA; Seattle, WA; and Fort Collins, CO) showed that children learned faster and performed better on American standardized tests in the classrooms with good day lighting [7]. The study was conducted on a large population of students (21000 elementary students) with controls for other factors such as teacher experience and demographic characteristics of each school. In a research in Sweden, a significant relationship was found between the patterns of daylight level, stress hormone level, and behavior of elementary school students [8]. In this research, researchers monitored health, behavior, and hormonal levels of about 90 children in four classrooms for one academic year. In another study on four case studies of schools in USA that have cost effectively implemented day lighting into their buildings, the evidence regarding day lighting and student performance and development was investigated [9]. The results indicated that construction costs of these schools did not impose a significant cost increase over conventionally designed schools. And, students who attended these schools benefited from day lighting both in terms of increased performance (as measured by test scores) and general health and well-being. In another research, the effect of three school design factors (movement and circulation, day lighting, and views) was evaluated on achievement of students [10]. In this study, daylighting significantly affected the variance in some test scores.

Considering the expressed content, appropriate lighting levels must be provided for educational buildings and spaces. For this purpose, natural lighting (which is more appropriate) and artificial lighting can be used. On the other hand, using daylight in space types that are used during the day (such as learning spaces) could save energy by reducing use of electric light sources. In the case study of this article, electric lighting along with daylight sources was used in a large number of classes and the ateliers all day long, which showed that daylight was not sufficient in those spaces.

According to these points, in this article, the case study spaces (ateliers and classrooms in School of Architecture and Environmental Designs, University of Science and Technology) were investigated, examined and modeled to answered the following questions:

1- What's the difference between student performance in classrooms with artificial lighting with their performance in classrooms and ateliers with appropriate daylight?
2- What factors have caused favorable or unfavorable daylight quality in these spaces?
3- Which architectural approaches could reform unfavorable factors of daylight quality?
4- How much daylight illuminance is sufficient for students tasks in classrooms and ateliers?
The results could be useful for physical reformation of the implementation examples and also in new designs.

1.2 Day lighting simulations and Software introduction

Lighting simulation tools, developed quickly during the last few decades, are reliable ways for simulating the complex lighting environment. There are a number of studies in which computer simulation is used to evaluate day lighting in educational spaces. In a case study at University of Nottingham, UK, lighting simulation tool RELUX was applied to simulate day lighting performance in classrooms [11]. In this case study, day lighting availability in the selected room was investigated based on daylight factor (DF). Validation of the simulation was conducted through comparison with field measurement by light sensor and handhold lux meter which were put at the desk level (0.75 m). The first sensor was set 0.5 m away from the window, which was the same as the grid set-up in software (the reference measurement plane was divided into several grids with the size of 0.5×0.5 m in order to get more precise results). In this study, deviation of the results between simulation and field measurement was within 20%, which is an acceptable agreement for deviation. The result of this study demonstrated that the annual potential energy saving from day lighting was between 40 and 46%.

In another case study at Shu-Te University, Taiwan, the feasibility of fitting windows with sun-shadings was investigated in order to minimize the lighting power costs in daylight-illuminated classrooms [12]. This paper performed LIGHTSCAPE simulations to investigate the illuminance conditions in classrooms and evaluated daylight intensity (in Lux units); minimum illuminance requirement for classrooms was considered 500 Lux. In this case study, illuminance was calculated in the date of Winter Solstice and Summer Solstice (different hours of the day) and in different positions (in a 0.8×0.8 m grid). Result of this study showed that the daylight access device not only improved the illuminance conditions within the classroom, but also reduced the lighting power cost by 71.5% compared to the case in which all the lights were turned on.

DIALux 4.10 software is one of the most powerful software in the field of interior and exterior lighting designs. This software is used in many projects and research papers and its results have For example, in a research that emphasized daylight factor estimation at an early design stage to reduce buildings' energy consumption due to artificial lighting, the simulations were performed using the DIALux software [13]. Also, in another study, DIALux was used to assess the relative impact of 22 different design factors on interior day lighting effects and to formulate design recommendations for gymnasiums in mid-latitude area of China [14]. DIALux can simulate overcast, clear and average sky conditions.

Overcast sky is a sky that has 100% cloud cover and the sun is not visible. Clear sky is a sky that has less than 30% cloud cover [15]. In DIALux software, daylight factor is calculated based on standard CIE overcast sky. Clear sky condition is related to calculation of daylight illuminance (in units of Lux and Foot Candle).

1.3 Methodology

In this study, conditions and characteristics of good daylight in educational facilities were briefly studied relying on library resources and documents. Then, in order to assess the impact of daylight on student performance, 82 students (who were using five types of college classrooms and ateliers in five academic group during at different times of a semester) have been questioned and their academic scores have been investigated. These students were spending a same course (the Design course). In order to evaluate student performance, besides investigating the factors such as feeling drowsiness, fatigue and weary in the atelier, the scores of the design course of five academic groups have been compared together. Then, quality of daylight was evaluated in ateliers and classrooms in measured spaces of this article by computer simulations using DIALux 4.10 lighting software (results of the computer simulations were validated by in-situ measurements by a light meter). Finally, strategies were provided for improving quality of daylight in this building. So, the research method of this article is descriptive-analytic and computer simulations were used in the case study. Moreover, objective observations were conducted to confirm some results of the survey (for example, the signs of drowsiness states, fatigue and weary among students) and find the tendency of students and faculty members to use classrooms and ateliers with natural or artificial lighting by observing the type of empty classrooms.

1.4 Geographical descriptions of selected site

The selected building of this study (IUST School of Architecture) is located in Tehran. Tehran features a semi-arid climate (Koppen climate classification: BSk). Tehran's climate is largely defined by its geographic location (35°41′46″N 51°25′23″E), with the towering Alborz Mountains to its north and the central desert to the south. It can be generally described as mild in the spring and autumn, hot and dry in the summer, and cold in the winter. Figures 1 shows cloud cover types of Tehran. This information is based on the historical records of Mehrabad International Airport (Tehran, Iran) weather station from 1996 to 2012.

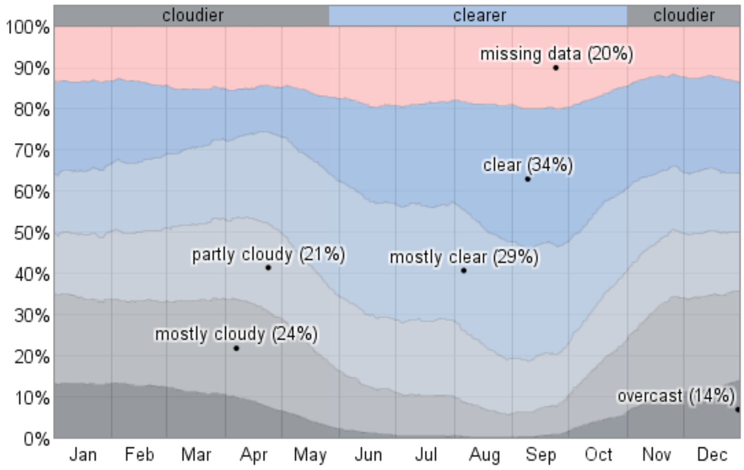

Figure.1: Cloud Cover Types of Tehran based on the historical records of Mehrabad International Airport (Tehran, Iran) weather station from 1996 to 2012.

In this study, according to the types of sky in Tehran at different times of the year (figure 1), computer modeling was done to check quality of daylight based on both methods, daylight factor for overcast and cloudy sky conditions and illuminance (in terms of Lux) for clear sky condition. School of Architecture and Environmental Designs, Iran University of Science and Technology, like other schools of this university, had north-south orientation with about 10 degrees of rotation to the east. All the classrooms and ateliers of this school were facing south or north. Figure 2 shows the general diagram of spaces in this building.

