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Assessment of daylight factors in classrooms using analytic hierarchy process: ensuring a healthy and productive learning environment

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Summary

A well-designed classroom environment is essential for effective learning, and natural light plays a fundamental role in creating a space conductive to concentration and comfort. This study investigates the intricate relationship between visual comfort and natural light in classroom by employing the Analytical Hierarchy Process (AHP). AHP emerges as an invaluable tool for lighting engineers, architects, and decision-makers in the education sector. It allows them to systematically identify rank, and prioritize the factors that most significantly influence daylight quality. The architectural elements examined in this study include the climate, color of walls and ceiling, window design, and dimensions, orientation of the classroom, and the presence of shading elements. Interior design considerations, such as furniture arrangement, choice of materials, and the height of desks and chairs, are also evaluated for their impact on natural lighting. Collectively, these variables shape the overall lighting environment of a classroom. This study aims to determine the relative importance of each factor, providing valuable insights that can guide evidence-based design strategies to enhance student performance through improved lighting. The findings confirms that daylight quality in classrooms necessitates taking into account a number of key factors, with a focus on climate and hour of the day as well as window design and color. These insights are guided by the outcomes of the AHP evaluation. It allows for comprehensive assessments of lighting quality by systematically weighing the various factors that influence both natural and artificial lighting, facilitating informed decisions about design improvements and optimal funding allocation.

Keywords

daylight factor • visual comfort • Analytic Hierarchy Process • classrooms • subjective assessment

1. Introduction

Visual comfort presents one of the most complicated subjects that faces the architects throughout the design process, especially when the design intention is to reduce energy consumption and improve the occupant's health and well-being. The challenge of providing optimal visual comfort conditions in educational places is crucial for creating a healthy learning environment. Research shows a strong link between visual comfort and cognitive function, with poor lighting causing eye strain, fatigue, and reduced performance [Dhingra 2023]. To enhance students' learning, school buildings must provide adequate quality and quantity of light [Buratti et al. 2018, Ricciardi and Buratti 2018].

It is well known that a well-designed lighting plan can significantly enhance the interior design of a space and create a sense of warmth and comfort. However, according to Haverinen-Shaughnessy et al. [2015], poor indoor environmental quality (IEQ) in schools can lead to increased student absenteeism, health issues, and impaired learning. Research highlights the importance of daylight quality in creating favorable IEQ, which directly impacts students' academic performance, as noted by Bluyssen [2013] and Winterbottom and Wilkins [2009]. Daylight quality in classrooms plays an important role for a good IEQ in classrooms and it is very important for pupils' learning [Leccese et al. 2016, Xue et al. 2014].

Extensive research has been conducted to evaluate the effects of daylight on indoor environments, with a particular focus on educational environments. Several studies have investigated methods and tools for evaluating daylight performance in buildings. Daylight quality is a complex interaction of various factors. These include building characteristics such as room orientation [Sangkakool and Jumani 2024, Potočnik et al. 2020], window size [Kong et al. 2018], glazing type and interior finishes [Day et al. 2019, Hirning et al. 2017]. In addition, daylight effectiveness is greatly influenced by weather conditions and occupant behavior. Research has emphasized the importance of daylight distribution [Chan et al. 2017, Marjaba et al. 2020], light illuminance, brightness and uniformity in creating comfortable and productive indoor environments.

The Analytic Hierarchy Process (AHP) is a quantitative decision-making tool that relies on expert judgment to establish priorities through pairwise comparisons. Developed by Thomas Saaty at the Wharton School of Business, AHP excels in handling complex decision scenarios by breaking down problems into hierarchical structures. This method effectively integrates both subjective and objective elements, enabling the identification of optimal solutions. A key strength of AHP lies in its ability to assess the consistency of decision-making judgments, thereby reducing potential biases [Ho and Ma 2018]. The AHP employs pairwise comparisons to quantify the relative importance of criteria, using a numerical scale to represent these judgments. The primary evaluation criteria's weights are generated at the conclusion of the procedure. the AHP method is used to extract the weights and the major and secondary variables after generating a database with all the variables [Badri et al. 2016, Saaty 1980]. This approach ensures that decision-making is systematic and reduces biases by incorporating a consistency check mechanism [Dehimi 2021].

