Journal of Architectural Sciences and Applications
JASA 2024, 9 (2), 844-864
Research article
e-ISSN: 2548-0170
https://dergipark.org.tr/en/pub/mbud

The Influence of Daylight Availability on Thermal Comfort in Classroom Environments

Büşranur MERCAN [1*], Gizem İZMİR TUNAHAN [2]

ORCID 1: 0009-0003-0776-6535
ORCID 2: 0000-0003-1473-9351
[1-2] *Dokuz Eylül University, Faculty of Architecture, Department of Architecture, 35390, İzmir, Türkiye*
**** e-mail**: mercan1643@outlook.com*

Abstract

Daylight, a critical environmental factor influencing the visual quality of indoor spaces, significantly impacts human health and well-being. Despite extensive research focusing separately on daylight and thermal comfort, their relationship and their effects on human behaviour remain insufficiently understood. This study aims to investigate how daylight conditions affect students' thermal comfort in a classroom setting, using student observations along with thermal and daylight measurements. This study concludes that while daylight affects participants' thermal comfort and behaviour, its impact is influenced more by individual perceptions and adjustments, and other factors, such as activity levels, also play a significant role. The limitations of the study include a small sample size and the reliance on mobile phones for measuring indoor air quality and comfort levels. Future studies should improve the reliability and validity of the results by using larger sample sizes and more specialized measurement instruments.

Keywords: *Daylight, thermal comfort, thermal behaviour, indoor environment quality, sustainability.*

Sınıf Ortamlarında Gün Işığı Mevcudiyetinin Termal Konfora Etkisi

Öz

Gün ışığı, iç mekanların görsel kalitesini etkileyen önemli bir çevresel faktör olmasının yanı sıra insan sağlığı ve refahı üzerinde de önemli bir etkiye sahiptir. Gün ışığı ve ısıl konfor üzerine ayrı ayrı yapılan kapsamlı araştırmalara rağmen, bu iki faktörün ilişkisi ve insan davranışları üzerindeki etkisi yeterince anlaşılamamıştır. Bu çalışma, gün ışığı koşullarının sınıf ortamında öğrencilerin ısıl konforunu nasıl etkilediğini, öğrencilerin gözlemlenmesi ile termal ve gün ışığı ölçümlerinden faydalanılarak araştırmayı amaçlamaktadır. Bu çalışma, gün ışığının katılımcıların ısıl konforu ve davranışlarını etkilediğini, ancak bu etkinin daha çok bireysel algılar ve ayarlamalarla şekillendiğini, ayrıca etkinlik seviyeleri gibi diğer faktörlerin de önemli bir rol oynadığını ortaya koymaktadır. Çalışmanın kısıtlamaları arasında küçük bir örneklem büyüklüğü ve iç mekan hava kalitesi ile konfor seviyelerini ölçmek için mobil telefonların kullanılması yer almaktadır. Gelecek çalışmalar, bulguların güvenilirliğini ve geçerliliğini artırmak için daha büyük örneklem büyüklükleri ve daha özel ölçüm araçları kullanmalıdır.

Anahtar kelimeler: *Gün ışığı, ısıl konfor, ısıl davranış, iç ortam kalitesi, sürdürülebilirlik.*

Citation: Mercan, B. & İzmir Tunahan, G. (2024). The influence of daylight availability on thermal comfort in classroom environments. *Journal of Architectural Sciences and Applications*, 9 (2), 844-864.
DOI: https://doi.org/10.30785/mbud. 1495366

