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Visual comfort assessment of daylit and sunlit areas: A longitudinal field survey in classrooms in Kashan, Iran

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ABSTRACT

Visual comfort in schools enhances not only health and wellbeing, but also satisfaction and therefore learning and visual performance. This research aims at testing students' evaluations on visual comfort through questionnaires in daylit and non-daylit areas in classrooms. Dynamic daylight metrics including Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), codified in LEED v4, are calculated and compared to students' evaluations. A typical high school in Kashan was selected in which subjective and field measurements were carried out simultaneously in two different oriented (south and north) classrooms during a school year (2014–2015).

Simulation results show that 71% of the space in south facing classroom and 20% of the space in north facing classroom receives adequate amount of daylight while 29% of the space in south facing classroom and 0% of it in north facing classroom receives excessive amount of sunlight. According to simulations, each classroom has been divided into daylit and sunlit areas, in which students' assessments about daylight and sunlight have been separately analyzed based on their position. Comparing simulation and survey results show that while students' evaluation about daylight availability in daylit areas is mostly positive, daylight uniformity is not considered "enough" in these areas. Moreover, students' impression about daylight availability in non-daylit areas is rather neutral and more optimistic than simulation results. More interestingly, most students in both sunlit and non-sunlit areas of classrooms do not feel much direct sunlight and glare. In fact, questionnaires' results show a wider range of sunlight acceptance in south facing classroom and visual comfort in north facing classroom than simulation results. According to the results non-daylit areas or sun-lit areas defined by dynamic metrics would not necessarily cause visual discomfort, suggesting that some other factors (e.g., view, configurations of windows, expectations and region) can change the degree of comfort experienced in each space.

1. Introduction

According to the fact that pupils spend about 30% of their time in schools, there is a necessity to enhance visual comfort in such buildings [1]. Daylighting as a visual sensory element [2] of schools plays a substantial role in achieving comfort. Daylight can influence reading, task involvement, productivity [3,4], sense of wellbeing, mood and health, comfort, perceptions of space, emotions, students' experiences, and behaviors [2].

Architecturally, daylight can be defined as the way natural light and building design affect each other to achieve good comfort level in physical environments [5]. Aspects including the amount of daylight, occupants' satisfaction, and energy conservation and efficiency should be taken into account in daylight assessments. In order to assess different aspects of daylight more reliably, scholars take advantage of both static and dynamic metrics [6].

To evaluate daylight performance, static metrics have been in common for a long time [7], but they have evolved considerably in the last few years to more advanced dynamic metrics, meaning variable with time as sky conditions change [8]. The merits of dynamic metrics over conventional, static daylight performance metrics have been explored in several studies [8–14]. In fact, one moment cannot quite represent daylight quality of a physical environment since daylight varies as sun moves, and seasons and weather conditions change [12]. Unlike dynamic metrics, static

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metrics do not take into account variations of daylight with daily and seasonal changes [9,10], and they usually do not account for occupants comfort [11]. By considering different sky conditions, dynamic metrics, so called "climate-based metrics", adopt a more comprehensive approach to analyze daylighting within a space [10,11]. In fact, they thoroughly evaluate daylighting based on buildings' location, orientation and occupation [13].

Standards which have adopted and published static metrics clearly show that these metrics do not consider all the factors which are influential on daylight level. Limits prescribed by standards are not reliable [15] and for instance, British Standards Codes of Practice, 1945, suggested 2–5% daylight factor in classrooms [16] or IES (Illuminating Engineering Society of North America) lighting code, 1955, specified that daylight level (lux) and DF (%) in classrooms should be more than 100 lx and 2%, respectively [17]. Moreover, a minimum of 300 lx has been recommended by CIBS lighting code 1977, CIBSE (Charted Institute of Building Science Engineering) code for interior lighting 1984, CIBSE code for interior lighting 1994, in classrooms, respectively [18–20]. Guidelines for environmental design 1997 recommended that a daylit classroom is supposed to reach an average DF of 4–5% and gain no less than 300 lx on the working plan [21].

In 2012 Illuminating Engineering Society of North America, IES, LM-83 has introduced two dynamic metrics in IES publication LM-831: spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) [22]. By evaluating daylight within a space for a whole year, these two metrics give us a deep insight of daylight performance [23].

Spatial daylight autonomy (sDA) describes how much of a space gains acceptable level of daylight. Specifically, it determines the percentage of floor area that takes at least 300 lx for at least 50% of the annual occupied hours [23–29]. Spatial Daylight Autonomy is a comprehensive performance metric that combines time and space, and is understood better by students [27].

Since Spatial Daylight Autonomy does not specify an upper limit on daylight level, ASE has been introduced to determine how much of space is exposed to too much direct sunlight [23], and is likely to become a source of visual discomfort or glare. It is defined as the percentage of analyzed area that receives a specified direct sunlight illuminance level (1000 lx) for more than a specified number of hours (250 h.) [23,26,30].

After being validated in some research projects, these metrics have been adopted by various building performance standards such as LEED (Leadership in Energy and Environmental Design) 2013 [28]. LEED Simulation-based Daylight Credit Compliance (2013) requires Spatial Daylight Autonomy ($sDA_{300lx,50\%}$) in more than 55% and 75% of the occupied time with Annual Sunlight Exposure (ASE1000lx, 250 h.) below 10% in all regularly occupied floor areas to achieve 2 and 3 points, respectively [22,23]. According to IES LM-83-12, when $Sda_{300,50\%} \geq 55\%$ the space is considered "neutral" or "nominally acceptable" and when $sDA_{300,50\%} \geq 75\%$ the space is considered "preferred" [31].

The reliability of dynamic metrics have been discussed in several papers [8–12] as dynamic simulations analyze daylighting conditions within a space annually and take into account occupation period. Dynamic metrics' appropriateness for architectural and urban design applications have also been verified by many papers [11,12,23,25,26,29], since they give the designer the opportunity to deal with daylighting with an annual perspective [12] and to modify and develop their designs based on performance data [11].

A few researches have tried to validate dynamic daylight simulations against subjective measurements or to find a meaningful correlation between simualtion results and users' responese. The research by Reinhart, C.F. and D.A. Weissman [6] tested current and emerging daylight metrics in a studio space in Cambridge, USA. Results show that that dynamic metric "Spatial Daylight Autonomy" portrayed students' assessment about daylight in the studio more reliably than other metrics. However, authors have suggested that the results need to be tested and evaulated in other spaces. Another reserarch [7], has carried out simulations at eleven schools, located in Brazil (2), Canada(1), Egypt(1), and the United States (7), and has comapred results with students' assessment. It shows that the satisfying correlation between daylight autonomy-based simulations and students' evaluation supports the adoption of dynamic metrics by both architects and standards. In both of these studies, students were asked to divide the space into a "daylit" and "non-daylit" area. By daylit, authors mean an area in which daylight level is "adequate, useful and balanced" for most of the year. Moreover, the paper by [9] has promoted the application of dynamic daylight metrics for sustainable building design, and has demonstrated the benefit of dynamic metrics on design decisions.

Literature review reveals that research on the evaluation of students' visual comfort in daylit and sunlit areas, using dynamic metrics has not matured yet, and more examination and studies are required, especially in regions with abundant amount of daylight and sunlight.

The aim of this paper is to assess students' perceptions about visual comfort during a whole year in daylit, non-daylit, sunlit and non-sunlit areas of classrooms. These areas are specified and defined according to dynamic metrics which have been calculated in two different oriented classrooms by onsite measurements and simulations. In addition, field study allowed authors to compare the daylight availability and the potential risk of direct sunlight, derived from subjective measurements in the mentioned classrooms.

2. Methodology

The methodology implemented in this paper has been focused on two successive stages: first, measured and simulated illuminances, and second, students' assessments about visual comfort in classrooms.

2.1. Location, building and participants

2.1.1. Location

A typical school was chosen in Kashan, Iran (33° 58′ 59″ N/51° 25′ 56″ E), characterized by clear-sky conditions and good daylighting potential due to its low latitude and geographical condition. Kashan climate is classified as BWh by the Köppen-Geiger system, with desert climate and virtually no rainfall during the year. According to Kashan Weather Station, the sky of Kashan is 67% clear, 24% partly-cloudy and 9% cloudy during a year [32].

2.1.2. Building

The school building is selected since it has been designed as a prototype high school building in accordance to the local building code to minimize the energy consumption while improving the thermal and visual comfort for the hot and dry climate of the Iran. The school building is located around a central courtyard area, with eight classrooms. As shown in Fig. 1, the north and south rows of classroom overlook the central courtyard, inclined 25° toward west. All classrooms are same in size and capacity (Fig. 2). To deeply assess the visual comfort over a year the sample size has been limited to two classrooms, one from each side of the building. The floor area of each class is 48.9 m2, 7.8 m wide by 6.4 m deep and 3 m high. Each classroom is day-lit through 4 double glazed windows (4 mm clear glass/20 mm air/6 mm clear glass) (Table 3) with the 0.15 m height windowsills, 0.5 m width, and 2.3 m height, without external shadings.

Table 1
a sample of the questionnaire.