The AHP has been widely adopted throughout numerous technical domain names to deal with complex decision-making demanding situations. Within the building sector, its application are enormous. For example, Nadoushani et al. [2017] hired AHP to pick most advantageous building façade structures based totally on sustainability metrics. Hopfe et al. [2013] and Kangaraj and Mahalingam [2011] leveraged AHP to evaluate normal and strength overall performance, respectively. Additionally, the method has been instrumental within the selection and improvement of intelligent building systems [Lee et al. 2011] and the assessment of residential facility management services [Lai and Yik 2011]. Beyond building overall performance, AHP has been implemented to enhance construction safety [Naziris et al. 2016] and optimize fireplace protection for cultural heritage structures [Santos et al. 2017]. In the area of indoor environment, Zhang et al. [2019] utilized AHP to evaluate the social life cycle evaluation of faculty buildings.

After identifying the factors affecting indoor daylight quality, it becomes essential to determine how it can be scientifically measured. Previous studies primarily relied on subjective assessments, such as questionnaires, to evaluate daylight perception and user satisfaction. However, a more comprehensive approach has emerged, recognizing the importance of multiple parameters in determining daylight quality. Analytical tools capable of comparing and ranking their relative importance are indispensable. The Analytic Hierarchy Process (AHP) is a prominent example of such a tool. Widely studied and applied in various fields, AHP has proven its utility in complex decision-making scenarios that involve multiple criteria [Reinhart and Selkowitz 2012].

This study proposes a novel Daylight Factors Assessment Method (DFAM) based on the Analytic Hierarchy Process (AHP) to evaluate daylight architectural parameters within a primary school classroom in Algeria. By considering multiple factors contributing to daylight quality, DAM identifies key areas for improvement. The methodology is designed to be adaptable to various educational settings, offering a practical tool for professionals in the field. This research applies DAM to a single classroom to assess daylight quality levels, taking into account specific classroom characteristics.

Many interrelated factors affect daylight quality, which is a crucial component of indoor environmental quality. The amount and distribution of daylight in interior rooms are greatly influenced by a building's orientation, facade design, and the existence of shading mechanisms. Climate factors, especially solar radiation and cloud cover, are also very important in controlling the amount of daylight available. Additionally, factors that affect interior design, such as window size, type of glazing, and interior finishes, affect how much light enters and diffuses a space. Four primary elements were selected to serve as the study's foundation.

- **Building orientation and design.** Building orientation and design, significantly influences solar exposure on facades, is a key factor in daylight quality. While south-facing facades in the Northern Hemisphere typically maximize daylight year-round, the optimal orientation varies based on location and climate. Facade design further impacts daylight quality through elements like window size and placement, glass type, and incorporation of light shelves or clerestories. External shading devices, such as overhangs, louvers, and blinds, help regulate daylight and glare.

- **Climate conditions.** The availability of daylight is significantly impacted by climate conditions. Compared to regions with mostly clear skies, those with regular cloud cover have shorter days. Intensity of solar radiation also fluctuates with the seasons and throughout different regions, influencing the amount and quality of daylight.
- **Interior design.** This is a key factor in the distribution and use of daylight. Light-colored walls and ceilings are examples of reflective interior finishes that can increase natural light penetration and lessen the demand for artificial lighting. While furniture placement can maximize sunshine distribution within a space, window coverings and blinds can regulate daylight levels and glare.
- **Furniture.** Visual comfort and daylight distribution can be affected by the arrangement and color of furniture. In terms of arranging furniture, to ensure that daylight is not blocked, positioning furniture immediately in front of windows should be avoided. Also, the color of furniture is significant. Namely, dark-colored furniture can absorb light, which lowers illumination levels. Brightness is enhanced by light-colored furniture because it reflects daylight [ASHRAE 2017].

The total daylight quality of a space is determined by the combined effect of these factors. For instance, larger south-facing windows with clear glazing and light-colored interior finishes may enhance daylight penetration in a structure located in an area with heavy cloud cover and short daylight hours.

2. Methodology of the research

The Daylight Assessment Method (DAM) developed in this paper is intended as an effective and practical tool for assessing dayligh factors in educational buildings. The method can also guide interventions to ensure adequate levels of daylight exposure.