Received: *June 3, 2024 –* ***Accepted:*** *October 19, 2024*

1. Introduction

In reality, light serves the purpose of aiding human vision, and variations in light output and colour temperature have been shown to alter operator perception, cognition, and mood (İzmir Tunahan et al., 2022). Daylight is important for optimizing natural light in buildings. Due to the awareness of its effects on human health, it influences many design parameters such as the orientation of the building, the position and even the colour of the windows, wall colour, interior space dimensions, and ceiling height (Bellia et al., 2021). The presence of daylight also makes it important to create environmentally friendly structures as it contributes to the building's energy production. Daylight plays a crucial role in providing visual comfort conditions to ensure user satisfaction indoors. It is also a factor that stimulates metabolism, controls bodily functions and affects individuals' health and performance in their daily lives (Kutlu, 2019). Additionally, the effect of daylight on thermal comfort should not be overlooked. Thermal comfort is the comfort individuals feel depending on parameters such as environmental temperature, humidity level, and airflow. Controlling the thermal comfort of an indoor environment and developing design strategies are essential for ensuring the comfort of building occupants, enhancing their performance in daily life, and limiting the building's energy consumption (Chinazzo et al., 2019a).

Daylight utilization in architectural designs has been extensively studied mostly regarding its impact on health and well-being, and energy efficiency (İzmir Tunahan et al., 2022). However, studies focusing specifically on its effect on thermal comfort are fewer in comparison. In particular, there is a notable lack of research investigating these effects within the context of daily activity environments in specific settings. The literature review indicates that while experimental setups have been created for this purpose, the impact of daylight on thermal comfort under existing normal conditions, along with environmental influences, has not been measured. Furthermore, most of the studies conducted involve outdoor measurements, whereas the number of studies focusing on indoor environments is significantly lower.

Examining the relationship between daylight and the concept of thermal comfort is important to understand how a well-designed structure contributes to individuals feeling comfortable within indoor spaces. Researchers have claimed that thermal comfort and behaviour are the initial objective responses to the physical environment and strongly correlate with physiological reactions. The balance created in the indoor environment to achieve thermal preference or thermal comfort is seen as a reflection of the level of acceptability and emotions; this, in turn, makes it possible to form a thermal assessment (Chinazzo et al., 2019a). It has been found that exposure to intense light at the start of the day induces a quick increase in body temperature (te Kulve et al., 2016).

Indoor Environmental Quality (IEQ) and Indoor Air Quality (IAQ) encompass many factors such as lighting, acoustics, and thermal comfort (Ganesh et al., 2021). In recent years, it has been recognized that Indoor Environmental Quality (IEQ) is important for enhancing comfort and health in all aspects, and this awareness has led to various studies being conducted (Geng et al., 2017). The connection between building occupants and the natural landscape around them is primarily established visually through windows. Studies have shown that the position of windows has positive effects on the comfort and behaviour of building occupants (Jiang et al., 2022).

There are also PMV values created to measure thermal comfort, similar to IEQ. The Predicted Mean Vote (PMV) index is designed to determine the average thermal comfort of a group of people using physical and individual data. PMV values are calculated for each participant, based on environmental measures, such as air temperature and mean radiant temperature derived from measured globe temperature, air velocity, and relative humidity. Additionally, factors like clothing insulation and metabolic rate are taken into account as physical attributes (Chinazzo et al., 2019a). PMV is commonly utilized in evaluating thermal comfort and building design. The PMV value can serve as a guide to assess how comfortable or uncomfortable the thermal environment is for individuals. Improving the accuracy of the PMV index, as proposed in Zhang, Yao and Li's (2024) research, can enhance predictive advantages and lead to better performance in evaluating thermal conditions in building design (Zhang et al., 2024).

It has been found that research has been primarily focused on health and a few basic user satisfactions. Therefore, investigating the impact of daylight indoors and understanding its relationship with thermal comfort necessitates exploring behavioural dynamics. In this context, a study focusing on a classroom environment aims to address this knowledge gap in the literature. The fundamental purpose of the study is to monitor the behaviour of individuals in a selected classroom at Dokuz Eylül University Faculty of Architecture and to measure thermal comfort by observing daylight in the classroom environment.