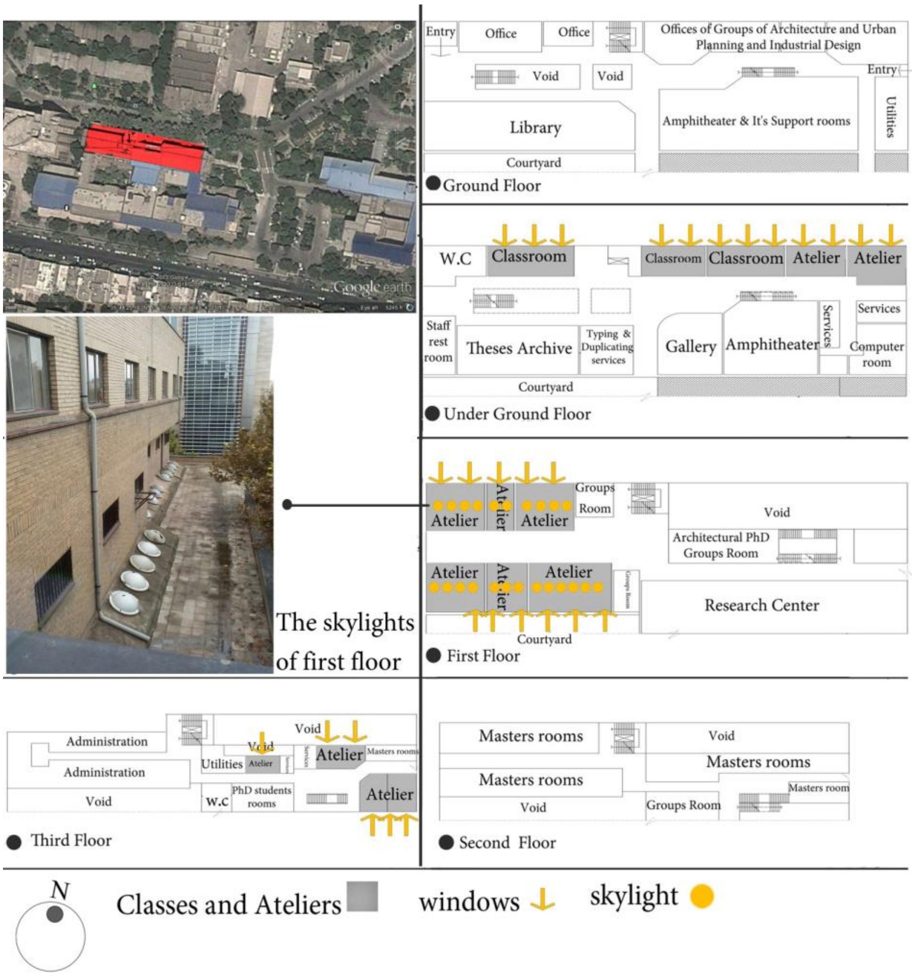

Figure 2: General diagram of spaces in building of School of Architecture and Environmental Designs, Iran University of Science and Technology (drawn by the authors).

The considered fields of this article (ateliers and classrooms) were specified in this diagram. These spaces were located in the basement or on the first and third floors.

2. Appropriate daylight conditions and its effective factors in classrooms

Daylight is the combination of sunlight, skylight and reflected light from the ground. Skylight is the light which is scattered by molecules of air, aerosols and particles such as water droplets in clouds in the atmosphere, excluding direct beam [16]. Factors affecting the amount of daylight in buildings include latitude and longitude, building form, building location, landscaping, building orientation, building usage, joinery construction materials of interior walls and exterior facades, window size and position and window components (such as glass ratio, glazing materials and shading devices) [16]. The amount of daylight in interior spaces can be measured by calculating method of daylight illuminance of space (in Lux and Foot Candle units) and daylight factor (DF). The sky condition in Tehran is clear in most days of the year, but from late autumn until the end of winter is overcast and Partially cloudy on most days [17]. Therefore, both computational methods were used in this study.
Daylight factor is the ratio of indoor illuminance and outdoor illuminance, which can be measured for a specific point or for an average of a space [18]. In more accurate definition, Daylight factor is the "ratio of the illuminance at a point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky, excluding the contribution of direct sunlight to both illuminances" [19]. Unlike the illuminance of daylight, this percentage is constant on different days during the year. The glazed area of the window, diffuse transmittance of the

glazing material, vertical angle subtended by the sky that is visible from the center of the window, total area of room surfaces including floors, ceilings, walls and windows, area-weighted average reflectance of the interior surfaces (including glazing) are known as effective factors in daylight [20]. With regard to the amounts of reflectance of the interior surfaces, to minimize influence of thermal energy and also take advantage of natural light, it is recommended to use joinery materials with high maximum reflection coefficient [21]. In the measured spaces of this article, dark colored ceilings were used in many places. Also, depth of rooms (deeper rooms have a poorer daylight factor at the back of the room compared with the front), height of window head (depth and amount of daylight increase with increasing height of windows. Also, the higher the window head, the deeper the penetration of day lighting would be), shading devices (interior and exterior shading devices and solar control glazing) and glazing type are the factors affecting the amount of daylight [22]. The standard amount of daylight factor is not the same for all building types and each building has its own value. Overall, if rate of daylight factors is below 2%, the space appears to be dark and depressing and often requires use of electric lighting during daytime and electric lighting dominates daytime appearance. If value of daylight factor is between 2% and 5%, windows have provided considerable daylight, but sometimes supplementary electric lighting is still needed; if daylight factor is 5% or more, there would be enough light into the room and daytime electric lighting is rarely needed [23, 24]. Also, there are standard criteria for the amount of daylight factor based on empirical and mathematical studies. Table.1 shows the appropriate amount of daylight factor for education spaces. Also, appropriate illuminance for learning spaces is demonstrated in terms of Lux in Table 2.

Table.1: Proper daylight factor in educational spaces [25].

space types	Average daylight factor (%)	Minimum daylight factor (%)	Measurement (working) Height
Classrooms	5	2	Desks
Laboratories	5	2	Benches
Assembly halls	1	0.3	Working plane
Corridors & Stairs	2	0.6	Floor & Treads
Art rooms	5	2	Desks & Easels

Table.2: Proper illuminance in educational spaces [26].

Standard Maintained Illuminance (lux)	Space types
300	Classrooms, tutorial rooms
500	adult classrooms
500	Lecture hall
500	Black board
500	Art rooms
750	Technical drawing rooms
200	Entrance halls
100	Circulation areas, corridors
150	Stairs
200	Student common rooms and assembly halls

In addition to the good amount of natural light, direct sunlight should be controlled to stop glare, overheating and disturbing thermal comfort in spaces, especially during the summer. Also, providing good visual contact with the outside and reflection coefficient of interior surfaces are important [25]. Figure 3 shows appropriate reflection factors for educational spaces. The appropriate amount is 70 to 90 percent for ceilings, 30 to 50 percent for floor, 40 to 60 percent for walls and over 20 percent for educational boards [15].

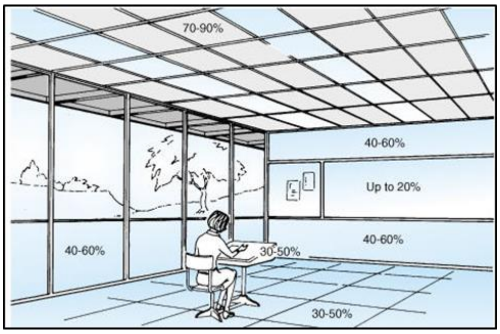

Figure.3: Appropriate reflection factors for educational spaces [15].

