Evaluation of the influence of interior design parameters on circadian daylighting of design-studio classrooms

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Abstract
There has been a growing emphasis on evaluating building performance in terms of its impact on human health and well-being. This study examines the impact of interior design parameters, such as wall color and desk arrangement, on the circadian lighting conditions of a conceptual design studio located in Phoenix, Arizona and Seattle, Washington. The results suggest that the circadian potential of the space is positively correlated with the melanopic reflectance of the wall materials and the collaborative desk arrangement. These findings provide valuable insights for designers who wish to enhance daylight-driven circadian stimulus in flexible and collaborative learning environments, such as design-studio classrooms, while preserving the space's geometrical characteristics.

Highlights
• Studios with collaborative desk arrangement and walls with higher melanopic reflectance (light-blue) resulted in a higher percentage of viewpoints meeting the required equivalent melanopic lux level of 275 lux.
• The combination of walls with lower melanopic reflectance (light-yellow) and single desk arrangement resulted in lower circadian entrainment.
• Changing the layout from single to collaborative had a more noticeable impact on the percentage of view positions with adequate equivalent melanopic lux compared to changing the wall color in Seattle, while in Phoenix, both solutions improved circadian lighting conditions significantly.

Introduction
The indoor environmental quality (IEQ) in educational settings significantly impacts comfort, cognition, and health of students as they spend a considerable amount of time in the classrooms (Castilla et al. 2017; Kong and Jakubiec 2021). Among various elements of the indoor environmental quality, lighting has been identified as one of the main factors influencing students’ learning progress and cognitive abilities (Barrett et al. 2015; Mirrahimi, Ibrahim, and Surat 2012). Researchers argue that the quality of the daily light exposure significantly impacts individuals’ productivity, sleep, alertness, and mood (Boyce, Hunter, and Howlett 2003).

In the recent years, the discovery of the intrinsically photosensitive retinal ganglion cells (ipRGCs), drew attention to the non-visual effects of light on occupants. These cells which are located on the top layer of the retina, mediate the non-visual photoreceptive tasks, including melatonin suppression and regulation of the circadian rhythms (Provencio et al. 2000). The non-image forming effects of light depend on both luminous factors, such as spectrum, quantity and directionality, as well as temporal factors, including timing, duration and history of light exposure (Khademagha et al. 2016).

Among the metrics that have been introduced to quantify non-visual aspects of light, two commonly cited metrics in literature are the Circadian Stimulus (CS), proposed by Rea et al. (2005), and the Equivalent α-opic lux, introduced by Lucas et al. (2014). The equivalent α-opic lux, employs weighing functions to measure effective irradiance of the five photoreceptors in human eyes. This metric has been adopted by the WELL building standard, in order to measure the equivalent melanopic lux (EML) to assess the circadian lighting conditions of the space (IWBI 2022). Given the dynamic and irreplaceable nature of daylight compared to constantly available artificial lighting, it has become necessary to provide suitable daylighting environments for higher education spaces (Kong et al. 2022). A recent study suggests achieving the target melanopic lux level in interior spaces primarily through daylight for appropriate and healthy lighting exposure (Brown et al. 2022).

Within architecture schools, design studios represent a common learning environment wherein lighting is considered the most significant interior feature (Obeidat and Al-Share 2012). A growing body of research has demonstrated the critical role of architectural characteristics on occupants’ perception of daylight (Alhataeb and Asadi 2021; Anaraki et al. 2023). Occupants’ interaction with daylight is defined through characteristics of the built environment which define the extent to which visual and non-visual responses of occupants are affected (Khademagha et al. 2016). Given that many design studio classrooms are typically expansive workspaces, many of the students are often seated at positions distant from windows, which results in a diminished exposure to daylight. Within these spaces, where students remain stationary for extended periods and...
have limited control over their position and direction toward the aperture, the location and arrangements of the furniture can significantly impact their perception of light and their proximity to windows, thereby improving their circadian health, productivity and cognitive abilities. Moreover, since the spectral characteristics of daylight will alter through its spectral interaction with surfaces and objects (Safranek et al. 2020), the interior characteristics of a space can be crucial to occupants’ perception of light. This paper aims to investigate the extent to which interior features, including layout of the seating and desk arrangements and wall color and reflection, can affect the non-visual effects of daylight in an architectural design studio to increase daylight-driven circadian stimulus within a design-studio learning environment.