2. The Role of Daylight in Thermal Comfort

For centuries, the sun, the most important renewable energy source for life on Earth, has been a natural source of energy. Before the discovery of various sources of energy production, people focused on the sun, developing designs to maximize its potential. Architects also consider harnessing daylight in their designs as an important criterion to ensure users can benefit from daylight optimally. The sun has been considered a natural lighting source and viewed as the ideal light source until the advent of artificial lighting sources. In indoor environments, especially enclosed spaces, daylight serves to reduce the building's energy consumption and aims to create visual quality in terms of lighting (Çiftçi & Arpacıoğlu, 2021). Especially in private residences, skylights are also utilized in addition to windows to maximize the use of natural light. Ensuring visual comfort, reducing the need for artificial lighting, and lowering energy consumption and costs are directly linked to the efficient use of daylight (Erdem et al., 2023). This situation often results in user dissatisfaction and may imply a deficiency in architectural design. The proper use of daylight can not only serve as an energy source but also enhance the quality of the indoor environment, thereby providing the comfort needed for an active lifestyle. This study aims to investigate how the impact of daylight on thermal comfort is reflected in users' behaviours. Particularly in work environments, exposure to direct daylight in areas near windows is not conducive to a healthy working environment (Figure 1). Therefore, it would be preferable to use areas near windows for circulation or relaxation purposes (Tatar, 2014).

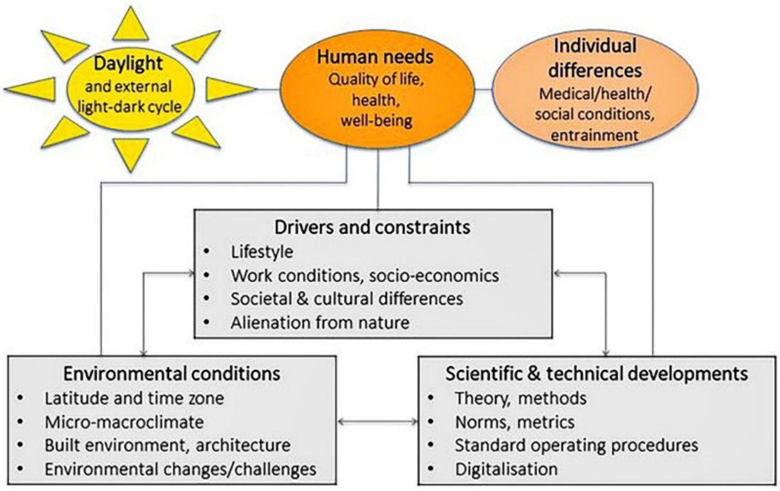


Figure 1. Daylight and other factors as determinants of human health (Münch et al., 2020)

The effects of natural light on spatial utilization can be examined in two primary categories: functional and symbolic. From a functional perspective, natural light should enhance visual comfort for the users of a space, improve the efficiency of activities carried out within the space, and meet the physical and psychological needs of users. In this way, the functional effects of natural light support users' daily activities, providing a healthier and more productive environment.

The Average Daylight Factor expresses the ratio of the total daylight flux incident on a plane to the area of the plane, relative to the outdoor daylight level under unobstructed overcast sky conditions. An Average Daylight Factor of 5% or higher indicates sufficient daylight presence within the space, while an Average Daylight Factor between 2% and 5% signifies situations that may require additional artificial lighting (Kılıç & Yener, 2017). In general, illuminance levels between 100 lux and 2000 lux are considered beneficial for users within a space. Research conducted on office buildings has determined the following illuminance ranges to be beneficial for workspaces (Mardaljevic & Nabil, 2005).

- Insufficient daylight illumination (<100 lux),
- Insufficient on its own, additional artificial lighting required daylight illumination (100<x<500 lux),
- Desired daylight illumination (500<x<2000 lux),
- Daylight illumination exceeding desired limits, causing thermal and visual discomfort (>2000 lux).