General information	age date and time	Location on the plan		Length of occupancy	
sDA	1. Daylight availability on the desk				
	little	not enough	average	enough	much
	2. Daylight distribution in the space				
	little	not enough	average	enough	much
View	3. Amount of view through windows				
	Total inadequate	inadequate	average	adequate	totally adequate
	4. Quality of view through windows				
		unpleasant	neither pleasant nor unpleasant	pleasant	very pleasant
ASE	5. Is sun shining directly on your body or into your eyes? Yes NO				
	6. The sun in this class is. . . . . . if any.				
	very unpleasant	unpleasant	neither pleasant nor unpleasant	pleasant	very pleasant
	7. Please mark the degree of glare that you may experience when doing visual tasks on desks or whiteboards:				
	Intolerable glare	Uncomfortable glare	average	Just acceptable glare	No glare
Overall assessment	8. Please specify your overall assessment of visual comfort in this classroom:				
	disturbing discomfort	perceptible discomfort	neither comfortable nor discomfort	comfortable	Totally comfortable
Students' behavior	9. Please indicate how you behave in case of excessive sunlight?				
	I draw the curtains		I change my seat	I take no action	

Fig. 1. Left, school's orientation.

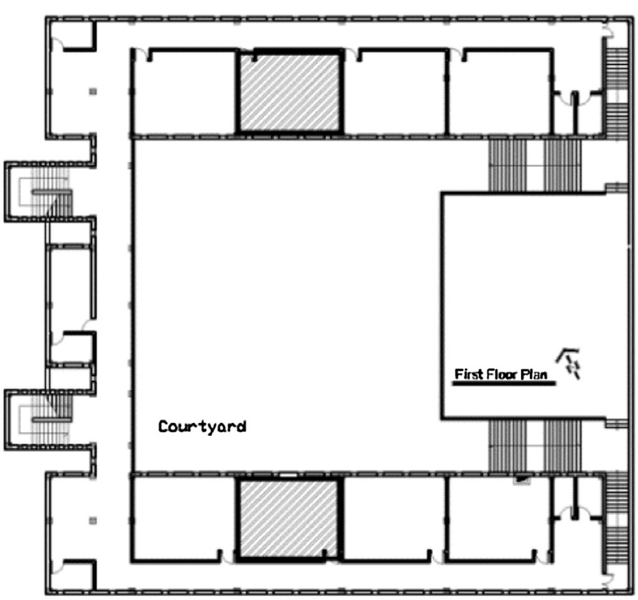


Fig. 2. Right, studied classrooms in first floor of the school.

2.1.3. Participants

Authors targeted 15 years old high school students who majored in mathematics. There were a total of 60 female participants, 27 students occupying the north facing classroom and 33 students occupying the south facing classroom. The classrooms are occupied from 8:00 to 14:00, Saturday to Thursday, from September 25 to June 18, 202 school days (formal school days in Iran); the occupied hours in a standard year are 6 × 202 = 1212.

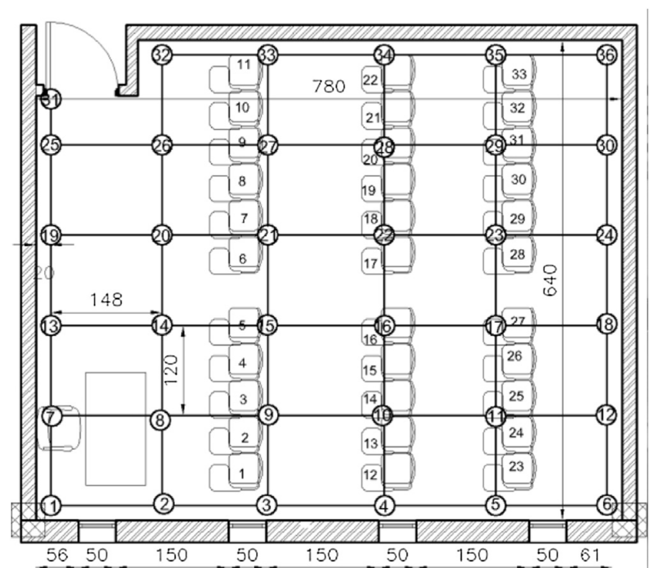


Fig. 3. Left, grid of (1.2 × 1.4 m) 36 points in south facing classroom.

2.2. Data collection

2.2.1. Physical measurements

Several studies have confirmed the validity of Radiance among which [9,33–35] are worth noting. As a result, field measurements have just been done to make the simulations of calculated dynamic metrics more reliable. Measurements were done at three sunny days from 8 to 14, October 15, 2014, January 15, and April 15, 2015. During a pilot study which was done in October, Illuminance levels were taken at a grid size suggested by IES LM 83–2012. Since no tangible differences were recorded for close points, illuminance levels were taken at a total of 36 points, grid of (1.2 × 1.4 m), at the height of 0.80 m every one hour (Fig. 3). Increasing the distance between the points helped to collect data while distributing questionnaires.

To achieve more reliable results, the lights were turned off and the curtains were drawn back (Fig. 4). Measurements were pro-

Table 2
lists the RADIANCE simulation parameters that were applied for simulation.

Annual Metrics	RADIANCE simulation parameters				
	ab	ad	as	aa	ar
SDA	6	1500	20	0.1	100
ASE	0	1500	20	0.1	100

Fig. 4. Right, studied north facing classroom in first floor of the school.

Table 3
Model optical surface properties.

Building element	Surface optical properties
Window	–Visible Transmission (VT): Center of glass (0.78) Whole window (0.66) –Solar Heat Gain Coefficient (SHGC): Center of glass (0.86) Whole window (0.76)
Ceiling	85% reflectance
Internal wall	70% reflectance
floor	50% reflectance
furniture	50% reflectance
External Wall	45% reflectance
External ground	Asphalt, 7% reflectance

duced using MLX-722 LUX meter with the accuracy of $\pm 5\% \pm 10$d (<10,000 lx). All equipment was calibrated before each experiment to ensure reliability and accuracy of the data recorded during the field studies. Moreover, to provide optical properties of all surfaces and glazing for simulations, the authors approximated the reflectance of surfaces with two Lux meters. One of them faces toward the surface and the other faces away from the surface. As a result, the reflectivity of the surface can be approximated according to the light absorbed by the surface and the reflected light.

2.2.2. Questionnaire survey

Daylight evaluation through both simulation and questionnaire survey has been accomplished in previous studies [36]. Moreover, daylight and sunlight quality has already been assessed by questionnaire survey and static metrics in different papers [3,4,36–39]. In the current study, using a longitudinal study approach, authors used a questionnaire in accordance with dynamic metrics to assess the visual comfort of a relatively small number of subjects over different times through the year. This approach could provide information that is not possible to acquire through the conventional transverse survey. To define the study population among the eight classrooms, which are all the same in number of Students, age range and occupation time, two class rooms, one in each side, are selected. To deeply assess the visual comfort of students, all the student in the selected classrooms are surveyed.

Prior to the full scale survey, a group of 10 students were randomly chosen from each class to answer a 7-point scale questionnaire in four days of a sunny week in October at 9, 11 a.m. and 13 p.m. Based on students' feedback, opinion and understanding, the questionnaire was time-consuming, confusing, and beyond their attention span. Accordingly, the questionnaire changed to a 5-point scale one, with fewer and more classified questions, resulting in acceptable feedback in its second edition. Results from the second edition of the survey showed no significant change in each student's vote during study, showing the validity of the questionnaire. Authors have referred to [3,4,36–39] to devise an appropriate questionnaire.

In terms of responsible supervision, the objectives of the study and how the students' responses could help researchers achieve them, was explained before passing out the questionnaire. Also, technical terms such as glare were explained to the participants.

The questionnaires survey was carried out throughout the whole school year, in three seasons, from 15th to 21st of October, November, January, February 2014 and April 2015, three times a day at 9:00, 11:00 am, and 1:00 pm Students' visual comfort has not been studied in some months including July, August, September which are Summer Holidays, March which coincides with New Year Holidays, and May-June which is students' exam time.

The English translation of the questionnaire has been presented in Table 1. The survey includes different aspects that can be classified as below:

- General information (age, date, seat number, etc.)
- Students' impression about daylight availability and uniformity (SDA-related questions)
- Students' impression about view
- Students' impression about sunlight (ASE-related questions)
- Students' overall assessment
- Students' behavior toward visual discomfort

Each Students' situation was fixed in the classrooms, so they were given a seat number to be written in the questionnaire form. Students ranked their comfort using Likert spectrum.

2.2.3. Daylight simulation

Since field measuring of daylight levels throughout the whole year is cost-prohibitive and time-consuming, authors rely on simulation results to analyze daylight availability in these classrooms. The 3D models were created in Rhinoceros 3D with approximate resemblance to the real condition, and simulations were run using Radiance through the DIVA version 3 interface. DIVA, which stands for Design Iterate Validate Adapt, is an environmental analysis plugin for the Rhinoceros 3D [40]. The DIVA environment supports a series of performance evaluations by using validated tools including Radiance [41].

A grid of sensors (0.64×0.65 m) was arrayed in the spaces to capture variations in daylight levels. Table 2 lists the Radiance simulation parameters that were set for the sDA and ASE according to IES regulations [17] i.e., ambient bounces (ab), ambient divisions (ad), ambient sampling (as), ambient accuracy (aa), and ambient resolution (ar). Furthermore, the surfaces optical properties are presented in Table 3. According to observations in the classrooms the curtains were not drawn most of the time so authors restricted to consider internal shadings.

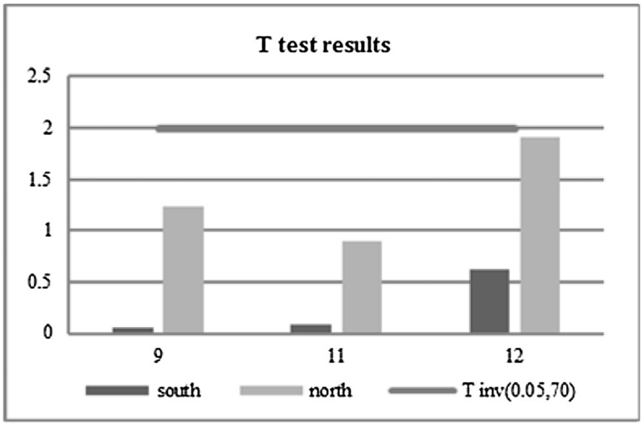


Fig. 5. The result of two tailed test.