2.1. Structure of the method and use of the AHP

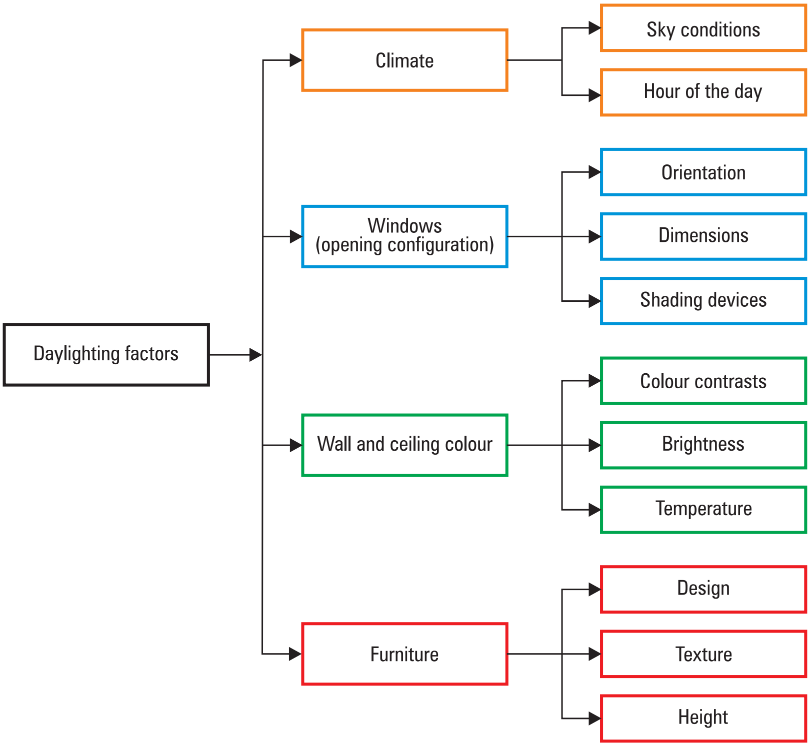
The Analytical Hierarchy Process (AHP) is employed as a decision-making tool in this study. AHP simplifies complex decision problems into a hierarchy system, using pairwise comparisons to determine the importance of each criterion. It assigns weights to each criterion, allowing for ranking and reducing decision-making biases through consistency checks. To address daylight quality in educational environment, the proposed Daylight Factors Assessment Method (DFAM) follows three structured steps:

1. **Identification of criteria and sub-criteria.** Determining daylight criteria and sub-criteria applicable to educational environments. Each sub-criterion is linked to specific indicators derived from technical standards or scientific research. The deviation between measured and reference values quantifies sub-criterion performance.

2. **AHP weighting.** Employing the Analytic Hierarchy Process (AHP), and assigning relative weights to criteria and sub-criteria based on expert judgments. Building physics experts conduct pairwise comparisons to establish the importance of each criterion, ensuring weight consistency.
3. **Evaluation and scoring.** Collecting data through calculations, to determine indicator values for each sub-criterion. By comparing these values to reference standards and applying the calculated weights, a final score representing the overall daylight quality is obtained.

Step 1. Identification of criteria and sub-criteria

The Daylight Factors Assessment Method (DFAM) begins by identifying a comprehensive set of criteria and sub-criteria to evaluate daylight quality within classrooms. To ensure balance between practicality and comprehensiveness, four primary daylight criteria (DC) were selected based on scientific literature [13.14.15.16] and international standards. Each primary criteria (DC) further divided into three daylight sub-criteria (DSC) to facilitate a detailed assessment of the visual environment (as shown in Fig. 1).



Source: Authors' own study

Fig. 1. Proposed DAM: List of daylight criteria (DC) and sub-criteria (DSC)

The chosen criteria were: climate, windows, colors, and furniture. Each sub-criterion corresponds to indicators derived from technical standards and research, ensuring a reliable assessment of daylight performance in educational spaces.

Step 2. Determination of daylight factors criteria and sub-criteria weights using AHP

To determine the relative importance of each daylight criterion (DC) and sub-criterion (DSC), an AHP-based expert weighting approach was employed. A questionnaire was electronically administered to a panel of nine building physics experts with at least three years of experience (Table 1). The experts evaluated the significance of DCs and DSCs through pairwise comparisons using 9-point saaty scale within a comparison matrix. The use of the 9-point scale is due to the capacity of providing greater sensitivity compared to 5- or 7-point scales. It is essential to note that these weights reflect expert consensus for educational environments and may vary across different building types. The obtained weights serve as a foundation for the proposed assessment method and can be refined through future research involving a larger expert panel. Table 2 provides details expert profiles, including their academic qualifications and professional experience. The AHP method was applied to derive the relative weights for each DC and DSC, ensuring consistency through consistency Ration (CR) checks. These weights reflect expert's consensus specific to educational environments and may vary across different building types. The derived weights form the foundation for this assessment method, which can be refined through future studies involving larger expert panels.