Architectural space can be perceived by users along with its boundaries and gains meaning by integrating with the life within it. Spatial elements provide limitations, guidance, and defining features in the perception of space (Bahar & Yalçınkaya, 2021). Outdoor climate comfort is influenced by microclimate conditions, along with various physical personal factors such as activity level, clothing, age, and psychological state, which affect the usability and perceptibility of outdoor spaces. Among these factors, air temperature, humidity, wind speed, and radiation fluxes (especially solar radiation) play crucial roles (Figure 2) (Menteşe & Koca, 2023).

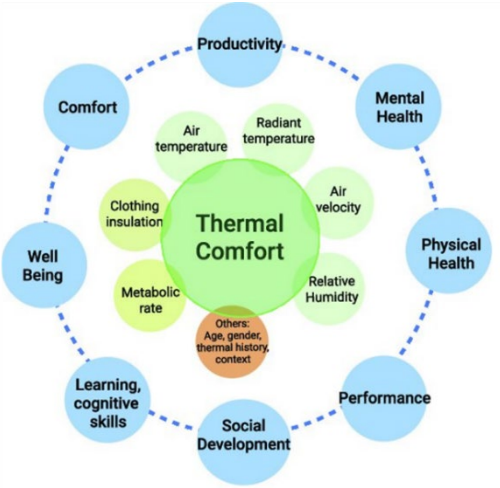


Figure 2. Thermal comfort factors and their effects (Lala & Hagishima, 2022)

Thermal comfort and the behaviours exhibited according to thermal comfort are of great importance in observing the satisfaction of users throughout their time in a place. Users achieve comfort when they achieve thermal balance in the space with the air temperature, globe temperature, and the temperature they emit to their surroundings. The PMV value, which helps to understand this value, provides information about how users feel according to specific conditions in which they are located. Understanding the PMV concept can provide insights into how researchers assess and measure thermal comfort experiences in indoor environments; this could be valuable for designing spaces that enhance users' well-being and productivity (Laouadi, 2022). If the PMV value is negative, people are generally expected to feel cold, while if it is positive, they are typically expected to feel warm. A PMV value close to 0 indicates an environment where people generally feel comfortable. It has been understood that besides the criteria necessary to calculate the PMV value, the selection of an external location is also important, and therefore observation parameters have been established (Toussakoe et al., 2023).

While daylight has been investigated in the context of energy efficiency and visual comfort, its effect on thermal comfort remains less understood (Table 1). Previous research has mostly focused on the effect of artificial lighting or temperature control systems on occupants' thermal comfort. However, little attention has been given to how daylight influences occupants' thermal perception and behaviour. This study seeks to address this gap by investigating how variations in daylight availability influence occupants' thermal comfort. Understanding this link has important consequences for building design, energy efficiency, and occupant well-being in the indoor environment.