3. Results and discussions obtained from questionnaire and assessment of student scores.

The measured spaces of this study were classified into five groups in terms of their location, lighting orientation and common characteristics (classrooms and ateliers in the basement facing north, ateliers on the first floor facing north, ateliers on the first floor facing south, ateliers on the third floor facing north and ateliers on the third floor facing south). In Table 3, variety of classrooms and ateliers is classified based on their location and average spatial dimensions and window areas are demonstrated. In order for more accurate simulation of classrooms, in addition to the area and height of windows, distance of bottom of windows from the floor was considered. Daylighting measurements and simulations indicated that, at the same height of the window, the windows near the ceiling had better performance in daylighting because of the reflected daylight from the ceiling (bright colored ceiling). These dimensions will be used in computer modeling.

Table.3: Average spatial dimensions, window size, O.K.B and joinery materials of different classrooms and ateliers in both north and south orientations (by the authors).

Space types	Number	Average floor area of classrooms (m^2)	Average length and width of classrooms (m)	Height of room (m)	Average of window area (m^2)	Window height (m)	Distance from floor (m)
North-facing Classrooms and ateliers on basement floor	5	51.30	5.40*9.50 Windows are in length of room	3.10 flat ceiling	5.28 17.9% of the wall	0.82	1
North-facing ateliers on first floor with skylight	3	52.65	6.50*8.10 Windows are in length of room	2.70-3.80 Flat and sloped ceiling	2.66 12.1% of the wall	0.90	1
South-facing classrooms and ateliers on first floor (2 ateliers with skylight)	3	74.52	8.10*9.20 Windows are in length of room	2.70 - 3.80 Flat and sloped ceiling	2.50 10% of the wall	0.90	1
South-facing ateliers on third floor	2	50.40	6*8.40 Windows are in width of room	2.90-3.80 sloped ceiling	3.15 13.8% of the wall	1	0.85
North-facing ateliers on third floor	2	33.75	5.40*6.25 Windows are in width of room	2.90-3.80 sloped ceiling	2.40 12% of the wall	1	1

According to this classification, it has been polled by questionnaire five groups of students they have used alternatively these classrooms and ateliers during a semester at various time in relation to amount of use of artificial lighting and their satisfaction of natural and artificial lighting in classrooms, their tendency to type of lighting and the parameters that affect their performance (having drowsiness states, fatigue and weary in classrooms and ateliers). besides these parameters, the scores of the Design course of five academic groups have been compared together. Questionnaire sheets were distributed among students and they filled them out during their class. This survey was conducted at the end of the semester. Students were 35 women and 47 men at the age range of 19 to 26 years old. Table 4, shows the results of the questionnaire and assessment of student scores. Results of the questionnaire showed that most students were generally willing to use natural lighting and they had lesser tendency to use dim classrooms in terms of natural lighting. Modes of fatigue, weary and sleepy were more reported among students in these classrooms. Also, the assessment of student scores showed that while the average scores of students in Design course in dim ateliers (in terms of daylight) is lower than their average total and semester scores, the average scores of students in the same course, is near or more than their average total scores and average semester scores in bright ateliers. Overall, the results showed better performance student, greater satisfaction and higher student academic scores in south-facing classrooms and ateliers.

Table 4: Questions, the number of participants and questionnaire results of assessing quality of natural lighting and assessment of student scores (by the authors).

Questionnaire to assess the quality of natural lighting in different classrooms and ateliers and assessment of student scores					
Questions	Results from different classrooms and ateliers				
	basement floor (north facing)	first floor (north facing)	first floor (south facing)	third floor (north facing)	third floor (south facing)
Number of respondents	23	16	17	12	14
1. How much (in terms of time) used artificial lighting in your classroom or atelier?					
Normally not used ☐	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Sometimes used ☐	0 (0%)	0 (0%)	14 (82%)	0 (0%)	11 (79%)
Usually used☐	5 (22%)	4 (25%)	3 (18%)	3 (25%)	3 (21%)
Permanently used ☐	18 (78%)	12 (75%)	0 (0%)	9 (75%)	0 (0%)
2. How much is your satisfaction of natural lighting in atelier or classroom?					
Very satisfied ☐	0 (0%)	0 (0%)	1 (6%)	0 (0%)	8 (57%)
Somewhat satisfied ☐	3 (13%)	0 (0%)	5 (30%)	0 (0%)	4 (29%)
Somewhat dissatisfied ☐	5 (22%)	5 (31%)	8 (46%)	5 (42%)	2 (14%)
Very unsatisfied ☐	15 (65%)	11 (69%)	3 (18%)	7 (58%)	0 (0%)
3. How much is your satisfaction of artificial lighting in atelier or classroom?					
Very satisfied ☐	3 (13%)	2 (13%)	2 (12%)	0 (0%)	2 (14%)
Somewhat satisfied ☐	8 (35%)	5 (31%)	9 (53%)	2 (17%)	10 (72%)
Somewhat dissatisfied ☐	10 (43%)	9 (56%)	6 (35%)	7 (58%)	2 (14%)
Very unsatisfied ☐	2 (9%)	0 (0%)	0 (0%)	3 (25%)	0 (0%)
4. How much do you feel drowsiness states, fatigue and weary in the classroom or atelier?					
I don’t have these states ☐	5 (22%)	5 (31%)	10 (58%)	3 (25%)	8 (57%)
I have these states rarely ☐	8 (35%)	5 (31%)	4 (24%)	5 (42%)	6 (43%)
I have usually these states ☐	10 (43%)	6 (38%)	2(12%)	3 (25%)	0 (0%)
I have these states permanently ☐	0 (0%)	0 (0%)	1(6%)	1 (8%)	0 (0%)
5. Which type of lighting is better to perform your activities in the classroom or atelier?					
Artificial lighting ☐	6 (26%)	4 (25%)	5 (29%)	4 (33%)	4 (29%)

Natural lighting ☐	15 (65%)	12 (75%)	11 (65%)	8 (67%)	9 (64%)
Not matter ☐	2 (9%)	0 (0%)	1(6%)	0 (0%)	1 (7%)
Assessment of students scores					
Average total scores of students	16.3888	16.2075	17.1048	15.8438	16.3737
Average semester scores of students	16.1215	15.9350	16.8875	15.8923	17.2512
Average scores of students in Design course	15.1682	15.4523	17.1214	15.0121	16.4212
Comparing average scores of students in Design course with their average total scores	7.5% lower than average total scores	4.7% lower than average total scores	0.01% more than average total scores	2.98% lower than average total scores	0.29% more than average total scores
Comparing average scores of students in Design course with their average semester scores	5.91% lower than average semester scores	3.03% lower than average semester scores	1.39% more than average semester scores	5.59% lower than average semester scores	4.80% lower than average semester scores

Figure 4: Unfavorable conditions of natural lighting in north-facing classrooms and ateliers and space lighting in the mode of artificial light (photos by the authors) (a) Related to one of the classrooms in the basement, (b) Related to one of the ateliers on the first floor and (c) Related to one of the ateliers on the third floor.