Table 1. Expert background summary

ID	Position	Field of expertise	Year of experience
1	Lighting engineer	Lighting engineering	15
2	Lighting engineer	Lighting engineering, designing lighting systems	06
3	PhD student	Sustainable architecture and urban planning	07
4	PhD student	Technology and environmental quality in architecture	07
5	PhD student	Environmental engineering	04
6	PhD student	Building physics	05
7	Interior designer	Interior design	04
8	Interior designer	Interior design	13
9	Interior designer	Interior design	06

Table 2. Weights obtained by experts using AHP for the daylight criteria (DC) and sub-criteria (DSC)

DC	DC weight	DSC	DSC weight
Climate	0.627	Sky conditions	0.157
		Hour of the day	0.470
Windows (opening configuration)	0.166	Orientation	0.053
		Dimensions	0.092
		Shading devices	0.020
Wall and ceiling color	0.115	Color brightness	0.019
		Color contrast	0.026
		Temperature	0.034
Furniture	0.092	Design	0.063
		Texture	0.018
		Height	0.011

Step 3. Evaluation and scoring

Data summary is presented in Table 3, whereas detailed DC and DSC comparison results are provided in Tables 4 and 5. The consistency ratios (CR) of all derived weights fall within the acceptable range of 0.001–0.021 (Tables 4 and 5), confirming reliable results ($CR < 0.1$). Based on the collected data, the four primary natural lighting criteria, ranked by overall importance, are climate accounting for 66.4% of the total windows ranked second in importance, with a percentage of 18.1%. Colors came in third place with 9.8%. Furniture was the least important factor, contributing only 5.6% (Table 3). Further analysis reveals key sub-criteria within each DC (Table 3). For clarity, DC weights are visualized in the radar chart (Fig. 2), and DSC global weights are presented in descending order in the bar chart (Fig. 3). Climate emerges as the most critical daylight quality factor, while furniture holds the least significance (Fig. 3). Further analysis of key sub-criteria within each DC is also included in Table 3.

Table 3. Results of pairwise comparisons

CR = 0.0033				
	Climate	**Windows**	**Wall and ceiling colors**	**Furniture**
Climate	1	5	7	9
Windows	1/5	1	/2	4
Wall and ceiling colors	1/7	1/2	1	2
Furniture	1/9	1/4	1/2	1

Table 4. AHP Evaluation of climate, sky conditions, and hourly comparisons

Climate CR = 0.001		
	Sky conditions	**Hour**
Sky conditions	1	3
Hour	1/3	1

Table 5. AHP Evaluation of windows' orientation, dimensions and shading devices (comparisons)

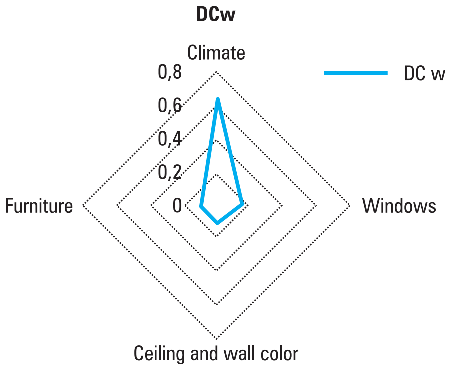
Windows CR = 0.0158			
	Orientation	**Dimensions**	**Shading devices**
Orientation	1	2	4
Dimensions	1/2	1	3
Shading devices	1/4	1/3	1

Table 6. AHP Evaluation of furniture design, texture, and height (comparisons)

Furniture CR = 0.021			
	Design	**Texture**	**Height**
Design	1	4	5
Texture	1/4	1	2
Height	1/5	1/2	1