Table 1. Literature survey on related topics in the last 10 years

Author/Year	Purpose	Method	Sample/ Location	Findings	Recommendations/Conclusions
Tatar, E. (2014)	Creating a new design that increases daylight usage, positively impacts work motivation, and incorporates sustainable solutions.	Case study	Studios	The use of daylight in architectural design is important for human health, psychology, spatial quality, and visual comfort.	Intentional daylight design increases comfort in workspaces and reduces glare and overheating. This helps people feel comfortable and happy, positively affecting their work motivation.
te Kulve, M., Schellen, L., Schlangen, L. J. & van Marken Lichtenbelt, W. D. (2016)	The article aims to highlight how light affects non-visual responses such as alertness, mood, and circadian rhythms beyond vision.	Literature Survey	48 articles	Light can trigger physiological responses not directly related to visual perception; for example, temperature regulation.	Light can evoke thermos-physiological responses, while visual input can alter the perception of the thermal environment.
Geng, Y., Ji, W., Lin, B. & Zhu, Y. (2017)	To examine the effects of indoor air quality (IAQ), lighting, acoustics, and overall environment, as well as the relationship between the thermal environment and occupant satisfaction and productivity.	Experimental Study	7 groups in the office environment	The thermal environment has a comparative effect on indoor air quality (IAQ), lighting, and acoustic perception.	Thermal discomfort is more pronounced in cool or cold conditions compared to warm or hot conditions.
Kılıç, Z., A. & Yener, A. (2017)	The purpose of this article is to emphasize the effective use of daylight in buildings and to propose metrics to enhance daylight performance in office structures.	Case Study	Office environment	The sensitivity of various daylight performance metrics has been determined.	Although no metric provides a complete assessment for successful daylight design, each offers evaluation services for different designs and rooms.
Chinazzo, G. Wienold, J. & Andersen, M. (2019a)	To investigate how daylight influences human thermal responses in indoor environments.	Experimental Study	84 participants	It shows that the amount of daylight affects people's thermal perception, particularly leading to a cross-modal effect.	Daylight should be considered a factor in thermal comfort models and research. Building operation and design strategies must be adjusted and modified to ensure the thermal comfort of occupants.
Münch, M., Wirz-Justice, A., Brown, S. A., Kantermann, T., Martiny, K., Stefani, O., Skene, D. J. (2020)	The effects of decreasing daylight and increasing electric lighting in urban areas on human health and quality of life, and to categorize the knowledge gaps into three groups.	Workshop	Members of Daylight Academy	The need to develop new tools, methods, and approaches is significant, and some possibilities are highlighted here.	New techniques are needed to monitor and assess exposure to daylight in the field.

Author/Year	Purpose	Method	Sample/ Location	Findings	Recommendations/Conclusions
Bahar, Z. & Yalçınkaya, Ş. (2021)	To explore the approaches for utilizing natural light in design, enabled by advancing technologies and construction techniques	Case Study	Buildings of Jean Nouvel	With metallic brise-soleils, reflective glass, light-sensitive motorized systems, sun-shading technologies, and brie-soleil glass, it has controlled the light entering the space and ensured the buildings' energy efficiency.	The view of natural light as one of the simplest and most effective ways to shift spaces from static to dynamic highlights the importance of daylight in spatial design.
İzmir Tunahan, G., Altamirano, H. & Teji, J., U. (2021)	To understand the relationship between seating occupancy and the availability of daylight.	Case Study	UCL Bartlett Library	Although daylight significantly influences seat selection, students' seating preferences cannot be explained by daylight alone.	Studies should continue to include individual perception alongside occupancy data, considering factors such as privacy, outdoor views, quietness, and daylight conditions.
Bellia, L., d' Ambrosio Alfano, F. R., Fragliasso, F., Palella, B. I. &	To investigate how warm and cool light affects thermal perception at different temperatures through an experiment using white adjustable LED sources.	Experimental Study	163 participants	Warm light appears to reinforce a warmer thermal sensation.	Due to thermohygrometric conditions close to comfort, there was no effect on thermal evaluation and preference in either microclimate scenario.
İzmir Tunahan G., Altamirano H., Teji, J., U. & Ticleanu C. (2022)	To develop a methodology for evaluating daylight perception within the context of cultural background.	Experimental Study	50 participants	It was found that the subjective rating and seat preference methods were consistent with actual daylight levels. However, the participants' boundary lines did not reflect the actual presence of daylight in the area.	In the context of cultural background, individual daylight perception can be evaluated using subjective rating and seat preference methods.
Kutlu, R. (2019)	To examine the effects of sunlight on climatic comfort and the performance of transparent surfaces, demonstrating how natural light can be utilized in lighting design.	Literature Survey	--	Using daylight in design is not difficult, but it requires the integration and optimization of many factors concerning user comfort and energy management.	The necessity of addressing design with a holistic approach is emphasized through the impact of design decisions on energy costs, drawing attention to the topic.
Çiftçi, M. E. & Arpacıoğlu, Ü. (2021)	To examine the contributions of daylight redirecting systems developed in the 19th century to indoor lighting and comfort, as well as their benefits in contemporary architecture.	Evaluation and rating method	Based on 6 criteria, systems are divided into two groups according to direct and diffuse light types.	The impact of artificial lighting on energy consumption can be reduced by using daylight lighting systems, which provide benefits for both people and the environment.	Daylight transport systems are important for both using sustainable energy sources and ensuring visual and thermal comfort in spaces.