Figure 4 shows examples of unfavorable conditions of natural lighting in north-facing classrooms and ateliers and space lighting in the mode of artificial light in a clear sky day.
In the south-facing ateliers on the first and third floors (as indicated in Figure 5), which were more favored by students and teachers, artificial lighting was less widely used. Also, modes of being tired, weary and sleepy were rarely reported in the students in these classrooms. But sometimes, direct solar radiation into these ateliers led to using artificial lighting and drawing the curtains. Figure 5 shows examples of these ateliers and classrooms. Also, ceiling skylight of the first floor ateliers is given in Figure 6.

Figure 5: Lighting conditions of south-facing classrooms and ateliers (photos by teh authors) (a) Related to good lighting in ateliers on the third floor, (b) Related to good lighting in one of the classrooms on the first floor and (c) Related to unfavorable lighting in one of the ateliers on the first floor with dark color in ceiling and improper window size and location.

4. Quality of daylight and its influencing factors in measured classrooms and ateliers.

Computer modeling was done to check quality of daylight based on daylight factor and illuminance (in terms of Lux) on 24 days of year (first and middle days of every month) in DIALux software according to the dimensions presented in Table 3, orientation of spaces, geographical location of city of Tehran (35 degrees and 36 minutes to 35 degrees and 44 minutes of north latitude), air pollution coefficient (0.7 for cities like Tehran in DIALux software), joinery materials of internal surfaces and glazing type (around 70% transparency coefficient), existing ceiling skylight in some places, surrounding structures and obstacles around the building, installation channels passing above the skylight wall and furniture of each space. Then, its results were compared with the standard values mentioned in Section 2. Illuminance calculations were done at 10:30 am (this time was the default of software. Also, most classes have been held at this time. In addition, there was daylight in space at this time on all days of the year and this time was not part of critical times in terms of solar radiation). Also, effect of influential factors in daylight was evaluated and finally reasons of desirable or undesirable daylight were investigated.

Figure 6: Ceiling skylights in the first floor ateliers (photos by the authors) (a) Related to optimal performance of ceiling skylights in one of the north-facing ateliers on the first floor with clean and healthy skylights (b) Related to poor performance of ceiling skylights in one of north-facing ateliers on the first floor with dirty and damaged skylights.

According to functions of spaces, daylight calculations were done in height of work. The results of these models are shown below. Figure 7 shows modeling of north-facing classrooms in the basement (based on the values in Table 3) in DIALux software. This modeling showed effect of light and dark colors of ceilings (ceiling surface in some classrooms was light and, in some others, it was dark) and effect of double increase in height of windows (in the existing situation, height of windows was limited due to crossing installation channel). Calculations showed that daylight factor in these classrooms was less than its appropriate minimum (2%) and equal to 1.69%. This amount was 1.60 % in the classrooms with dark ceiling color. In terms of daylight illuminance, according to the calculations on the first and middle days of each month, daylight illuminance was variable between 160 and 310 Lux (under 300 Lux on most days) on different days of the year. This amount was further (about 6.1%) in the classrooms with light color of ceiling. According to minimum optimal illuminance in this space type (Table 2), daylight illuminance of the space for general education classrooms was often inappropriate and, for the ateliers, it was inappropriate at all times and required using artificial lighting. On the other hand, inappropriate place of installation channels (above the windows) was a limiting factor for height of windows. The modeling results showed that, with double increase in height of windows, daylight illuminance would be nearly doubled.

In Figure 8, the calculation related to north-facing ateliers on the first floor is represented. These ateliers had ceiling skylight. In these calculations, effect of these skylights and also height of double windows (window height was limited due to crossing installation channels) on ateliers lighting was evaluated. The calculations showed that daylight factor in these classrooms was less than the appropriate minimum (2%) and equal to 1.39 %. In terms of daylight illuminance in the present situation, daylight illuminance was variable between 100 and 480 Lux (under standard level of 500 Lux on all days) on different days of the year. On the other hand, in order to evaluate the impact of skylights on daylighting in ateliers, situation of these spaces was simulated in a condition of ignoring skylights (the natural light coming through windows is the only light source in this manner). Result showed that, by removing these skylights, illuminance of the spaces was reduced by about 50% (in the present situation, many of the skylights did not have enough performance due to dirtiness of skylights). Calculations demonstrated that, by relocating installation channels and double increasing in window height and length, daylight illuminance increased (180 to 840 Lux) and daylight factor increased (to 3.61%).

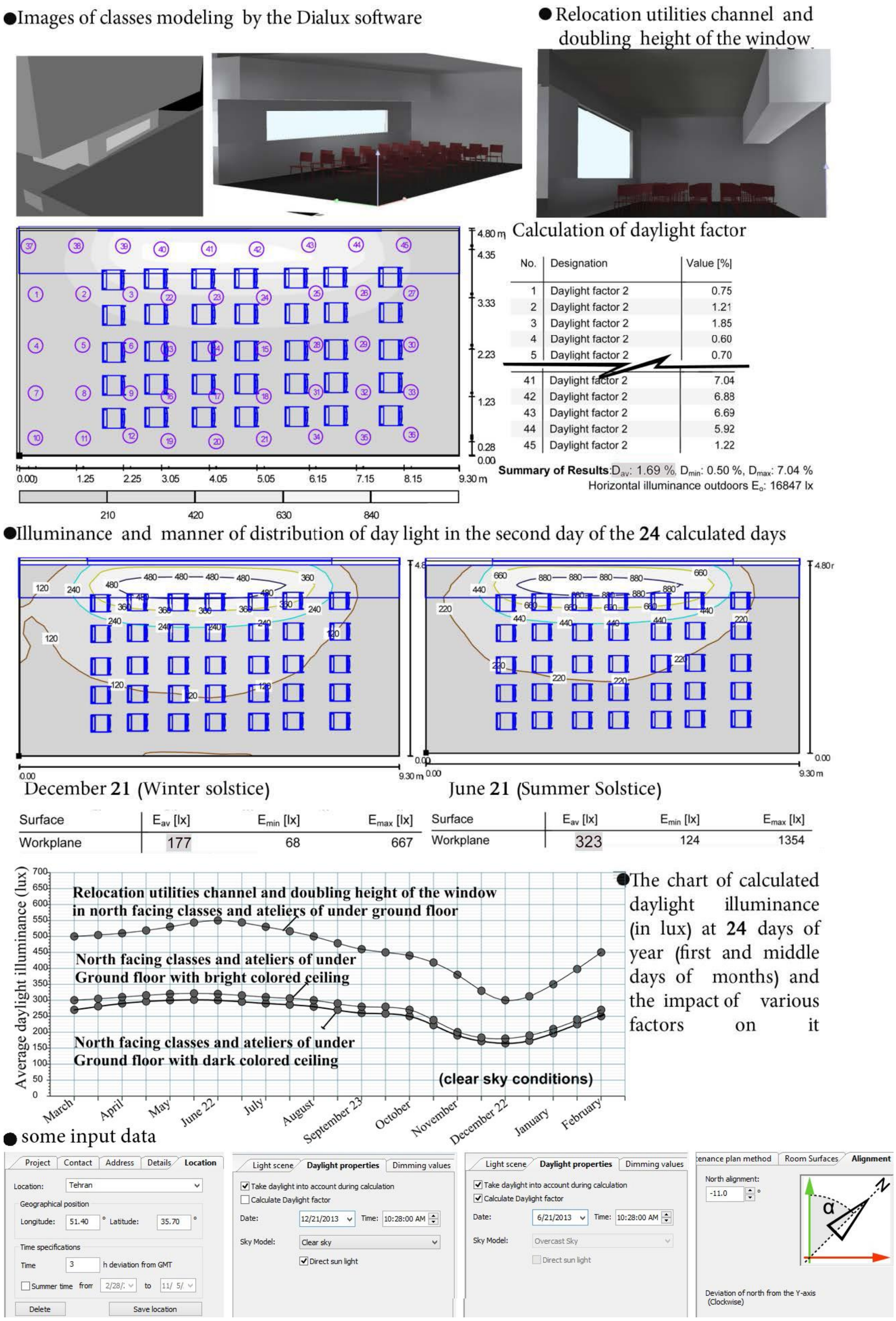

Figure 7: Modeling north-facing classrooms in the basement in Dialux software (by the authors).