According to the definitions of metrics by LEED, simulations are run for the whole year from 8 am. to 18 pm., but authors have removed unoccupied days and hours to provide more reliable data. Accordingly point-in-time illuminance simulation results were sorted in excels sheets, and occupied hours were analyzed by filtering data. Using point-in time illuminance simulation results has provided the possibility to calculate dynamic metrics based on the occupied time.

3. Results

3.1. Simulation verification

The comparison between measured days and simulated results shows that mean bias error lies in the acceptable limit which verifies simulations with measurements. For instance, Table 4 shows mean bias error for north and south facing classrooms on April 20th from 8:00 am to 2:00 pm Also a series of two tailed test confirms the results, as shown in Fig. 5. Using a significance level of 0.05 ($Z = \pm 1.96$, T inv = 1.9944), all the results are below critical value, shows that there is no significance difference between the results from simulation and measurements.

3.1.1. Calculated dynamic metrics

Table 5 shows the percentage (%) of *occupied hours* ($6 \times 202 = 1212$) which receive ≥300 lx and the number of *occupied hours* which receive ≥1000 lx. On the other hand, Table 6 shows the percentage of the hours (%) which receive ≥300 lx and the number of hours which receive ≥1000 lx *from 8 to 18 throughout the whole year* ($10 \times 365 = 3650$). To measure $SDA_{300/50}$, at least 606 h (50% of 1212 h) of each specific point should receive ≥300 lx, and to measure ASE $_{1000lx,250h}$, at least 250 h of each point should receive ≥1000 lx. Table 4 lists points and the percentage of occupied hours which meets above criterion. As can be seen in Table 5, SDA 300/50% equals 20% and 71%, and ASE (1000, 250) equals 0% and 29% for north facing and south facing classrooms, respectively.

Considering the whole year (8–18), a total of 3650 h ($10 \times 365 = 3650$) are sorted and their percentages of hours (%) which receive ≥300 lx are presented in Table 6. These metrics have been calculated to be compared with the metrics defined by authors. As can be seen in Table 6, SDA 300/50% equals 20.8% and 44%, and ASE (1000, 250) equals 0% and 43% for north facing and south facing classrooms, respectively.

In Table 5, points receiving "adequate" amount of daylight, 300 lx for at least 702 h, and "excessive" amount of sunlight, 1000 lx for at least 250 h, can be observed, according to which daylit and sunlit boundaries can be drawn. In this paper, the area which receives excessive amount of sunlight is called sunlit. Daylit and sunlit areas, simulation grid, and students' seat numbers in north and south facing classrooms can be seen in Figs. 6 and 7.

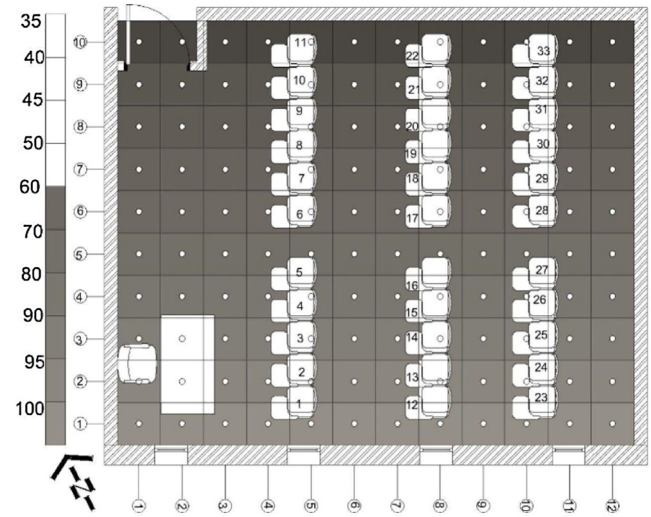


Fig. 6. shows simulation grid and students' seat numbers in south facing classroom.

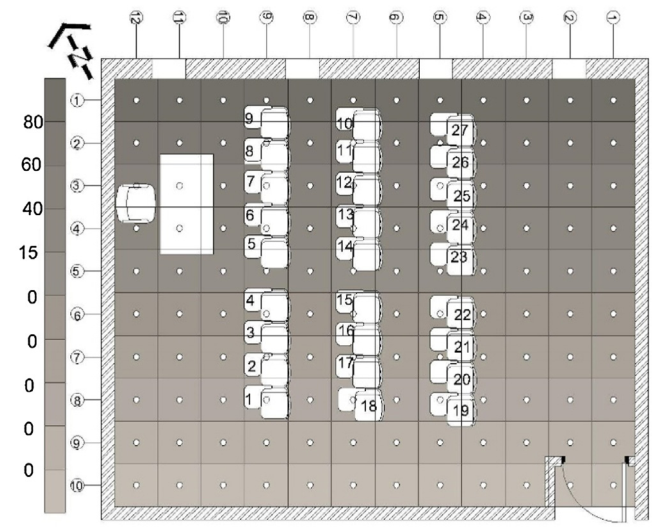


Fig. 7. shows simulation grid and students' seat numbers in north facing classroom.

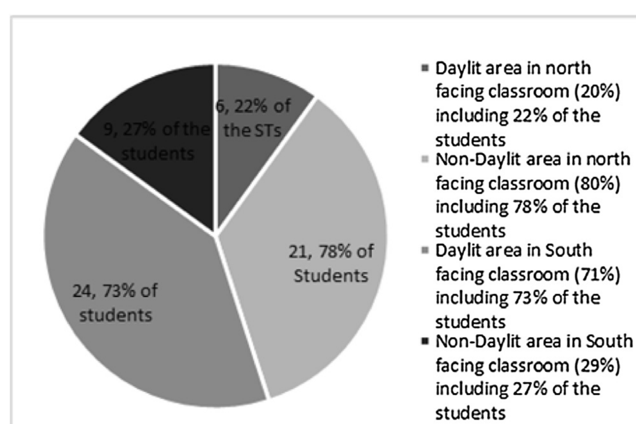


Fig. 8. Number of students in daylit and non-daylit areas.

Table 4
shows mean bias error for north and south facing classroom from 8:00 a.m. to 2:00 p.m.

Mean bias error for different hours in classrooms	Mean bias error						
	8:00 a.m.	9:00 a.m.	10:00 a.m.	11:00 a.m.	12:00 a.m.	1:00 p.m.	2:00 p.m.
South facing classroom	+0.10	+0.10	+0.07	+0.07	+0.09	+0.08	+0.09
North facing classroom	+0.08	+0.09	+0.05	0.00	+0.04	+0.04	+0.09

Table 5
Calculating SDA and ASE for occupied hours.

points	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
	South facing Classroom, the percentage of occupied hours (%) which receive ≥300 lx										North facing Classroom, the percentage of occupied hours (%) which receive ≥300 lx									
1	98	95	88	77	67	57	52	46	41	33	94	80	46	15	2	0	0	0	0	0
2	96	94	89	80	65	59	52	50	40	39	88	73	45	20	3	0	0	0	0	0
3	94	94	91	81	72	60	56	48	44	43	63	62	45	23	2	1	0	0	0	0
4	98	95	90	83	75	62	55	49	43	38	92	79	45	29	3	1	0	0	0	0
5	96	94	89	83	71	65	54	49	46	45	93	72	35	20	3	0	0	0	0	0
6	92	94	87	81	74	66	58	48	46	46	67	62	30	15	4	0	0	0	0	0
7	97	94	88	81	69	67	54	48	45	42	85	60	39	11	3	1	0	0	0	0
8	97	94	89	75	67	62	55	50	43	42	94	76	45	20	1	0	0	0	0	0
9	93	94	90	81	64	64	58	49	45	41	73	64	46	19	0	0	0	0	0	0
10	95	94	88	76	68	58	54	45	46	35	73	65	40	23	0	0	0	0	0	0
11	98	93	86	80	65	59	53	46	37	34	94	70	31	11	0	0	0	0	0	0
12	93	89	84	73	65	58	47	45	34	32	84	63	29	6	0	0	0	0	0	0
SDA 300/50%	SDA 300/50% = 71% South facing Classroom, the number of occupied hours which receive ≥1000 lx										SDA 300/50% = 20% North facing Classroom, the number of occupied hours which receive ≥1000 lx									
1	506	387	306	67	231	20	18	0	15	0	0	0	0	0	0	0	0	0	0	0
2	443	291	276	90	275	0	61	76	0	0	0	0	0	0	0	0	0	0	0	0
3	299	421	185	149	61	147	0	0	3	0	0	0	0	0	0	0	0	0	0	0
4	494	345	285	126	230	67	3	3	0	0	0	0	0	0	0	0	0	0	0	0
5	452	365	326	234	275	3	0	61	0	0	0	0	0	0	0	0	0	0	0	0
6	339	337	305	258	61	61	185	0	3	3	0	0	0	0	0	0	0	0	0	0
7	436	408	311	59	214	215	0	3	0	0	0	0	0	0	0	0	0	0	0	0
8	530	333	306	147	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	323	351	344	185	178	61	61	61	0	0	0	0	0	0	0	0	0	0	0	0
10	466	487	263	134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	506	404	229	67	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	477	206	142	70	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASE (1000,250)	ASE = 29%										ASE = 0%									

3.2. Questionnaire results

The data collected from questionnaires have been categorized in north and south face class, presented in different seasons, in Figs. 8–17 . In order to investigate whether there are any significant differences between the means of the groups in these classes or not, the analysis of variance (ANOVA) and t- test have been done for questions 1–8 which shows a significant difference between those classes in questions regarding "the presence of direct sunlight", "the pleasantness of sunlight" and "degree of glare" and the through the school year. Results show that questions 1,2, 6 and 7 have been answered in a resembling variances, and there is not a significant difference in the above mentioned topic occupant's assessment, as the $F(2,9)$, $p < 0.05$ is totally less than the F critical (4.6) in each case as presented in Table 7.