Author/Year	Purpose	Method	Sample/ Location	Findings	Recommendations/Conclusions
Ganesh, G. A., Sinha, S. L., Verma, T. N. & Dewangan, S. K. (2021)	To examine the effects of Indoor Environment Quality (IEQ) on human comfort and health.	Literature Survey	Published articles in the last 10 years	Various indoor environmental quality (IEQ) issues, such as sick building syndrome, cold air drafts, and hot-cold radiation, are being discussed.	It is no longer sufficient to design a static building; the building design must also be tested for the health, performance, and well-being of its occupants.
Lala, B. & Hagishima A. (2022)	To investigate the thermal comfort of primary school students and discuss the challenges specific to children in machine learning-based predictions	Articles published since 1962/ Primary school students	Literature Survey /Case Study	A case study on AI/ML shows that model performance is significantly different for children and adults.	Further research is necessary to elucidate the impact of temporal factors, such as circadian rhythm and time of day, on thermal comfort predictions.
Jiang, Y., Li, N., Yongga, A. & Yan, W. (2022)	To investigate the effects of visual windows that provide natural views and daylight on thermal perception, health, and energy savings	19 participants	Experimental Study	It was found that participants with visual windows felt more comfortable in cool conditions.	This research provides evidence that biophilic design elements affect thermal comfort, stress levels, and fatigue.
Erdem, Y. D., Yılmaz Erten, Ş., & Umaroğulları, F. (2023)	To highlight the effects of daylight on energy savings and indoor comfort, and to address efforts related to energy efficiency and sustainable architecture.	2 builder models	Case study	Daylight levels are efficient in single-story buildings, but in multi-story structures, the efficiency decreases as one moves from the upper floors to the lower floors.	Daylight must be efficiently delivered to lower floors by coating the skylights with reflective surfaces and considering the size of the windows opening to the skylights.
Menteşe, S. & Koca, S. (2023)	To examine the thermal comfort conditions of the outdoor environment.	Bilecik, Turkey	Case study	The PET index analysis revealed that thermal comfort varies throughout the year and is only at an optimal level in May.	No season directly falls into the 'comfortable' category in the work area. The season' s closest to the comfortable
Zhang S., Yao, R. & Li, B. (2024).	To propose a new algorithm to enhance the performance of the PMV index.	14 climate zones	Data Analysis	The new algorithm-based PMV index can effectively avoid the 'zero crossing' issues in the original solution process, match data with low errors under various thermal conditions, and improve average performance by 34.5-37.7% compared to previous optimization methods.	The new PMV curves demonstrate a better fit with actual TSV and can significantly reduce predicted deviations across various temperature ranges.
Cılasun Kunduracı A. & Kızılörenli E. (2024)	To evaluate the efficiency of TDGS and movable shading elements in enhancing daylight performance in a deep-plan layout that receives daylight.	Classroom/ Studio	Measurement and simulation	Compared to the existing condition scenario, the design proposal increased daylight usage for each area and met the latest LEED daylight criteria, requiring at least 55% sDA and a maximum of 10% ASE in the workspace.	The proposed design strategy has demonstrated that a large portion of the area meets LEED criteria and that the systems work effectively together.