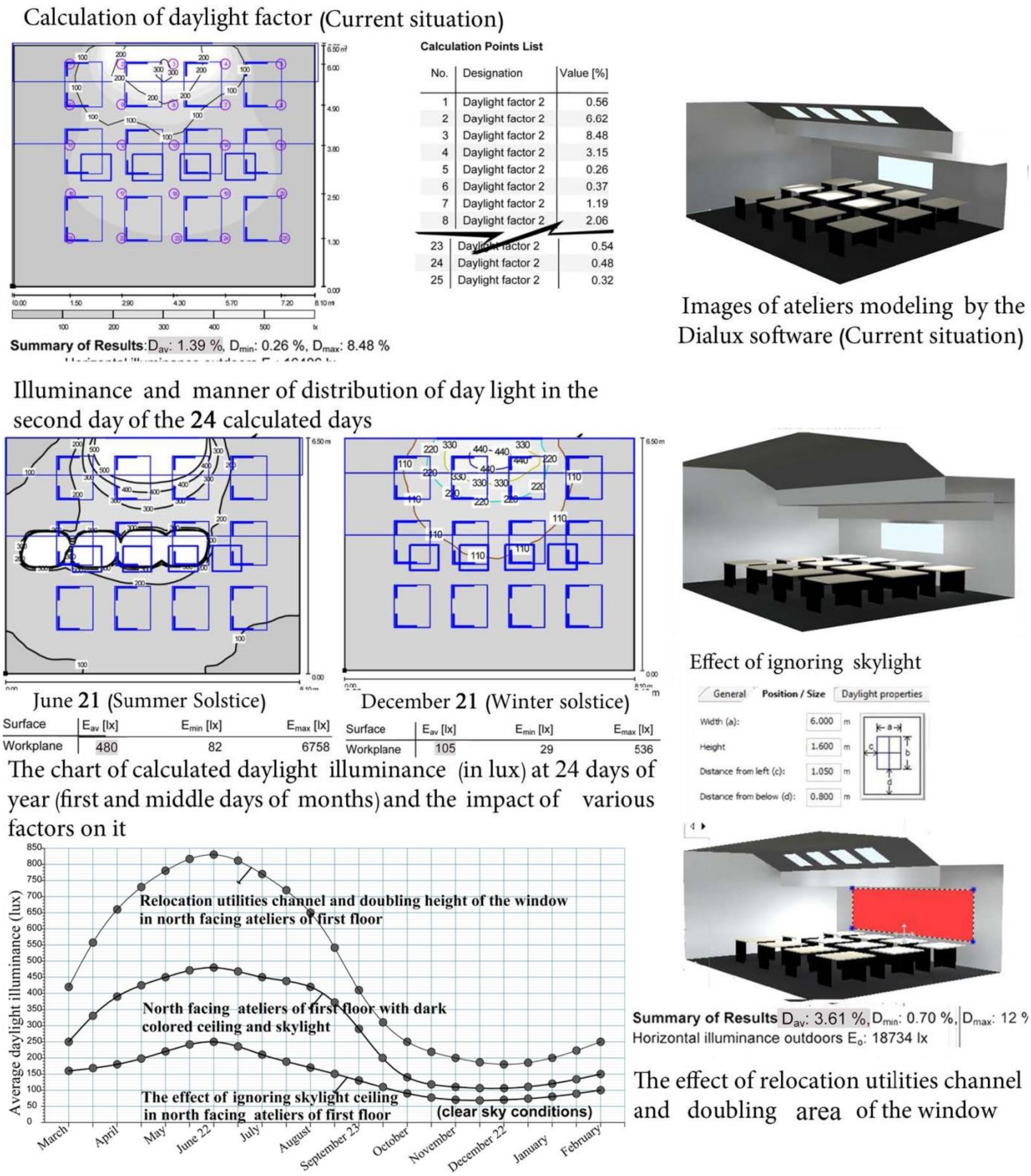

Figure 8: Modeling north-facing ateliers on the first floor in Dialux software (by the authors).

Figure 9 shows the same calculations in the south-facing ateliers on the first floor. The calculations showed that daylight factor in these spaces was more than its appropriate minimum (2%) and equal to 2.48%. In terms of daylight illuminance, according to the calculations on the first and middle days of each month in the present situation, daylight illuminance was variable between 400 and 750 Lux (under standard level of 500 Lux on some days) on different days of the year. On the other hand, the role of ceiling skylights was significant in this illuminance and, with removing these skylights, illuminance of spaces reduced by about 20% in the summer and about 50% in the winter. In clear sky conditions, maximum illuminance was on Dec. 21 due to greater penetration of solar radiation due to more oblique radiation and minimum illuminance was on Jun. 21 due to less penetration of sunlight into spaces due to the most vertical rays of the sun (contrary to catching light from the north). But, if conditions of the cloudy sky were considered, maximum light capture occurred on Jun. 21 and the minimum occurred on Dec. 21. These cases are shown in the graph of annual average daylight illuminance.