According to Figs. 6 and 7, 6 out of 27 students (22%) in north facing classroom and 24 out of 33 students (72%) in south facing classroom are seated in day-lit areas. According to the definition of sDA, a daylit area receives at least 300 lx for at least 50% of the annual occupied hours. Therefore, all students in at least 50% of the occupied time are expected to feel enough or much daylight in daylit areas. Since we are analyzing the whole occupied time and not 50% of it, at least 50% of the students are expected to have a positive impression about daylight availability in this area for the entire year. Moreover, 9 out of 33 (27.2%) students in south facing classroom and 0 out of 27 (0%) students in north facing classroom are seated in sunlit areas. A sunlit area receives at least 1000 lx for at least 250 h. As a result, students are expected to feel glare, direct, or unpleasant sunlight in sunlit areas for at least 250 h which is 20.6% of the occupied time (250 of 1212 h). In other words, at least 20.6% of the students are expected to feel annoying or intolerable glare, direct or unpleasant sunlight in this area. According to the explanations, questionnaires' results have been classified and analyzed based on students' seats number and their position in daylit or sunlit areas. As students were asked to write down their seat number, analyzing data based on their position in daylit or non-daylit areas has become possible. As can be seen in Table 5 and Figs. 6 and 7, seat numbers 1–8, 12–19, 23–30 in south facing classroom and seat numbers 8–11, 26–27 in north facing classroom are in daylit areas. Moreover, seat numbers 1–3, 12–14 and 23–25 in south facing classroom place in sunlit area of south facing classroom (Table 5, Fig. 6), while no students seats in sunlit area of north facing classroom (Table 5, Fig. 7). To see the number of students in each area, below Figs (Figs. 8 and 9) are presented.

To assess the effect of seasonal variation on students' impressions, votes are grouped based on the season, i.e. autumn, winter and spring (Fig. 10). To have students' overall impression (positive, neutral or negative) about the space during a whole year, authors have calculated the average of votes in each season for the same student. Averaging seems quite a reasonable method since authors witnessed no significant changes in the answers collected from each studied season.

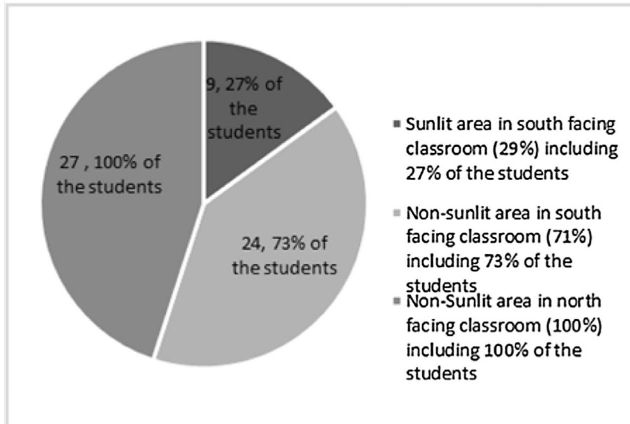
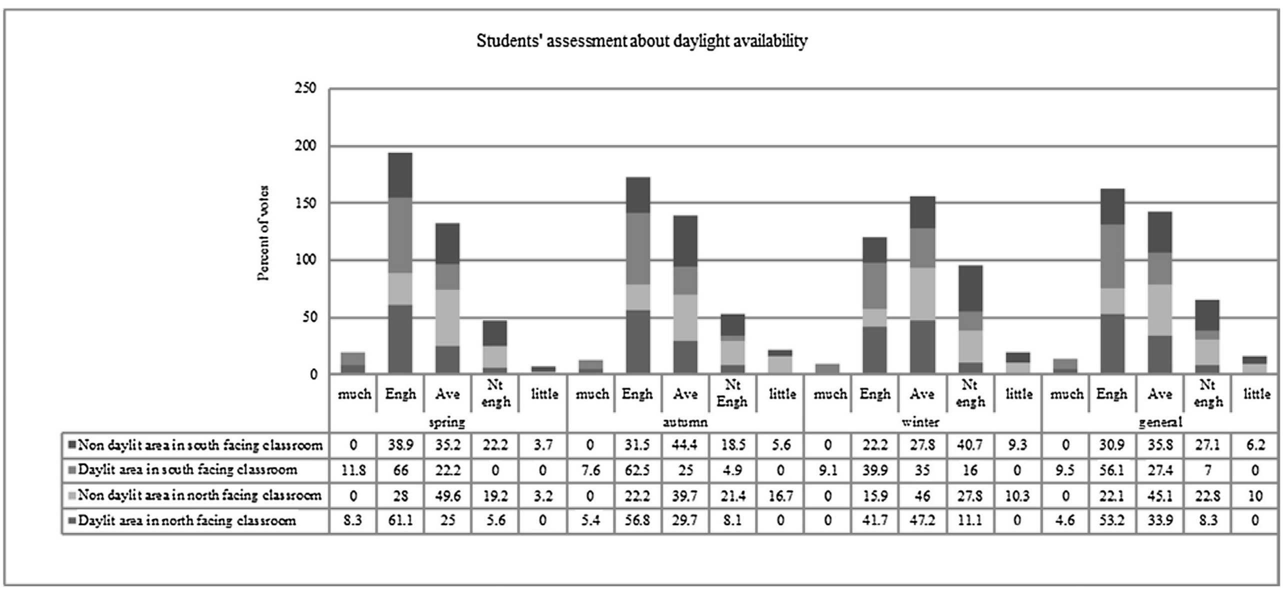
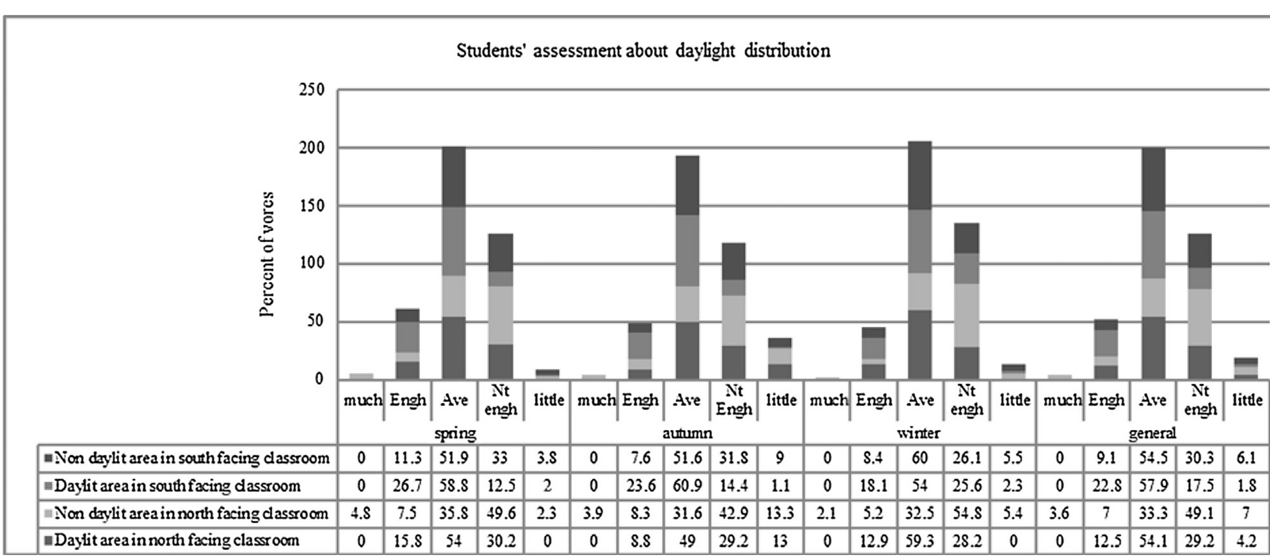


Fig. 9. Number of students in sunlit and non-sunlit areas.



	spring					autumn					winter					general				
	much	Engh	Ave	Nt engh	little	much	Engh	Ave	Nt Engh	little	much	Engh	Ave	Nt engh	little	much	Engh	Ave	Nt engh	little
Non daylit area in south facing classroom	0	38.9	35.2	22.2	3.7	0	31.5	44.4	18.5	5.6	0	22.2	27.8	40.7	9.3	0	30.9	35.8	27.1	6.2
Daylit area in south facing classroom	11.8	66	22.2	0	0	7.6	62.5	25	4.9	0	9.1	39.9	35	16	0	9.5	56.1	27.4	7	0
Non daylit area in north facing classroom	0	28	49.6	19.2	3.2	0	22.2	39.7	21.4	16.7	0	15.9	46	27.8	10.3	0	22.1	45.1	22.8	10
Daylit area in north facing classroom	8.3	61.1	25	5.6	0	5.4	56.8	29.7	8.1	0	0	41.7	47.2	11.1	0	4.6	53.2	33.9	8.3	0

Fig. 10. Percent of votes about daylight availability in the classrooms, comparing north and south facing classrooms.



	spring					autumn					winter					general				
	much	Engh	Ave	Nt engh	little	much	Engh	Ave	Nt Engh	little	much	Engh	Ave	Nt engh	little	much	Engh	Ave	Nt engh	little
Non daylit area in south facing classroom	0	11.3	51.9	33	3.8	0	7.6	51.6	31.8	9	0	8.4	60	26.1	5.5	0	9.1	54.5	30.3	6.1
Daylit area in south facing classroom	0	26.7	58.8	12.5	2	0	23.6	60.9	14.4	1.1	0	18.1	54	25.6	2.3	0	22.8	57.9	17.5	1.8
Non daylit area in north facing classroom	4.8	7.5	35.8	49.6	2.3	3.9	8.3	31.6	42.9	13.3	2.1	5.2	32.5	54.8	5.4	3.6	7	33.3	49.1	7
Daylit area in north facing classroom	0	15.8	54	30.2	0	0	8.8	49	29.2	13	0	12.9	59.3	28.2	0	0	12.5	54.1	29.2	4.2

Fig. 11. Percent of votes about daylight distribution, comparing north and south facing.