**Literature Review**

With the realization of the significance of non-visual aspects of light, many have attempted to investigate the influence of the features of the built environment on the spectral characteristics of the daylight entering the space before reaching occupants’ eyes. The investigated parameters in the previous studies can be classified into four categories: Surrounding environment, geometrical and optical characteristics, and the interior layout of the space.

It has been reported that the circadian stimulus of daylighting in indoor environment is notably dependent on the common sky conditions of a geographical location (Acosta et al. 2019); Hence the proper window to wall ratio in educational settings should be selected accordingly to ensure adequate circadian effects. Research on office spaces has demonstrated that the sky condition has a considerable effect on the depth of penetration of light into the space, resulting in a significant difference in percentage of occupants receiving a sufficient amount of daylight for circadian stimulation (Altenberg Vaz and Inanici 2021).

In an investigation of the effects of multiple geometrical and optical parameters on the non-visual effects of light, it was concluded that window is the most crucial element regarding the circadian potential of the space (Potočnik and Košir 2021). Additionally, a study conducted in educational environments indicated that the average circadian stimulus falls with the increase of the distance from the window (Acosta et al. 2019). Similarly, results from a study in side-lit offices reveals that the influence of building parameters on occupants’ perception of light alters with their distance from the window (Potočnik and Košir 2021).

An investigation on the impact of seven glazing types and six different wall colors indicated that higher visual transmissivity and reflectance results in a better non-visual environment (Potočnik and Košir 2020). It has been reported that furniture materials with higher reflectance result in higher circadian metric values (Safranek et al. 2020). A study by (Danell et al. 2022) also revealed that wall reflectance and EML levels have a nearly linear relationship. An evaluation of circadian lighting conditions on scale models, indicated that the circadian stimulus can be considerably affected by the color of interior surfaces (Hartman et al. 2014).

Furniture layout directly affects how occupants receive and interact with daylight, as it determines their position and distance from the window. Zeng et al. concluded that changing the workstation arrangement in the office spaces can improve the circadian lighting conditions (Zeng et al. 2021). A recent study also investigates how various characteristics of partition design, including partition layout and occupants direction toward the window, partition height and its optical properties can augment the circadian potential of the spaces (Anaraki et al. 2023). The arrangement of furniture in design studio classrooms, especially desk layout, plays a crucial role in facilitating interactions between students for various activities, lectures, and meetings. A study in educational and office environments showed that the occupants’ position towards the luminaires affects the circadian lighting conditions (Safranek et al. 2020).

Current literature has demonstrated the notable impact of the architectural features on the quality of the indoor daylighting to deliver circadian stimulations. However, the vast majority of the investigations have been conducted in the offices and less have focused on other space types. Moreover, the literature lacks a comprehensive investigation of the impact of spectral characteristics and color of the inner surfaces. In the built environments where changing the size of the window or the geometry of the space is not feasible, altering the interior features, such as surface optical properties and furniture layout can alter the daylight access and herby its related circadian effects. In spaces such as classrooms, where occupants spend the majority of their time in designated locations with limited options to change the position, the location and arrangement of furniture can be crucial in access to quality daylighting, as it defines the distance from the windows as well as the view direction towards the window. Therefore, we investigate the extent to which optical properties and spectral characteristics of the wall material and furniture layout in an architecture design studio can improve the non-visual environment.

The evaluations are conducted in two geographical locations to take the variation of sky condition into account.

**Methodology**

This study examines the impact of wall colors and students seating arrangements on the circadian lighting metrics in design-studio classrooms located in two geographically distinct regions with extreme climates, namely Phoenix, Arizona and Seattle, Washington. These two cities have been selected due to their distinct climate conditions, which encompass both clear and overcast sky conditions. The studies are conducted in two cities have been selected due to their distinct climate conditions, which encompass both clear and overcast sky conditions. The studies are conducted in two geographical locations to take the variation of sky condition into account.