3. Material and Methods

The study's primary goal is to evaluate daylight's effect on individual thermal comfort in a classroom setting. To achieve this goal, days with intense classes were initially selected. It was decided to assess a total of six different days during the last week of March, which has the highest average student attendance, continuing into April 2024. Additionally, the classroom location was determined by considering the times when maximum classroom usage was ensured. It was also taken into account that the selected classroom should be easily accessible. After identifying the classroom, observations were conducted during afternoon classes between 1:00 PM and 4:00 PM on Mondays, Tuesdays, and Fridays, when the classroom was most frequently used. The specific observation days were March 25, 26, 29, and April 1, 2, 5. The focus of the study was on behaviours. Therefore, the main approach was to observe participants during the class sessions to determine whether they were affected by daylight and to make notes of those moments.

3.1 Development of the Evaluation Process

The methodology of the research was developed through a systematic approach consisting of specific stages. At the beginning of the study, appropriate environments and users were selected to understand the impact of daylight on thermal comfort and behaviours. However, sufficient devices that could be used within the methodology of the study could not be accessed. Instead, a more accessible systematic method was developed, considering the purpose and progress of the study, allowing for easier adaptation. For this purpose, improvements were made based on the results of the pilot study, facilitating further development (Figure 3).

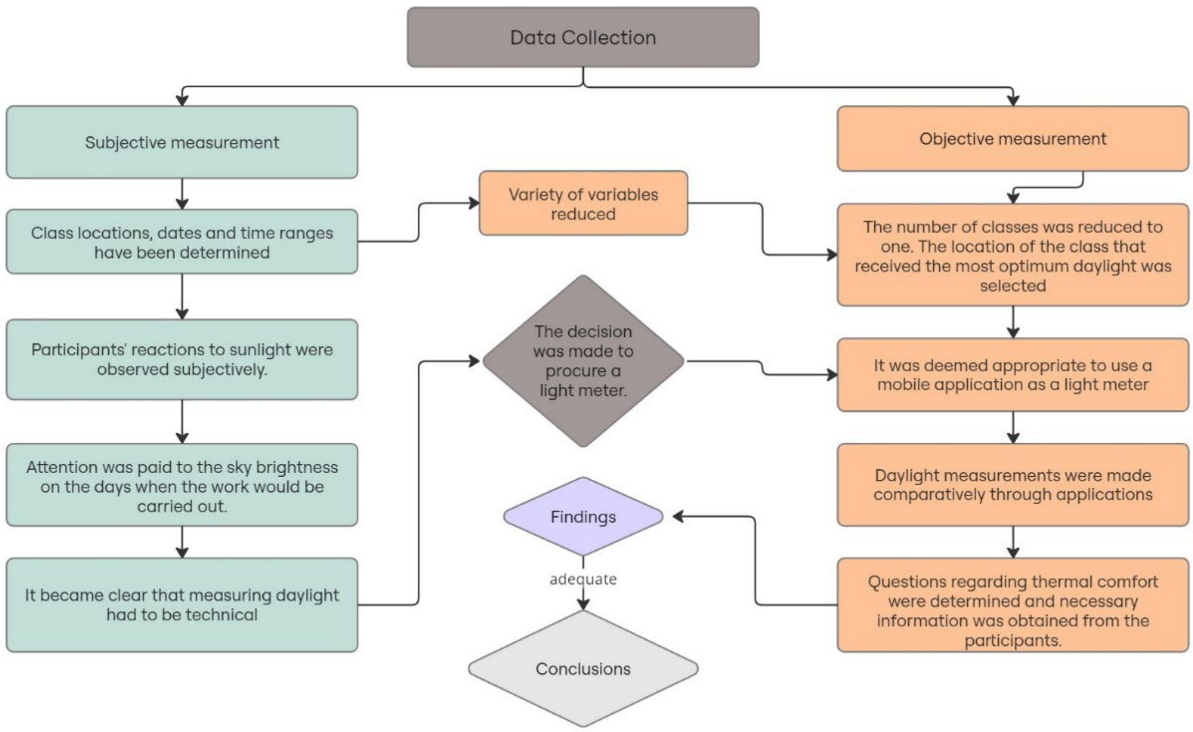


Figure 3. Flowchart of the methodology stages

Stage 1

In the initial stage of the study, two classes were identified, and these two classes were examined on the same days of the week (Figure 4). Photographs were taken from the classes, and the brightness levels of the photographs were compared. On days determined to have bright daylight, students were observed, and at this stage, only the answer to the question "How do you feel in terms of thermal comfort?" was expected. Additionally, no information was collected from the observed individuals, and only the colours of the clothing they chose were noted. As a result of the first stage, parameters were developed. The thickness of the clothing and any extra jackets they brought with them were questioned, and age, height, and weight information were requested.