Table 6
Calculating SDA and ASE for the whole year (8–18).

points	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
	South facing Classroom, the percentage of hours (%) which receive ≥300 lx from 8–18 throughout the whole year										North facing Classroom, the percentage of hours (%) which receive ≥300 lx from 8–18 throughout the whole year									
1	81	72	62	55	48	42	39	34	31	26	84	75	50	23	8	4	2	2	1	1
2	78	72	63	57	47	43	39	38	30	30	79	71	49	26	8	4	4	2	2	1
3	74	72	65	57	52	43	41	36	33	33	64	63	48	28	7	6	3	2	1	1
4	79	74	65	58	53	45	41	37	33	29	82	74	47	33	7	6	3	2	1	1
5	79	74	64	59	51	47	40	37	35	35	82	70	38	23	8	4	2	1	1	1
6	73	73	64	57	53	48	42	36	36	35	67	63	32	19	8	3	2	1	1	1
7	76	71	65	57	50	48	41	37	35	33	78	60	40	15	7	5	2	1	1	1
8	80	73	66	54	48	46	41	38	33	32	83	71	45	23	5	2	2	1	1	0
9	75	73	67	58	46	47	44	37	35	31	69	63	46	21	3	2	1	1	0	0
10	74	73	65	55	49	43	41	35	35	27	71	63	40	24	2	1	1	0	0	0
11	81	74	65	59	47	43	40	35	29	27	83	65	31	12	2	1	1	0	0	0
12	77	71	64	54	48	43	36	34	27	26	74	57	27	8	1	0	0	0	0	0
SDA 300/50%	SDA $_{300/50\%}$ = 44% South facing Classroom, the number of hours which receive ≥1000 lx from 8–18 throughout the whole year										SDA $_{300/50\%}$ = 20.8% North facing Classroom, the number of hours which receive ≥1000 lx from 8–18 throughout the whole year									
1	1127	844	656	171	508	57	45	0	32	0	38	131	126	0	0	0	33	0	0	0
2	962	629	575	232	635	0	153	185	0	0	0	82	69	0	0	33	0	0	33	0
3	636	872	412	370	153	310	0	0	21	0	132	0	0	0	33	0	0	33	0	0
4	1093	787	675	257	507	171	21	21	0	0	0	69	82	33	0	0	33	0	0	0
5	1177	812	725	516	635	21	0	153	0	0	90	82	94	0	0	33	0	0	0	0
6	727	773	672	597	153	153	427	0	21	21	137	33	0	0	33	0	0	0	0	0
7	995	915	719	86	481	482	0	21	0	0	33	71	82	33	0	0	0	0	0	0
8	1167	725	717	310	0	21	0	0	0	0	118	93	33	0	0	0	0	0	0	0
9	727	799	749	412	375	153	153	153	0	0	71	84	0	0	0	0	0	0	0	0
10	1027	1052	622	338	0	0	0	0	0	0	84	0	0	0	0	0	0	0	0	0
11	1120	928	531	171	171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1181	470	413	179	187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASE (1000,250)	ASE = 43%										ASE = 0%									

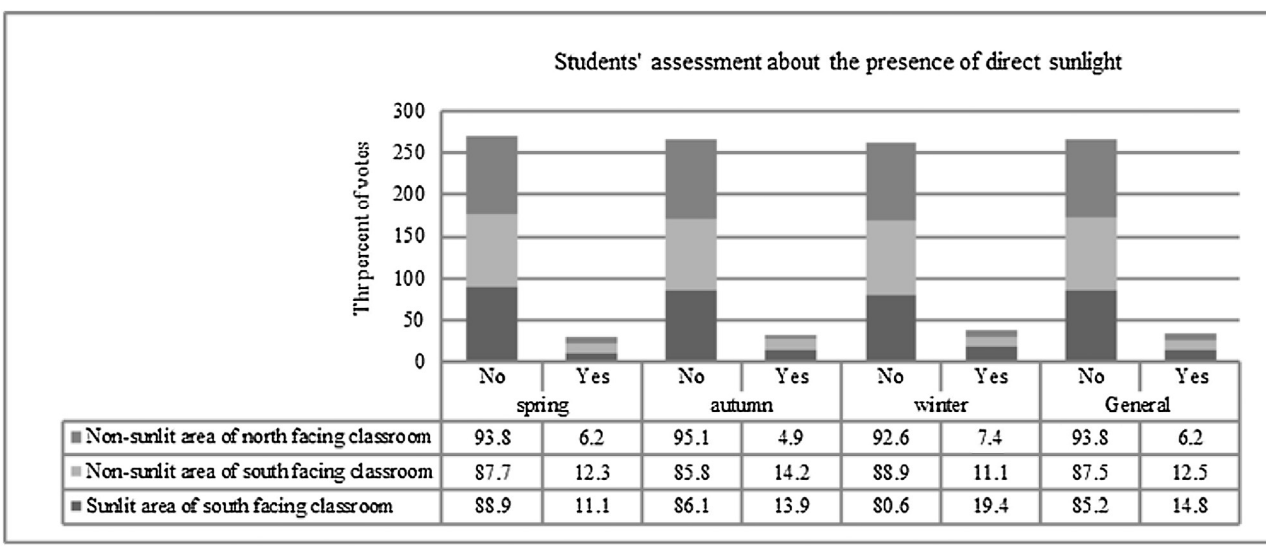


Fig. 12. percent of votes about direct sunlight in the classrooms, comparing north and south facing classrooms.

Regarding daylight availability in daylit areas, 69.4%, 62.2%, and 41.7% of the students voted for "enough" and "much" amount of daylight in north facing classroom in spring, autumn and winter, respectively (Fig. 10). In south facing classroom a more positive impression about daylight availability is dominant, with 77.8%, 70.1% and 49% of the students voting for "enough" and "much" amount of daylight in spring, autumn and winter, respectively (Fig. 10). Generally, 57.8% of the students in north facing classroom and 65.6% of the students in south facing classroom voted that daylight is "enough" and "much" in daylit areas.

Examining daylight availability in non-daylit areas, the most voted box is "average" in north facing classroom with 49.6%, 39.7% and 46% of the students in spring, autumn, and winter, respectively. Yet averagely, 22.1% of the students believe that daylight is "enough" (Fig. 10). Similarly, the most voted box in general is "average" in non-daylit area of south facing classroom with 35.8% of the votes. The percent frequency of "average" box (35.8%) is higher than "enough" (30.9%) in non daylit area of south facing classroom.

Regarding daylight distribution in daylit areas, 54%, 49% and 59.3% of the students voted for "average" in north facing classroom in spring, autumn and winter, respectively (Fig. 11), likewise most of the votes fell in "average" region of the scale in south facing classroom, with 58.8%, 60.9%, and 54% of the students in spring, autumn, and winter, respectively. Generally, 54.1% of the students

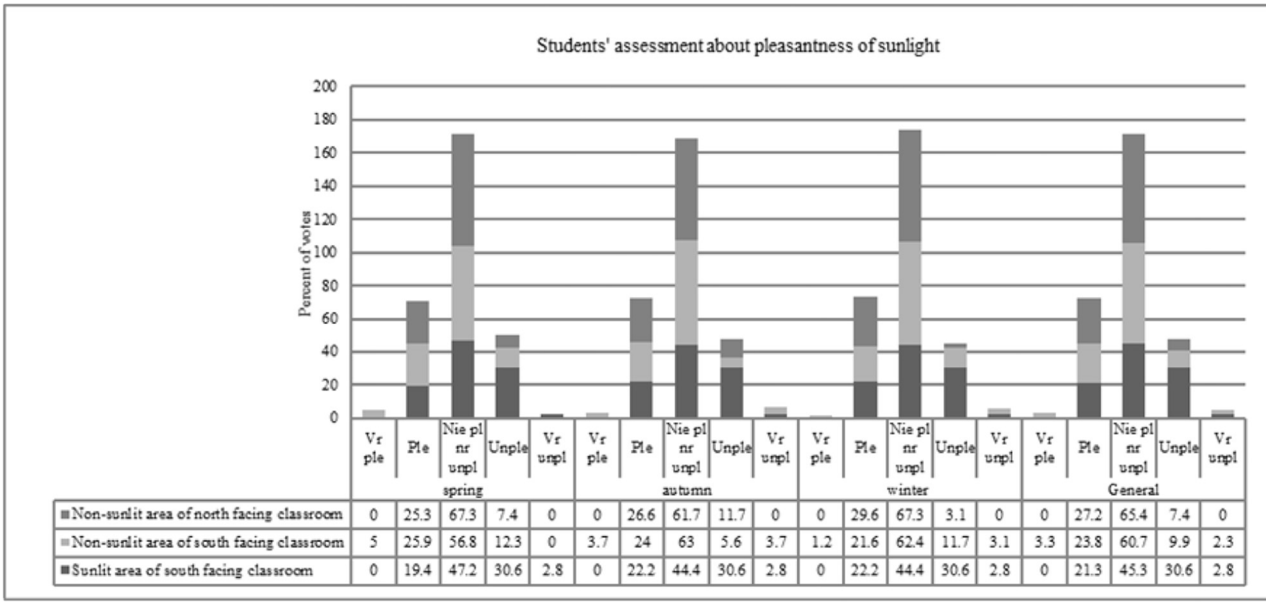


Fig. 13. percent of votes about pleasantness of sunlight, comparing north and south facing classrooms.