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A 3D model of a design-studio classroom has been created in Rhinoceros, which serves as an input for the ALFA plugin. Design studios involve several collaborative teamwork activities that requires students to sit together, in addition to individual project work and lectures wherein all students face the lecturing board. To this end, the desk arrangement of the design studio space is assumed to have two different layouts, namely, a typical forward-facing position layout (single seating position) where all students face the board and a collaborative-learning desk arrangement providing various view directions for students. The studio classroom used in this study is 154 m² (9.65 m wide, 16 m deep, and 3.80 m high)- representing a typical design studio in the Design School at Arizona State University - with a window located on the north side of the building to represent the most challenging daylight condition for circadian effects. The model was simulated without occupants, and the materials of the interior floor, ceiling, window glazing, and desk surfaces were kept constant. The geometrical and optical parameters of the model are detailed in Tables 1 and 2.

### Design variables

Simulations were conducted based on the predominant sky conditions in Phoenix and Seattle, with average of the total sky covers of 0.76 and 7.18, respectively, as per the Energy Plus weather data for the period 2007-2021. These values are the average of the total sky cover output in the EPW component in the ladybug plugin (version 1.6.0), which represent the extent of sky dome that is covered by clouds on an hourly basis, ranging from 0 to 10, where 0 indicates a completely clear sky and 10 shows full coverage of the sky by clouds. Therefore, simulations were carried out under clear sky condition in Phoenix and overcast sky condition for Seattle. Three days of the year, specifically March 21st, September 21st, and December 21st, were chosen to represent different seasons and weather conditions and to account for variations in lighting conditions throughout the academic year when students attend studio classes. Summer time has been excluded from the simulations as academic institutions refrain classes during this time of the year. Lighting calculations were performed for two time points, 9:00 am and 3:00 pm, which are typically the average times for studio classes held in the morning and evening, respectively. Spectral sky was constructed in ALFA, which employs atmospheric data defined by the U.S. Air Force Geophysics Laboratory (AFGL) (Anderson et al. 1986) in the LibRadTran library (Mayer and Kylling 2005), resulting in distinct sky spectral power distributions for each time, date and geographical location. The simulation settings are presented in Table 3. The wall materials have been considered in four different color hues for the simulation, including a neutral typical white color commonly used in most of the design studio classrooms as well as three other materials, having light yellow, blue and green color hues that are suitable for interior design of studio classrooms. These selected materials have slightly similar photopic reflectance (Rp) of about 60 percent with different melanopic reflectance (Rm) levels ranging from 33.1 to 71.6 percent (Table 4).

### Table 1: Constant geometrical parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room size</td>
<td>9.65 m wide * 16 m deep * 3.80 m high</td>
</tr>
<tr>
<td>Window dimensions</td>
<td>3.15 m * 2.60 m</td>
</tr>
</tbody>
</table>

### Table 2: Constant optical parameters and glazing type parameters (Rp: photopic reflectance, Rm: melanopic reflectance, M/P: melanopic to photopic reflectance ratio)

<table>
<thead>
<tr>
<th>Surface</th>
<th>Material Type</th>
<th>Rp (%)</th>
<th>Rm (%)</th>
<th>M/P (%)</th>
<th>Specularity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>White Painted Room Ceiling</td>
<td>82.2</td>
<td>77.4</td>
<td>0.94</td>
<td>0.4</td>
</tr>
<tr>
<td>Floor</td>
<td>Light Grey Floor tiles Non-slip</td>
<td>41.8</td>
<td>37.6</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Desk surface</td>
<td>White cup board top surface</td>
<td>85.2</td>
<td>83.9</td>
<td>0.99</td>
<td>1.3</td>
</tr>
<tr>
<td>Glazing parameters</td>
<td>Material Type</td>
<td>Tp (%)</td>
<td>Tm (%)</td>
<td>M/P (%)</td>
<td></td>
</tr>
<tr>
<td>IGU Clear</td>
<td>Double Glazing</td>
<td>70.1</td>
<td>70.1</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Simulation properties

| Ground Albedo | 0.15 |
| Sensor Height | 1.20 m |
| Ambient Bounce | 6 |
| Limit Weight | 0.01 |
| Number of passes | 100 |