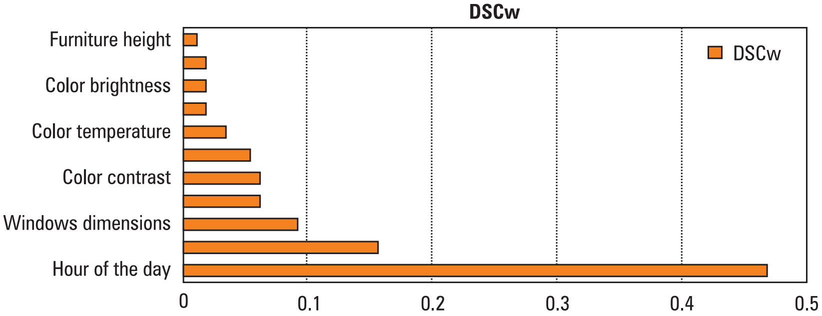
Table 7. AHP Evaluation of wall and ceiling color contrast, brightness, and temperature (comparisons)

Wall and ceiling colors CR=0.017			
	Color contrast	**Brightness**	**Temperature**
Color contrast	1	2	1
Brightness	1/2	1	1/3
Temperature	1	3	1



Source: Authors' own study

Fig. 2. Radar chart of the daylight criteria (DC) weights



Source: Authors' own study

Fig. 3. Bar chart of the daylighting sub-criteria (DSC) weights

3. Results

Upon reviewing the data, it aligns with previous studies confirming that the climate is the most critical factor for enhancing natural lighting in classrooms, with weight of 0.627. climate covers both time of day and weather conditions, indicating that daily variations in natural lighting significantly influence classrooms lighting. Research shows that fluctuations in natural lighting affect both academic performance and visual comfort. Since morning light has a different quality than afternoon or evening light, the time of day (weight 0.470) is crucial for maximizing lighting. Furthermore, the quantity of natural light that enters the classroom is decreased by weather factors like rain and cloud cover, which affects the overall illumination quality. This emphasizes how crucial it is to take weather and seasonal differences into account while planning for the best possible daylight exposure. Window come in second place with weight of 0.166, whereas shading orientation and windows dimensions are important sub-factors. The weight indicates that maximizing natural light flow and decreasing reliance on artificial lighting require well-designed windows.

For instance, by letting in more light, large, appropriately aligned windows can greatly enhance visual comfort. Window dimensions (weight 0.09) are especially important in this category. Higher daylighting and less reliance on artificial lighting during the day are achieved by larger windows. The third most significant component (weight 0.115) is the color of the walls and ceilings. Intensity, contrast, and color temperature are examples of sub-factors. Light-colored ceilings and walls reflect more light, which improves the room's natural lighting and distribution of light. Appropriate color selection has been shown to have a positive impact on concentration and visual comfort. The last item with the least direct effect on natural lighting is furniture (weight 0.092). Nonetheless, the way furniture is arranged, made, and raised can affect how light enters the classroom. Modern furniture with a strong sense of design can help distribute natural light more efficiently, which enhances visual comfort.

4. Conclusion

This study provides valuable insights into how architectural elements such as window orientation, color schemes and climatic conditions can be strategically integrated to improve daylight quality and visual comfort in classrooms. The findings of this paper highlights the fact that well-designed spaces can significantly enhance student performance and well-being, offering practical applications for school architects and designers. A single crucial aspect is the importance of optimizing window orientation and size to ensure consistent daylight penetration throughout the day, as illustrated by the upper-floor classrooms with north-south -facing windows. Architects should highlight dual-window orientation in future school designs to ensure better light distribution, especially in classrooms used during different times of day. Additionally, choosing brighter colors for the walls and ceiling is an effective choice to enhance light reflectivity, minimizing the need for artificial lighting and improving the overall learning environment. With a focus on creating a balance between artificial and natural lighting systems, these findings can be used as a reference for building and renovation efforts in schools. Among the realistic solutions are: Controlling glare with shade elements without obstructing vital daylight, using flexible furniture arrangements so that students may adapt to changing lighting conditions. and putting in place smart lighting systems that adjust artificial light in accordance with daylight availability. However, the study has several drawbacks. There were just nine members on the expert panel, which may have limited how broadly the results can be applied. Moreover, the study's geographic focus was limited to Ain M'lila, Algeria, thus the findings might not accurately represent lighting issues in schools situated in other climate zones. To improve the findings' applicability, future research should consider incorporating larger sample numbers and a more comprehensive regional focus. Finally, using of multi-criteria decision-making (MCDM) tools in this situation, including the Analytic Hierarchy Process (AHP), shows how useful it is to combine user feedback with objective environmental observations. Future attempts to create evidence-based design methods for raising the standard of learning environments can be guided by this paradigm. When this method is applied consistently, it guarantees that the opinions of educators and students are included in the design process, resulting in more practical, user-centered solutions.

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