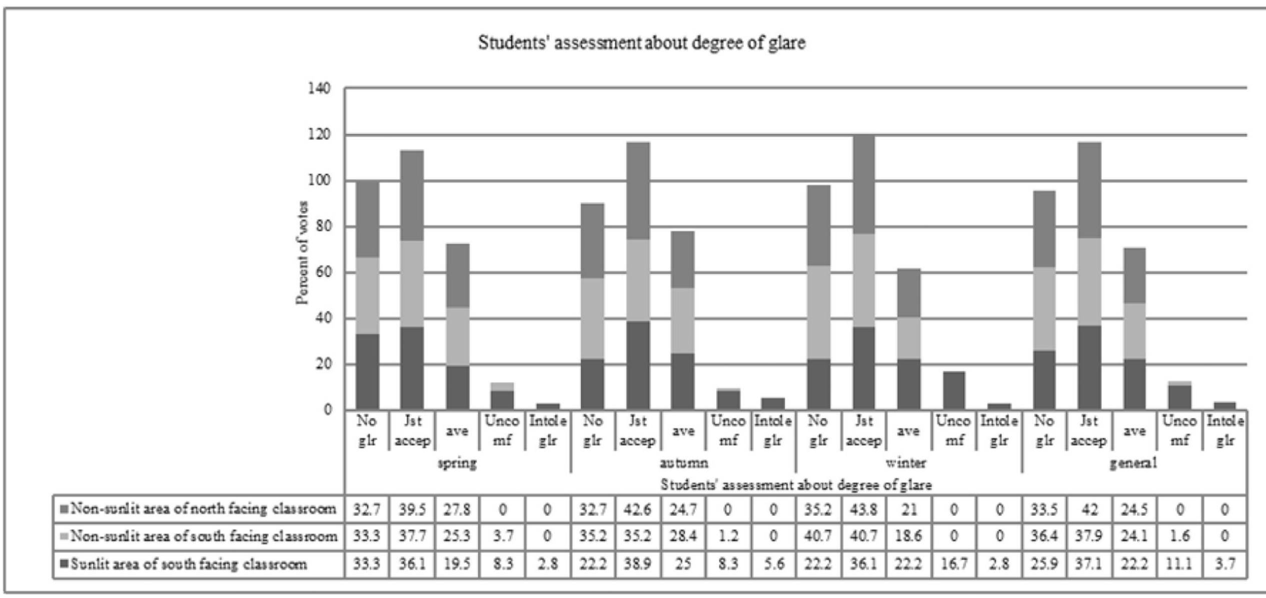


Fig. 14. percent of votes about degree of glare, comparing north and south facing classrooms.

in north facing classroom and 57.9% of the students in south facing classroom voted that daylight distribution is average in daylit areas which is the most voted box. Regarding daylight distribution in non-daylit areas, most of the votes fell in "less-than average" region of scale in north facing classroom, with 51.9%, 56.2%, and 56.1% of the students who perceive daylight "not enough" and "little" in spring, autumn, and winter, respectively. Conversely, most of the votes fell in "average" region of the scale in non-daylit area of south facing classroom; 51.9%, 51.6% and 60% of the students in spring, autumn and winter, respectively (Fig. 11). Overall, the general vote falls in "less-than-average" region of scale in non-daylit area of north facing classroom (56.1%) and "average" region of scale in non-daylit area of south facing classroom (54.5%).

As stated earlier, no student seats in the sunlit area of the north facing classroom, so authors considered the whole of north facing classroom non-daylit. As explained earlier, at least 20.6% of the students are expected to feel glare, direct or unpleasant sunlight in sunlit areas since according to the definition of ASE, a sunlit area receives at least 1000 lx for at least 250 h which is 20.6% of the occupied time. In response to the question about direct sun shining on body or into eyes, averagely, 14.8% of the students in sunlit area and 12.5% of the students in non-sunlit area of south facing classroom feel direct sunlight (Fig. 12). Moreover, in north facing classroom, more than 93% of the students do not feel any intense sunlight on their body or into their eyes. The frequency of votes at different seasons can be seen in Fig. 12.

Asking about pleasantness of sunlight if any, most subjects opted for "neither pleasant nor unpleasant" in both classrooms in different seasons, but among those who perceive direct sunlight in sunlit areas of south facing classroom, just 33.4% of them find sunlight "unpleasant" and "very unpleasant" (Fig. 13). Averagely, 45.3% of the students in sunlit area of south facing classroom, 60.7% of the

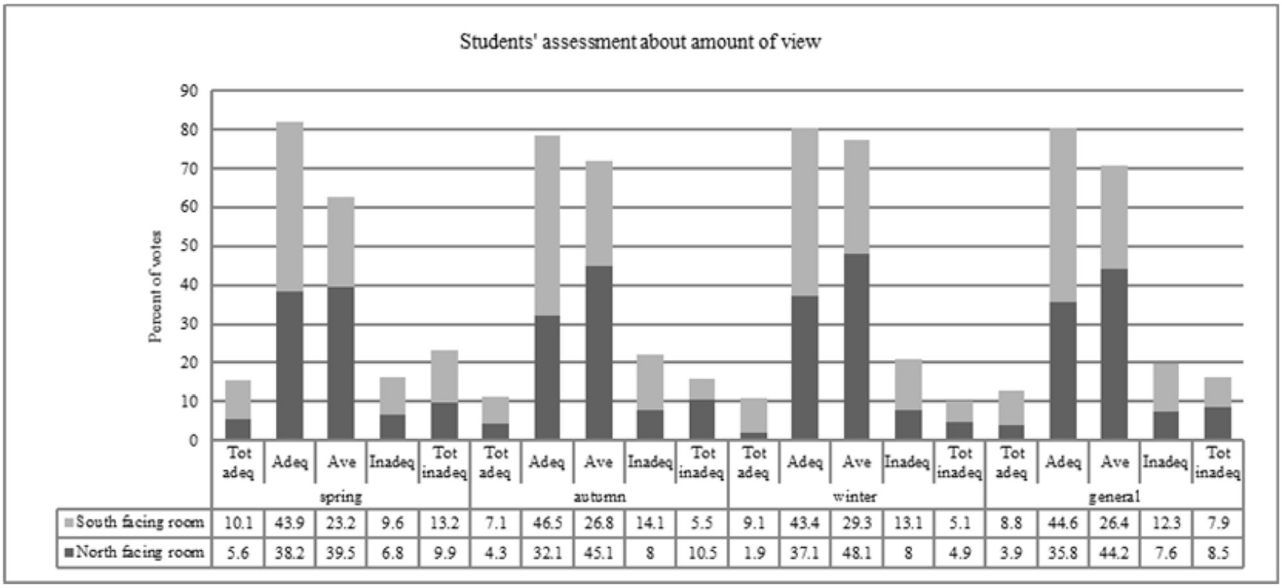


Fig. 15. percent of votes about amount of view, comparing north and south facing classrooms.

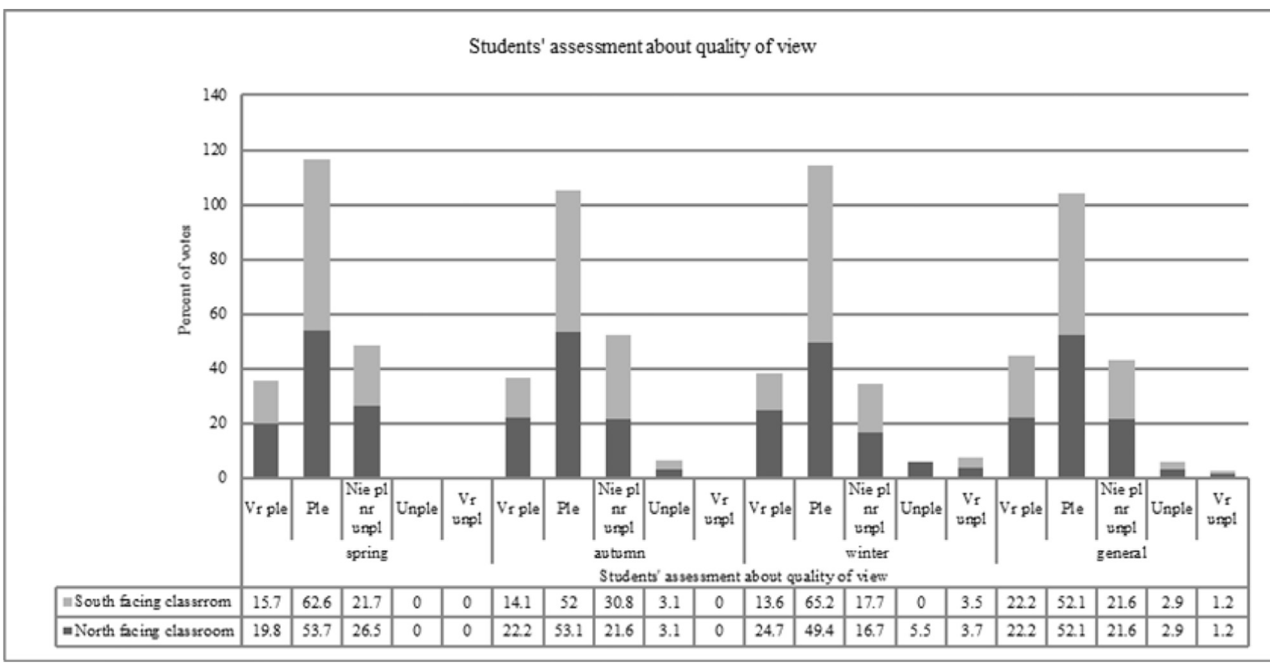


Fig. 16. percent of votes about quality of view, comparing north and south facing classrooms.

students in non-sunlit area of south facing classroom, and 65.4% of the students in non-sunlit area of north facing classroom find sunlight "neither pleasant nor unpleasant" (Fig. 13).