### Table 4: Characteristics of wall colors

<table>
<thead>
<tr>
<th>Type</th>
<th>Rp (%)</th>
<th>Rm (%)</th>
<th>M/P (%)</th>
<th>Specularity (%)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munsell 10BG 8-4</td>
<td>58.7</td>
<td>71.6</td>
<td>1.22</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Dupont Pale Green 48</td>
<td>61.8</td>
<td>51</td>
<td>0.83</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Munsell Yellow 69</td>
<td>60</td>
<td>33.1</td>
<td>0.55</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Macbeth Neutral 0.8</td>
<td>60.5</td>
<td>60.2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

For the single desk arrangement layout, the studio space is presumed to have six rows of desks with a distance of
1.0 meters between each row. Each row consists of four desks, with the dimensions of 0.9 meters by 1.20 meters and the height of 0.76 meters. A total number of 24 sensors with a height of 1.2 meters and 180 degrees field of view were located behind each desk in the seating position, with all sensors facing the east side of the studio space. The 3D model did not include other furniture, such as chairs and monitor screens. The collaborative-learning desk arrangements consisted of four sets of eight desks each, with a total of 32 sensors positioned throughout the studio space. These desks were connected vertically and horizontally, offering students various view directions towards the east, west, north, and south. Since students are mostly in the seated position during the class hours, the desk surface height of 0.76 m and eye-level height of 1.20 m were considered in the simulation process. Desk dimensions were measured from typical design studios’ desks in The Design School at Arizona State University.

In the single arrangement layout, the desks are positioned 1.80 meters away from the walls and have a distance of 1.90 meters from the window and back wall. In the second alternative, the collaborative desks are placed 2.70 meters away from the walls and 1.50 meters from the back wall and the window located in the north side of the classroom. Characteristics of the two layouts are illustrated in Figure 1 in detail.

A total of 96 alternatives were generated and evaluated in ALFA by combining the aforementioned variables. All independent variables used in the study are listed in Table 5.

**Table 5: Study Variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desk arrangements</td>
<td>Single desk layout</td>
</tr>
<tr>
<td></td>
<td>Collaborative desk layout</td>
</tr>
<tr>
<td>Location</td>
<td>Phoenix (clear sky condition), Seattle (Overcast sky condition)</td>
</tr>
<tr>
<td>Wall Material</td>
<td>4 distinct materials</td>
</tr>
<tr>
<td>Time of the day</td>
<td>9:00 AM, 3:00 PM</td>
</tr>
<tr>
<td>Date</td>
<td>21 Sep, 21 Mar, 21 Dec</td>
</tr>
</tbody>
</table>

**Evaluation Metrics and simulation process**

Results were analyzed in accordance with the recommended daytime lighting thresholds for indoor environments proposed by Brown et al. (2022). In this study a standard for melanopic light exposure based on laboratory studies in relation to the melatonin suppression sensitivity, circadian rhythm, and subjective alerting responses was established. This standard recommends a minimum melanopic EDI of 250 lux (equal to 275 EML) at the eye level measure in the vertical plane in the height of 1.2 meters (in a seating position) to promote human health and well-being. Since the aim of this project is to evaluate how daylight interact with the space and affects occupants’ perception of light, the 275 EML threshold was adopted from this research study to assess the daylight’s influence on providing satisfying circadian lighting requirements without electrical lighting consideration.

**Results**

**Impact of interior wall material**

This section investigates the impact of wall color on two evaluation metrics regarding the non-visual environment, the percentage of view positions which receive above 275 EML and average EML, in a design studio classroom summarized in Figures 2 and 3. The error bars demonstrate the ±20% error range of ALFA simulations when compared to measurements.

The results indicate a direct relationship between the melanopic reflectance of materials and the percentage of view positions receiving above the 275 EML threshold in design studio classrooms located in Phoenix. The highest percentages were observed on March 21st and September 21st at 3 PM with a collaborative desk arrangement and light-blue wall color, while the lowest were seen on December 21st at 9 AM with a single layout and light-yellow wall color. In studios with a single layout located in Phoenix, increasing melanopic reflectance of wall color led to higher percentages of view positions receiving sufficient EML, except in December 21st at 9 AM, where only changing the wall color from bright yellow to bright green had a minimal impact of 4.14% on EML. Therefore, the highest values for the percentage of view positions receiving sufficient EML, are observed in design studios.
with light-blue wall color with melanopic reflectance of 71.6%, while the lowest values are seen in studios with light-yellow wall color with melanopic reflectance of 33.1%.