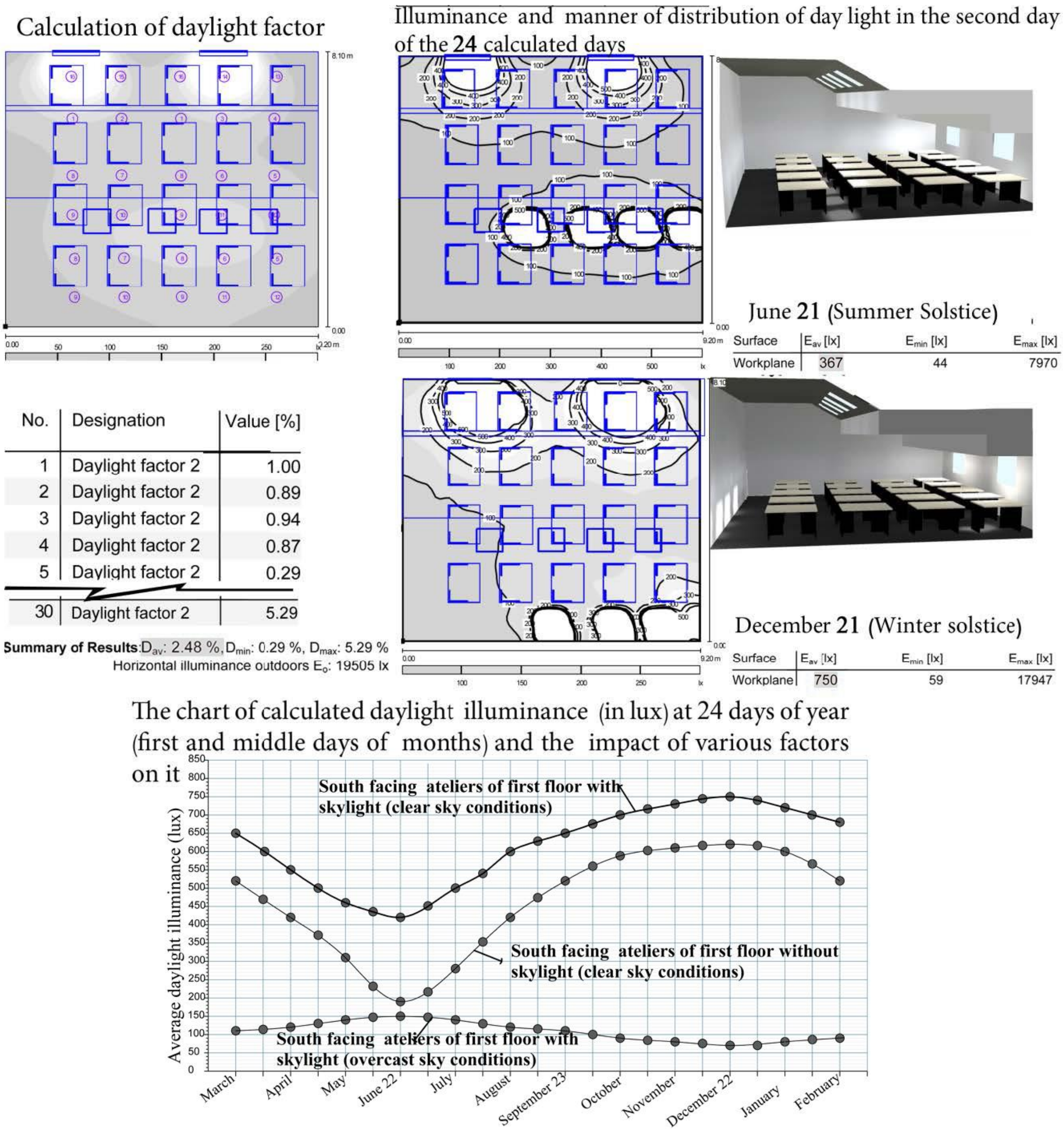

Figure 9: Modeling south-facing ateliers on the first floor in Dialux software (by the authors).

Also, Figure 10 shows illuminance on both Jun. 21 and Dec. 21 at different hours of the day in south-facing ateliers on the first floor. In the south-facing ateliers, illuminance was more at some hours on Dec. 21 due to greater penetration of solar radiation in mode of oblique radiation. However, this illuminance did not occur on the cloudy days (in winter, often days were cloudy in city of Tehran) and also decreased rapidly compared with the balanced illuminance on Jun 21.

Figure 11 and Figure 12 show the same study in north-facing and south-facing ateliers on the third floor. The calculations showed that daylight factor in north-facing ateliers on the third floor, was less than its appropriate minimum (2%) and equal to 1.02%. In terms of daylight illuminance, according to the calculations on the first and middle days of each month in the present conditions, daylight illuminance was variable between 100 and 200 Lux (under the standard level of 500 Lux on all days) on different days of the year. Because the window size in north-facing ateliers on the third floor was considered equal to that of south-facing ateliers on the third floor, these spaces were dim. The modeling result demonstrated that north-facing ateliers needed larger windows by four times or skylights similar to those in Figs. 8 and 9. Great difference between the two curves in Fig. 11 was related to the present daylighting situation of these spaces compared to the desired status. The calculations showed that daylight factor in south-facing ateliers on the third floor was more than its appropriate minimum (2%) and equal to 2.46%. In terms of daylight illuminance, according to the calculations on the first and middle days of each month in the present conditions, daylight illuminance was variable between 390 and 710 Lux (under the standard level of 500 Lux on some days) on different days of the year. Also, in the cloudy sky condition, daylight illuminance reduced to 120-200 Lux (Figure 11).

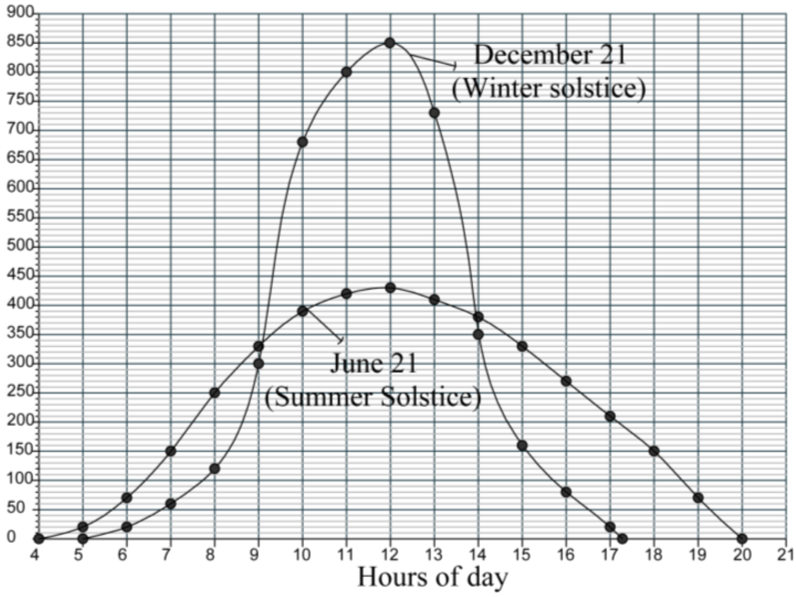

Figure 10: Illuminance on both Jun. 21 and Dec. 21 at different hours of the day in south-facing ateliers on the first floor (by the authors).

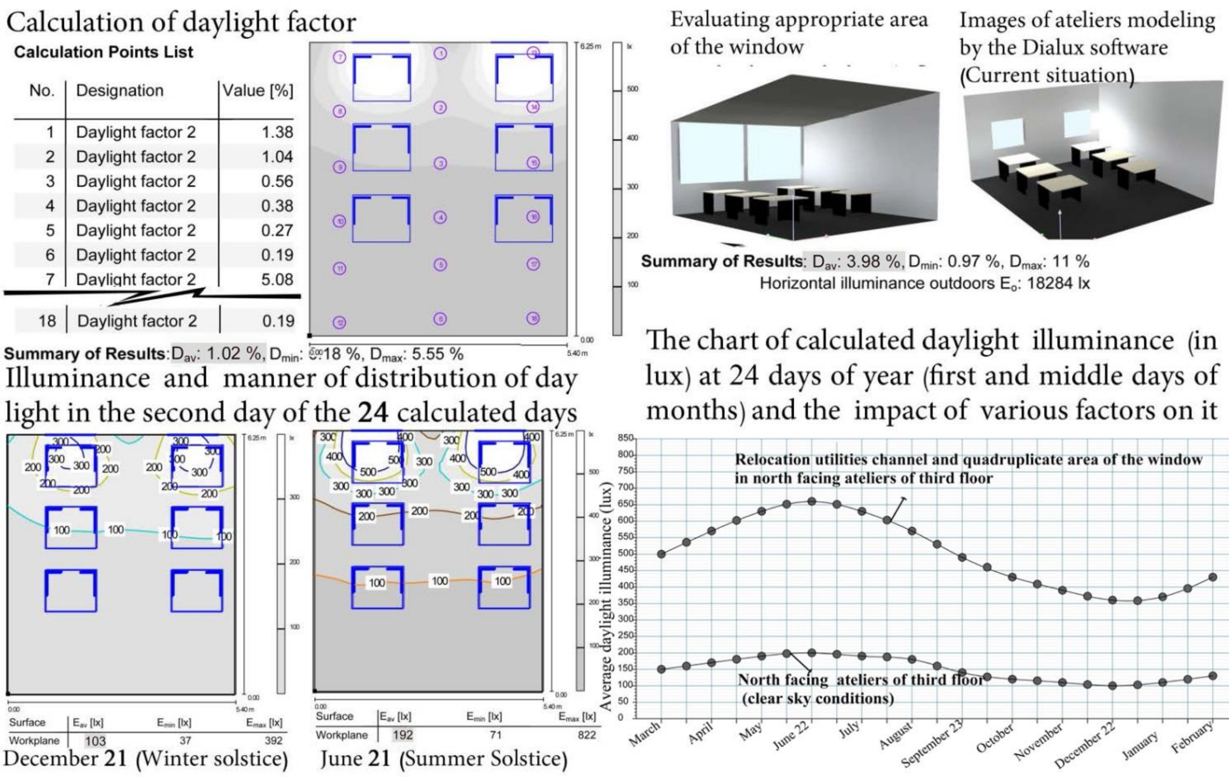

Figure 11: Modeling north-facing ateliers on the third floor (by the authors).