As can be seen in Fig. 14, the degree of glare is reported very low; 63% of the students in sunlit area of south facing classroom, 74.3% of the students in non-sunlit area of south facing classroom and 75.5% of the students in north facing classroom feel "no glare" and "just acceptable glare". Averagely, only 14.7% of the students in sunlit area of south facing classroom feel "uncomfortable glare" and "intolerable glare".

Authors have also asked about amount of view and quality of view which may be influential in students' visual comfort. Considering the highest percent frequency in general, 53.4% of the students feel that the amount of view is "adequate" and "totally adequate" in south facing classroom (Fig. 15), while 44.2% of the students voted for "average" in north facing classroom. Interestingly, students have a more positive impression about amount of view in south facing classroom.

Regarding quality of view, averagely, more than 70% of the students in both classrooms believe that outside views are "pleasant" and "very pleasant" (Fig. 16). Students' impression about quality of view in different seasons can be seen in Fig. 16.

Regarding visual comfort, 53.1%, 50% and 51.8% of the students in north facing classroom expressed their visual comfort as "neither comfortable nor dis-comfortable" in spring, autumn and winter, respectively (Fig. 17). Yet, a high percentage of students still believe that north facing classroom is visually comfortable, with 44.4%, 42.6% and 34.6% of votes in spring, autumn and winter, respectively. On the other hand, 56.5% of the students in spring, 54.5% of the students in autumn and 52.5% of them in winter find south

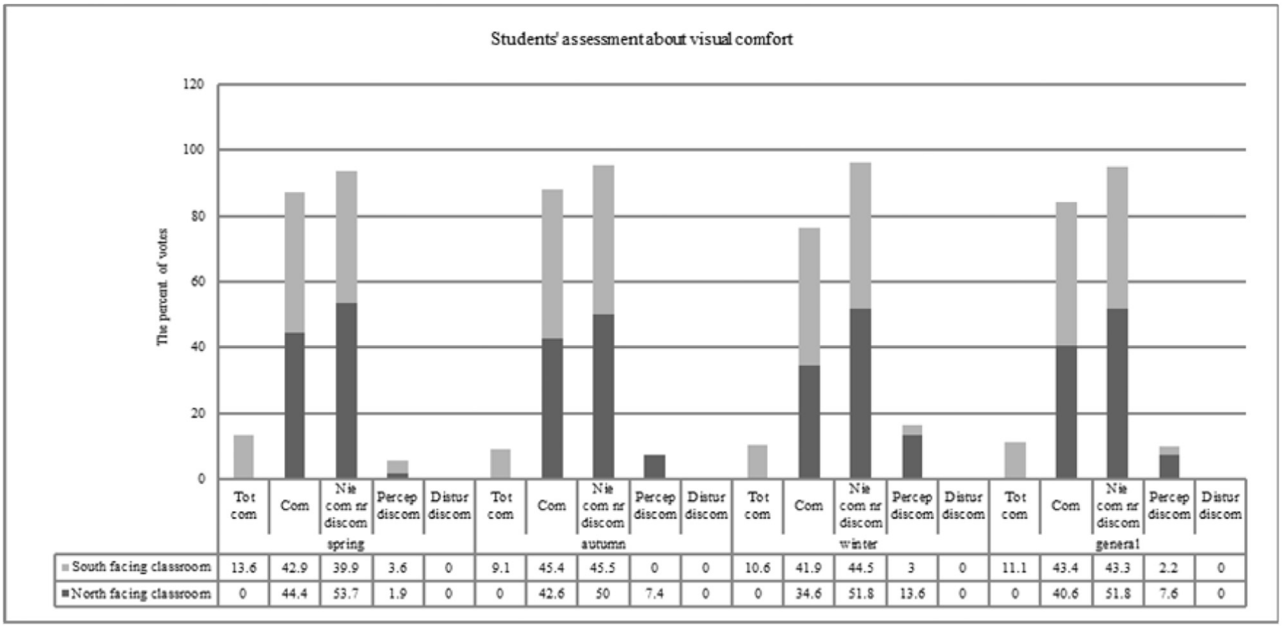


Fig. 17. percent of votes about overall assessment of visual comfort, comparing north and south facing classrooms.

Table 7
Comparison of questionnaire results in the north and south classroom.

	Questions		−2	−1	0	1	2	F
1	Students' assessment about daylight availability	North class	38	95	207	141	5	1.4033
		South Class	10	74	176	292	41	
2	Students' assessment about daylight distribution	North class	32	207	173	55	19	0.8687
		South Class	17	125	339	113	0	
3	Students' assessment about amount of view	North class	41	37	215	174	19	2.4588
		South Class	47	73	157	265	52	
4	Students' assessment about quality of view	North class	6	14	105	253	108	2.4555
		South Class	7	6	139	356	86	
5	Students' assessment about presence of direct sunlight	North class			30	456		108
		South Class			77	517		
6	Students' assessment about pleasantness of sunlight	North class	0	36	318	132	0	10.325
		South Class	14	81	344	139	16	
7	Students' assessment about degree of glare	North class	0	0	119	204	163	26.467
		South Class	4	20	141	224	205	
8	Students' assessment about visual comfort	North class	0	37	252	197	0	4.1355
		South Class	47	73	157	265	52	

facing classroom visually "comfortable" and "totally comfortable". The average of votes is also presented in Fig. 17.

One part of the questionnaire is also devoted to students' behavior in case sunlight causes discomfort. In south facing classroom, 83% of the students voted for 'drawing the curtains', 7% of the students voted for 'changing the seat' and 10% of them voted for 'no action', while in north facing classroom, 72% of the students voted for 'drawing the curtains', 18% of the students voted for 'changing the seat' and 10% of them voted for 'no action'. Consequently, most of students avoid visual discomfort by drawing the curtains.

4. Discussion

Comparing calculated dynamic metrics, in south facing classroom, 71% of the space is daylit and 29% of the space is sunlit. While the south facing classroom provides the required daylit area, fails to limit the large sunlit area. Conversely, while the north facing classroom fails to provide the required daylit area with only 20% of the daylit space, provides no sunlit area (0%). Simulation result of ASE for north facing classroom is in the acceptable range mainly due to north orientation which according to previous studies provide less intense sunlight and more uniform daylight [42,43]. Comparing simulation results when considering occupied time or the whole year shows a noticeable difference in the amount of annual metrics in south facing classroom where sDA decreases to 44% and ASE increases to 43%. Generally, daylight performance has decreased significantly when considering the whole year (from 8:00 to18:00 and without removing holidays). In the following, it is possible to find out students' impression about visual comfort in different areas of classrooms. While assessing questionnaire results in different areas defined by dynamic metrics and simulation results, students' general impression about north and south facing classrooms has been compared.

Considering the first two questions which are related to sDA in daylit or non-daylit areas shows students' feeling about daylight availability and daylight distribution. More than 50% of the students in daylit areas of north and south facing classrooms feel that daylight is "enough" and "much". In other words, the results related to daylight availability are in complete agreement with the definition prescribed for sDA and simulation results. In other words, daylight is perceived enough and much more than 50% time in daylit areas.

Interestingly, daylight level is perceived higher in both daylit and non-daylit areas of south facing classroom than of north facing one, meaning higher percentage of students have a positive impression ("enough" or "much") about daylight availability in the south facing classroom than in north facing one (65.6% of the students in daylit area of south facing classroom versus 57.8% of the students in daylit area of the north facing classroom and 33.3% of the students in non-daylit area of the south facing classroom versus 22% of the students in non-daylit area of north facing classroom). It implies that higher levels of daylight and sunlight in the south facing classroom affect students' perception about daylight availability.

To assess daylight uniformity in daylit areas, students were asked to express their feeling about daylight distribution. Although students' impression about "daylight availability" is positive in daylit areas, the highest voted option is "average" not "enough" in both classrooms. Authors believe that students assess daylight uniformity by considering the whole class; unlike "daylight availability" it cannot be judged by only considering ones' desk. Since only 20% and 71% of the classrooms are daylit, it is natural that students do not feel enough uniformity. Consequently, according to results, daylit areas do not guarantee enough uniformity but enough daylight availability. As it was expected, higher percentage of students in south facing classroom (22.8%) than in north facing one (12.5%) perceives daylight uniformity "enough" since south facing classroom provides higher percentage of daylit area.