In design studio classrooms located in Phoenix with the collaborative desk arrangement, the impact of wall color on the percentage of view positions with sufficient EML is less pronounced compared to the single layout. For instance, changing the wall color from light-yellow to light-blue at 9 AM on March 21st increases the percentage

![Figure 2](https://example.com/figure2.png)

**Figure 2:** The percentage of view positions receiving more than 275 EML in design studios with different wall colors, in different times of the year and in the two cities of Phoenix and Seattle. The vertical axis shows the percentage of view positions with adequate EML and the horizontal axis illustrates the time of year. The optical materials of walls are summarized as color_melanopic reflectance.

![Figure 3](https://example.com/figure3.png)

**Figure 3:** Average EML in design studios with different wall colors, in different times of the year and in the two cities of Phoenix and Seattle. The vertical axis shows the value for average EML and the horizontal axis illustrates the wall color of the design studio.
of view positions with adequate EML values by 16.66% in a single layout studio, but only by 6.25% in a collaborative layout.

The simulations indicate that design studios located in Phoenix with higher melanopic reflectance walls, undergo greater change in circadian lighting conditions across time and season, compared to studios with lower melanopic reflectance walls. For example, in a single layout studio with blue wall color, the difference between the percentage of view positions receiving adequate EML on 21st of March at 9 AM and the same time in December is 20.86%, while in the same layout with yellow wall color, the difference is 8.34%.

In Seattle, changing wall color in design studios has a less significant effect on the percentage of view positions receiving adequate EML compared to Phoenix. For instance, in studios with single layout in Seattle, changing the wall color from yellow to neutral did not affect the percentage of view positions receiving 275 EML on March 21st and September 21st at 3PM. In these cases, this percentage will only change with the alteration of wall color to blue, increasing the EML value by 8.33% and 4.17% in March and September, respectively. Moreover, no improvement can be seen in the non-visual environment with the alteration of wall color in the single layout on December at both 9AM and 3PM and also in the collaborative layout on December at 9AM, as none of the view positions in the space receive the sufficient EML. In Seattle, the most noticeable impact can be observed in the single layout during March at 3 PM, where a shift from light-yellow to light-blue on the walls enhances the percentage of view positions with sufficient EML by 8.33%.

The average EML value in all of the simulated design studio classrooms located in both Phoenix and Seattle, has a direct relationship with the melanopic reflectance of the wall material (Figure 3). However, the impact of wall color varies based on the geographical location and the time of the year. The highest impact of alteration of wall color on average EML in design studio classrooms located in the city of Phoenix occurs on 21st of March at 3 PM, while in Seattle the maximum difference in the average EML by changing the wall color is seen on 21st of September at 9 AM, in both desk arrangements. The impact of wall color on average EML reaches its lowest point in both cities on December 21st at 9 AM in both single and collaborative layouts. It has to be noted that the impact of wall color on EML average is less pronounced in design studios located in Seattle, compared to Phoenix.

### Influence of Desk Arrangement

This section evaluates the influence of alteration of desk arrangement on the percentage of view positions receiving EML 275 or higher and average EML. In most of the investigated cases, the collaborative layout, in which students are sitting in various view directions, has higher values for the percentage of view positions which receive more than 275 EML compared to the single layout, in both Phoenix and Seattle (Figure 4). However, the impact of alteration of the desk arrangement on circadian lighting conditions varies according to wall color and simulation time.
The highest impact of layout arrangement in Phoenix is seen in studios with light-green wall color on March 21st and September 21st at 9 AM, where changing the layout from single to collaborative arrangement increases the percentage of view positions receiving above the 275 EML threshold by 20.84%. On the other hand, the lowest impact is observed in studios with light-blue wall color on March 21st at 3 PM, where changing the layout would improve this percentage by only 2.09%. In Phoenix, on 21st of March and 21st of September, altering the layout from single to collaborative in the morning hours produces a more pronounced effect on the percentage of view positions receiving EML higher than 275 Lux in the afternoon hours, regardless of wall color. For example, in studios with green walls, transitioning from a single to collaborative layout at 9 AM on March 21st boosts the percentage of view positions with adequate EML by 20.84%. Conversely, in the same studio and on the same day but at 3 PM, the layout change yields only 8.34% increase in the percentage of view positions achieving above 275 EML.