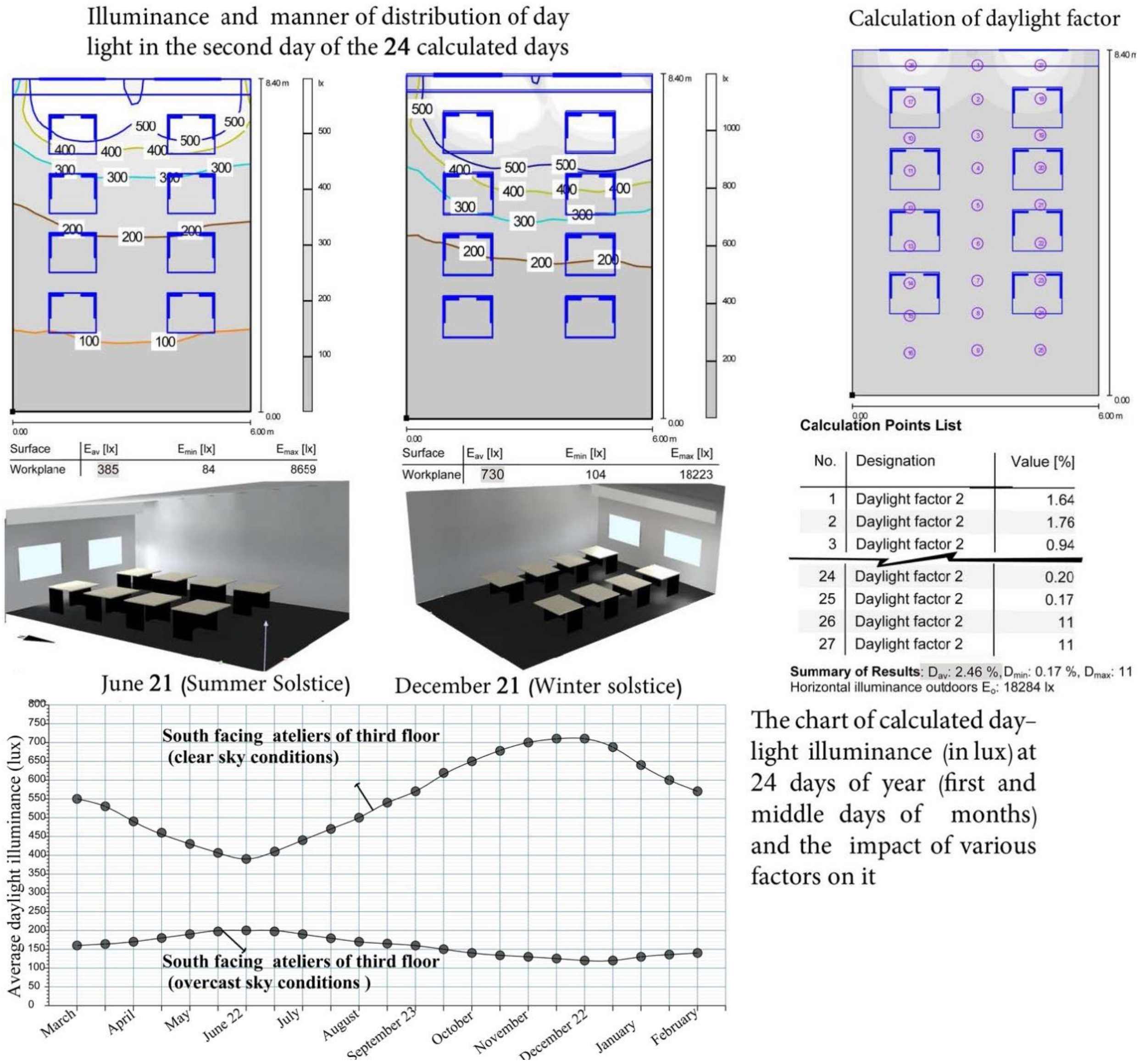

Figure 12: Modeling south-facing ateliers on the third floor in Dialux software (by the authors).

5. Simulation verification

In order to verify the simulation results, DIALux software outputs were compared to the amounts of light measured by the light meter (Table 5). Measurement of the DF and illuminance in computer simulation and field measurements was approximately conducted in terms of 1 m2 for classrooms and 1.5 m2 in ateliers (commensurate with the current furniture arrangement in these spaces) and was conducted at working height (height of chairs and tables). Field measurements was done using a handhold luxmeter (LM-81LX Light Meter, 0- 20,000 lux range, 1 lux resolution, and +/-0.5% accuracy) based on illuminance and in clear sky conditions (dominant sky condition in Tehran). For this purpose, the first and middle days of January were selected (considering changes in the amount of daylight at different hours of the day and months of the year, two days were selected). A light meter was used at approximately10:30 am (calculation time of the software).

In Figure 13, photos of utilizing the light meter in the classrooms and ateliers are presented. The comparison results showed that outputs of DIALux software and the amount of light measured by light meter were almost identical. Also, results of in-situ measurements by the light meter showed that the classrooms located on the upper floors, due to fewer obstacles around them, received more daylight.

Table 5: Comparing Dialux software outputs by the amounts of light measured by the light meter on the first and middle days of Jan. The comparison results showed that outputs of Dialux software and the amount of light measured by the light meter were almost identical.

Space types	Dialux software outputs. average illuminance at working level (Lux)	Light meter results. Average illuminance of measured point at working level (Lux)	deviation of the results between simulation and field measurement (%)	Comparison of results	Date
North-facing classrooms and ateliers on basement floor	190	155	18%	almost identical , both Inappropriate	First day of January
	220	182	17%	almost identical , both Inappropriate	middle day of January
North-facing ateliers on first floor with ceiling skylight	110	130	15%	almost identical , both Inappropriate	First day of January
	120	134	10%	almost identical , both Inappropriate	middle day of January
South-facing classrooms and ateliers on first floor	720	682	5%	almost identical, both appropriate	First day of January
	700	670	4%	almost identical, both appropriate	middle day of January
North-facing ateliers on third floor	110	122	10%	almost identical , both Inappropriate	First day of January
	120	148	19%	almost identical , both Inappropriate	middle day of January
South-facing ateliers on third floor	640	723	11%	almost identical, both appropriate	First day of January
	600	578	4%	almost identical, both appropriate	middle day of January

The average deviation of the results between simulation and field measurement is 11.3%. The main cause of this deviation is the dirtiness of skylights and windows. The results of field measurement shows that the effect of pollution on the surfaces of windows on north-facing walls in reducing internal illuminance is more than its effects in the surfaces receiving direct sunlight in roof and south-facing walls.