In response to the question about direct sun shining on body or into eyes, only 14.8% of the students in sunlit area of south facing classroom feel direct sunlight. Moreover, when asked about pleasantness of sunlight if any, only 33.4% of them find sunlight "unpleasant" and "very unpleasant". As mentioned earlier, at least 20.6% of the students were expected to feel annoying or intolerable glare, direct or unpleasant sunlight in sunlit area of south facing classroom, but questionnaire survey shows a wider range of sunlight acceptance in this area (14.8%).

Three reasons can be stated for this higher level of sunlight acceptance in sunlit area of south facing classroom; firstly, due to the small width of windows = 0.5 (windows' configurations), the source of glare is small, and students do not find sunlight intense, direct, and annoying. This reason can be supported by [44], stating that in small windows the glaring source is small, and perceived sensation is not disturbing. Secondly, glare in these classrooms is largely tolerated due to the enjoyment of the natural views to the courtyard (more than 70% of the students find outside view and its quality "pleasant" and "very pleasant"). The fact that glare from daylight with pleasant views is more tolerated than glare from artificial light sources has already been verified in studies by [3,43,45]. Thirdly, questionnaires have been filled out in a city with relatively a lot of intense sunlight, which naturally changes students' expectations and feelings. Students are usually exposed to a lot of sunlight in this region, so they do not consider the level of sunlight entered through "those windows with small width" high.

Reinhart believes that the limit prescribed for annual sunlight exposure is too strict and it may prevent direct sunlight from entering a space, resulting in "dull spaces" [46]. He recommends applying the 1000 lx direct sunlight criterion only to areas where 'critical visual tasks" like desks or white boards take place. Although "critical visual tasks" take place in these classrooms, students show a wider range of sunlight acceptance and glare tolerance than expected, which can be justified by taking into account the importance of windows' configurations, quality of view and students' expectations.

Fig. 18. Left, view to courtyard with natural elements.

Direct sunlight is as well perceived lower in north facing classroom than of south facing classroom, which goes back to higher levels of sunlight and daylight in south facing classroom.

Regarding overall assessment about visual comfort in the whole classrooms, around 51.8% of the students in north facing room expressed their visual comfort as "neither comfortable nor discomfortable" (Fig. 17). Yet, a high percentage of students (40.6%) believe that north facing classroom is still visually comfortable. As can be inferred from questionnaires' results, students' impression about visual comfort is more positive and optimistic than simulation results; "sDA = 20%" is most voted as "average" while sDA = 20% is low according to standards. Moreover, most of students have a neutral point of view about non-daylit areas of the classrooms. Two reasons can be stated for students' feelings:

Firstly, the classroom's window configuration (number of windows (4) and their heights (2.3 m)) gives a more positive feeling about the space (Fig. 14) and students do not feel they are in a relatively dark classroom, while windows do not let adequate amount of daylight due to the north orientations of windows.

Secondly and more importantly, view should also be considered as an integral part of visual comfort and impression about the space, which is usually ignored in simulations. Students usually have a positive feeling about view and that surely affects their evaluation about the space. There are two important factors related to view; amount of view and quality of view.

Regarding amount of view, while dimensions of windows are exactly the same in these two classrooms, "the amount of view provided by windows" is expressed as "adequate" in south facing classroom and is perceived "average" in north facing classroom. It's because south facing classrooms provide more daylight, and students find the space brighter, more transparent, and more connected to outside view. Another reason is the intensity of daylight in south facing classroom which draws the attention of students more to windows and the outside view. It clearly demonstrates that the amount of daylight can even affect students' feelings and judgments about the size of windows.

According to questionnaires' results, more than 70% of the students find outside view and its quality "pleasant" and "very pleasant" in both classrooms, which according to previous studies can surely affect students' academic and visual performance [47–49]. The classrooms overlook a beautiful courtyard, full of trees and flowers (Figs. 18 and 19). Students can rest their eyes and minds by looking outside from time to time. Views to natural elements (trees, vegetation and plants) is found to have a positive effect on users and their health [43,49].

To sum up, questionnaire results show a wider range of visual comfort in north facing classroom, which can be justified by tak-

Fig. 19. Right, view to courtyard with natural elements.

ing into account the importance of windows' configurations and quality of view.

On the other hand, averagely, 54.5% of the students in south facing classroom find daylight visually "comfortable" and "totally comfortable" (Fig. 17). Despite the fact the 29% of the space is sunlit, most students have a positive impression about visual comfort.

Questionnaires' results are more close to simulation results when considering only the occupied hours. By considering the whole year (without removing unoccupied hours), SDA decreases to 44% and ASE increases to 43%, which greatly decreases visual performance. On the other hand, questionnaire results show that more than 54.4% of the students in south facing classroom find daylight visually "comfortable" and "totally comfortable". As a result, subjective evaluations are more in agreement with simulation results.

Students' control over their environment largely affects the amount of available daylight in classrooms. Drawing the curtains in case of excessive sunlight leads to reduction in the amount of natural daylight and turning on the lamps. Apart from energy consumption and its cost, students become deprived from natural daylight and its benefits. Moreover, higher number of students in the north facing classroom than in the south facing one vote for changing seats temporarily in case of discomforting sunlight (28% against 7%). Although the classes are exactly of the same dimension, the number of students in north facing classroom (27 students) is lower than the south facing one (33 students). That gives them more freedom to change their seats when experiencing discomfort. In addition, arrangement of the chairs in the north facing classroom was more flexible than that in the south facing one. In other words, freedom in changing seats temporarily or providing some extra chairs in the classrooms may prevent students from drawing the curtains in case of excessive sunlight, and occupants can still enjoy natural daylight.

In previous researches [6,7], fully daylit, partially daylit and non-daylit areas could be identified through overlaying areas evaluated by students. This method seems very close to the definition provided by dynamic metrics and can evaluate dynamic metrics against subjective evaluations. These studies have shown that there is quite a positive correlation between students' impression and dynamic simulations. To find out about high school students' opinion about visual comfort in daylit and sunlit areas of classrooms, authors felt obliged to think of questionnaire survey and longitudinal study. Questionnaire survey is easier to understand especially for non-architect students and can be analyzed precisely based on seat numbers and their positions in daylit and sunlit areas.

As stated earlier, students most voted "enough" or "much" about daylight availability in daylit areas of both classrooms which is in complete agreement with simulation results, since according to the definition of these metrics, daylit areas are supposed to provide enough daylight. Yet, daylit areas did not provide uniform daylight for students since students are influenced by daylighting condition of the whole class. One solution to increase students' positive impression about daylight distribution is to increase daylit areas, so the whole class will be perceived daylit and uniform. As mentioned earlier, students' impression about sunlight and glare in sunlit area of south facing classroom is more positive and optimistic than simulation results. In this study, generally, subjective evaluations show a wider range of sunlight acceptance in south facing classroom and visual comfort in north facing classroom than simulation results. The research by [9] shows that while dynamic performance metrics consider the architectural aspects of daylighting, it is implied that they cannot guarantee a "well daylit space". It is as well suggested that a good daylighting depends on how daylight and building form affect each other to provide visual comfort and satisfaction for occupants. That is why evaluating students' perception of daylighting conditions in the classrooms and comparing them with simulation results is of utmost importance. For instance, dynamic metrics do not adopt a commonly acknowledged method to assess "view to the outside" while authors concluded that outside view can significantly affect students' impression and feelings about the space as mentioned in previous studies [47–49].

5. Conclusion

To conclude, this article implies that although the adoption of dynamic metrics by both architects and standards has matured during recent years and is now commonly used, more studies should investigate the correlation between subjects' perception of the classrooms and dynamic metrics. According to the results of this paper, dynamic metrics do not guarantee visual comfort and values lower or above the limits prescribed by these metrics do not necessarily cause visual discomfort. As stated earlier, questionnaires' results show a wider range of sunlight acceptance in south facing classroom and visual comfort in north facing classroom. Moreover, according to the results, daylit areas did not provide enough daylight uniformity but enough daylight availability. Higher percentage of daylit areas is required to give students the impression of daylight uniformity, especially in north facing classroom. According to discussion, the importance of the region, users' expectations and behaviors, configuration of spaces and view should also be taken into account in daylighting analysis and visual comfort. Authors believe that there are differences in the way visual comfort is perceived by users in different regions with different amount of sunlight and in spaces with different spatial configurations and views, all of which is recommended to be fully considered in evaluating visual comfort in the next papers. Moreover, it is strongly recommended that metrics be revised by taking into account the exact building schedule for calculating dynamic metrics to draw more reliable results which are more consistent with questionnaire survey rather than using the default occupation which is considered 8:00–18:00.

Regarding suggestions, to promote the definition of visual comfort according to dynamic metrics and to achieve an evaluation system for educational buildings in these regions, it is necessary to extend studies by analyzing more cases especially in this region to yield more reliable results. Doing further studies may also define a more flexible definition of dynamic metrics in different regions. For instance, the number of specified hours (250 h) or percentage of area in ASE definition may increase in regions with abundant amount of sunlight after conducting further studies.

As mentioned earlier, the design approach of north and south facing classrooms are exactly the same in this school, and designer has ignored different intensities, colors, levels and distributions of daylight entering from different facades and orientations. Further studies are encouraged to take into account orientation, windows configurations including window-wall-ratio, window sill, window shape, window glazing, installing light shelves, etc., classrooms' dimensions and arrangement of chairs and furniture to optimize results by simulations.

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