In the design studio classrooms located in Seattle, in almost all of the investigated alternatives, except for December, changing the layout from single to collaborative will result in consistent increase of 16.67% in the percentage of view positions with adequate EML. The only times of the year in Seattle in which altering the layout results in no change in the circadian lighting conditions in the studio space is on December at 9 AM in all of the wall colors, and on the same day at 3 PM in design studios with light-green and light-yellow wall color, where none of the view positions meet the required EML value.

It has to be noted that on 21st of December, when altering the layout in studios in Seattle has a minimal to no effect on circadian potential of space, changing the layout in design studios in Phoenix has a noticeable impact on circadian lighting conditions of the design studio.

Similar to the trends seen in the percentage of the view positions receiving EML 275 or higher, in all of the investigated times of the year, the average EML is higher in design studio models with collaborative layout, compared to single layout. The lowest impact of alteration of layout on average EML in design studio classrooms located in both Phoenix and Seattle is seen on 21st of December at 9 AM, while the highest impact of it is observed on March 21st at 3 PM in both cities, in all of the wall colors.

**Discussion and Conclusion**

This study investigated the impact of interior design parameters, including wall color and desk arrangement layout, on circadian lighting conditions in an architecture design studio located in two cities with notably different weather and sky conditions: Phoenix, Arizona, and Seattle, Washington. Simulations were conducted for four different wall colors and two desk arrangements (single and collaborative), at three different times of the year.

The findings of this study can bring significant implications for selecting appropriate interior design for studios where altering the geometrical characteristics of the space is not applicable. According to the results, none of the investigated design studio alternatives were able to meet the requirement of receiving the 275 EML threshold at all the designated view positions. Results indicate that the circadian lighting condition of a space is strongly dependent on the view direction of occupants and optical properties of walls. The highest values for average EML and the percentage of workstation receiving the 275 EML or above were observed in studios with walls with the highest melanopic reflectance, in light-blue color, and the collaborative layout. Conversely, the lowest values were observed in studios with walls with the lowest melanopic reflectance, in light-yellow color, and in the single desk arrangement layout. This is in line with the results reported by Potočnik and Košir (2020), which indicated that blue wall color results in higher non-visual entrainment in office environments.

Based on the results of simulations in Seattle, changing the layout from single to collaborative has a more noticeable impact on the percentage of the view positions receiving the 275 EML or higher compared to changing the wall color, while in Phoenix, both solutions can improve the circadian lighting conditions significantly. The results also showed that maintaining a suitable circadian lighting condition in Seattle is more challenging compared to Phoenix due to the overcast sky conditions which reduces the daylight availability in the space. In addition to this, in both cities the calculated EML values during morning time (9 AM) were lower than the evening time (3 PM). This could be due to the lack of daylight entering the space in the early morning hours and the lower daylight availability in the design studio, which results in lower EML levels. Several studies up to date have mentioned the importance of having higher EML values in the morning time to match human circadian rhythm and improve health and well-being (Brown et al. 2022).

While assessing the circadian lighting conditions of the space, it has to be acknowledged that the distance of the occupants from the window has a notable effect on the average EML. In some of the alternatives, the average EML may be elevated due to the high illuminance received by occupants sitting close to the window, despite the inadequate EML values experienced by occupants situated further from the window. Therefore, evaluating the percentage of view positions which receive sufficient EML would result in a more thorough assessment of the distribution of EML in the space, compared to the average EML.

All in all, this study suggests that a combination of wall colors with higher melanopic reflectance and with a collaborative desk arrangement results in higher circadian entrainment. However, the conducted study lacks generalization, as only a limited number of wall colors and layouts in a specific space were investigated. In addition, considering the combination of daylighting and electric lighting in the space, which is closer to real-life...
situations in educational spaces, is also needed to provide a more thorough understanding of the impact of interior elements on the non-visual effects of light on occupants.

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