6. Conclusions

The results of this study indicated very low use of artificial light and better performance students in the classrooms and ateliers with more natural lighting. In these spaces the satisfaction of students is greater and modes of tiredness and drowsiness were lesser reported among students. Also, the student academic scores were higher in these spaces and more students tended to have natural light in classrooms and ateliers. In relation to the illuminance value and daylight factor, the calculations showed that daylight factor was less than its optimal minimum in the classrooms in the basement and daylight illuminance in these classrooms was below the appropriate standard for educational classrooms (300 Lux) on many days and below the appropriate standard for the ateliers (500 Lux) on all days. This condition was satisfied in north-facing ateliers on the first floor (with daylight illuminance between 100 and 480 Lux) and third floor (with daylight illuminance between 100 and 200 Lux). In these spaces, artificial light was used all the time and boring and sleepy modes were more reported among the students. Also, students and faculty members had less tendency to use these classrooms and ateliers. The modeling results showed that the amount of natural light in these spaces on most days could be appropriate by shift installation channels and double increase in the windows height (there was a need to four-fold increase size of the windows in north-facing ateliers on the third floor). On the other, effect of using dark color on the ceiling of the ateliers and classrooms was evaluated and the results indicated an increase of about 6% in the average of daylight illuminance in the classrooms and ateliers in modes of using bright colors with optimum reflection coefficient (70 to 90 percent). Skylights of the ateliers on both sides on the first floor had high effect on increase in the average illuminance in these spaces.

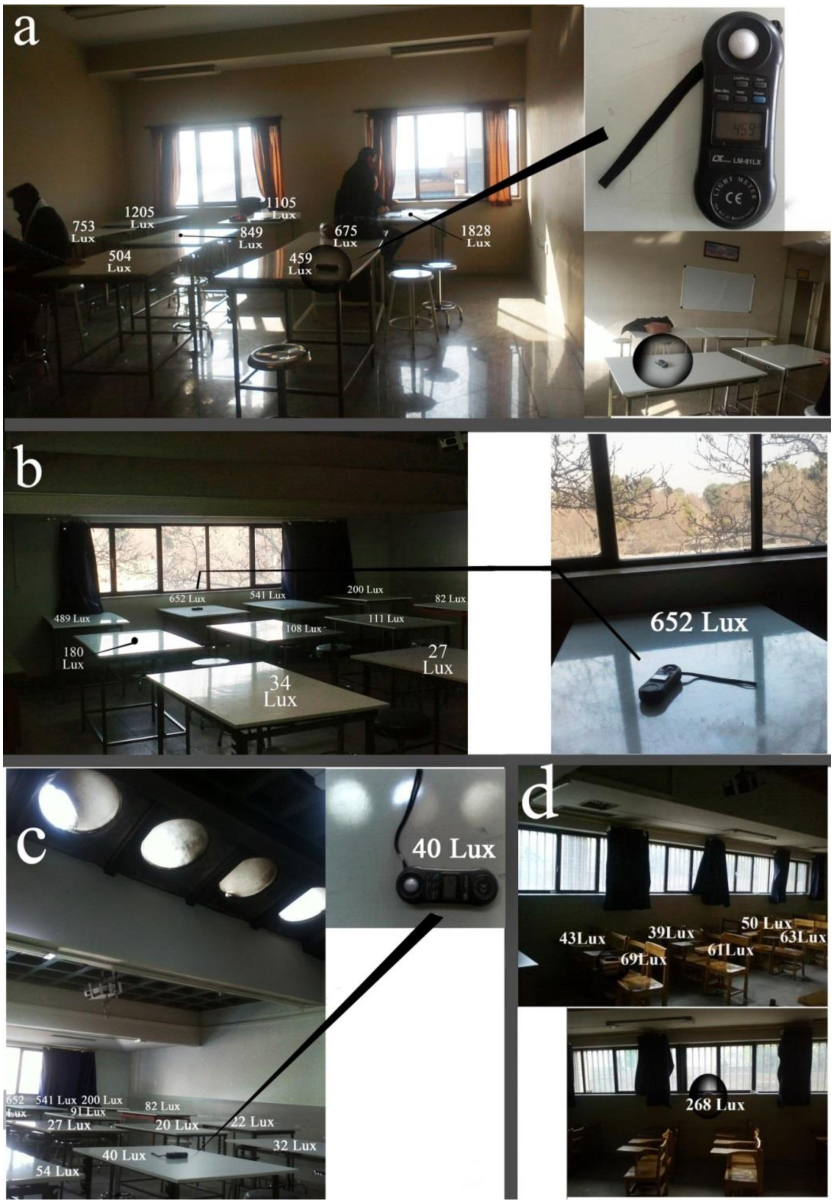

Figure 13: Photos of utilizing the light meter in the classrooms and ateliers a: South-facing atelier on the third floor, b: North-facing atelier on the first floor with ceiling skylight, c: North-facing atelier on the first floor with ceiling skylight, d: North-facing classroom in the basement.

Modeling the results showed that, in north-facing ateliers, daylight illuminance was reduced by about 50% by removing ceiling skylights. In the south-facing ateliers, this amount was about 20 % in the winter and 50 % in the summer. However, in the present condition, dirtiness of skylights hampered their performance. The calculations and modeling of daylight illuminance and daylight factor were also done in the south-facing ateliers on the first and third floors and the results indicated appropriate window size and usefulness of ceiling skylights. However, illuminance of these spaces reduced greatly on the cloudy days and they required using artificial lighting. Daylight factor in these spaces was above 2% and the average illuminance of sunlight was over 500 Lux on most days. On the other hand, most classrooms and ateliers were north-facing, and south-facing spaces were dedicated to the spaces such as office rooms and library. Also, assigning the basement to classrooms and some of ateliers and assigning ground and second floors to the functions apart from main use of this building were inappropriate in terms of optimal use of daylight. In general, the most important design problems and other obtained results of this case study include:

- Optimal area of windows in north-facing educational spaces. In this study, optimal area of windows in north-facing classrooms was estimated to be about 5.41% of the total internal surface area. This ratio was 6.08% in north-facing ateliers. In this regard, to prevent heat loss in the winter, double- and triple-glazed windows must be used.
- Relative equality of windows area in north-facing and south-facing ateliers. Lack of attention to the impact of orientation in daylight quality in the present case study spaces was represented. The area of windows in south-facing ateliers was sufficient and equal to 1.59% of total internal surface area. During warm and sunny days, to prevent heat gains and/or glare, south facing windows should have a light shelf. Future studies, based on the conclusions of the current one, should thoroughly evaluate the characteristics of appropriate light shelf in this case study.
- Unsuitable place for installation channels (above the windows). This issue limited the height and area of the windows.
- Inappropriate location of classrooms on the floors. Results of in-situ measurements by the light meter showed that the classrooms located on the upper floors, due to fewer obstacles around them, received more daylight. Illuminance in the classrooms and ateliers in the basement was 315 Lux near the windows. This amount was 861 Lux and 1196 Lux on the ground and first floors, respectively. All the windows were north-facing.
- Inappropriate color of ceiling. Average daylight illuminance in the classrooms and ateliers in mode of using bright colors with optimum reflection coefficient (70 to 90 percent) was more by about 6% - 10% (depending on the ceiling area).
- Dirtiness of skylights. Simulation results showed that skylights increased illuminance of ateliers by about 50% when its area was 1.28% of total internal surface area. But, in practice, due to dirty skylights, the amount of light measured by the light meter showed a lower value. In general, skylights, regarding their size, had maximum impact on improving daylighting in the classrooms and ateliers.
- Appropriate daylight illuminance. The results of computer simulations and field measurement indicated that in the educational spaces in which the reports of tiredness and drowsiness are fewer and students satisfaction is greater, daylight illuminance was variable between 400 and 750 Lux on different days of the year.

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