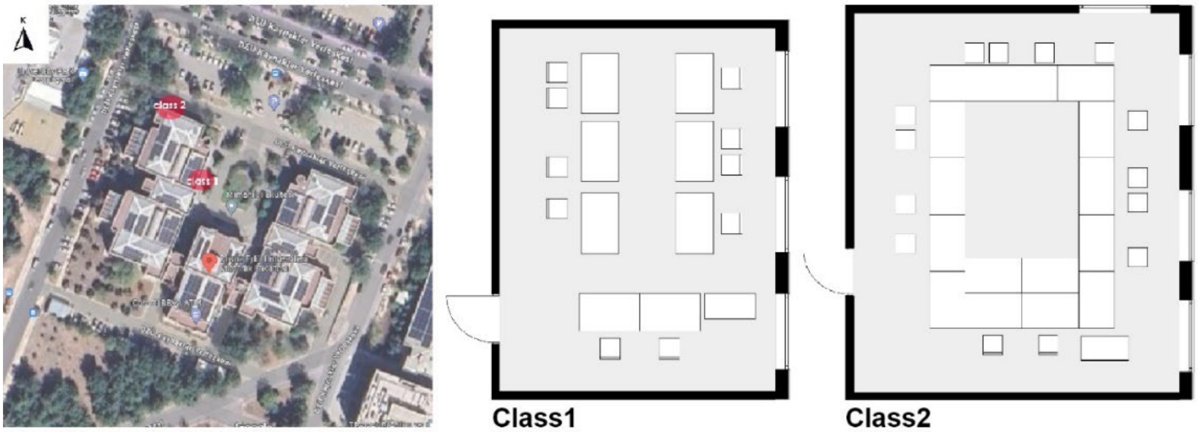


Figure 4. Stage 1- Selected classroom locations and plans

Stage 2

At this stage, thanks to improvements made in observations and parameters compared to the pilot study, more detailed feedback was obtained from the individuals observed. However, the various locations of the assigned classrooms made it difficult to achieve precise results when measuring and comparing daylight values (Figure 5). Thus, it was determined that there would be only one class. Additionally, the number of days was increased, and the number of students was also increased.

Figure 5. Comparison of the daylight availability in different classrooms

Stage 3

In the final stage, efforts were made to find a device for accurately measuring daylight values. However, due to the institution's limited resources, a measurement device could not be found. Instead, additional research was conducted to explore daylight measurement methods, and it was concluded that mobile devices could be used (Figure 6). This enabled the measurement of daylight values, resulting in a more accurate measurement of the Predicted Mean Vote (PMV) value.

3.2. Measurements

Since this study takes place in a school environment and involves observing behaviours, daylight measurements were conducted using a mobile application. During the literature review, it was found that mobile applications provide measurements of daylight at least as accurately as conventional daylight measurement tools, with a negligible margin of error (Gutierrez-Martinez et al., 2017). The conclusion of this study indicates that smartphones can be used in methodological studies where highly precise measurements are not necessary (Figure 6). Additionally, there is no objection to using smartphones due to advancements in technology and the improved sensor features of smartphone cameras during the time frame in which this study was conducted. This is because the PMV (Predicted Mean Vote) value to be measured in the determined thermal behaviour observational process does not require high precision.

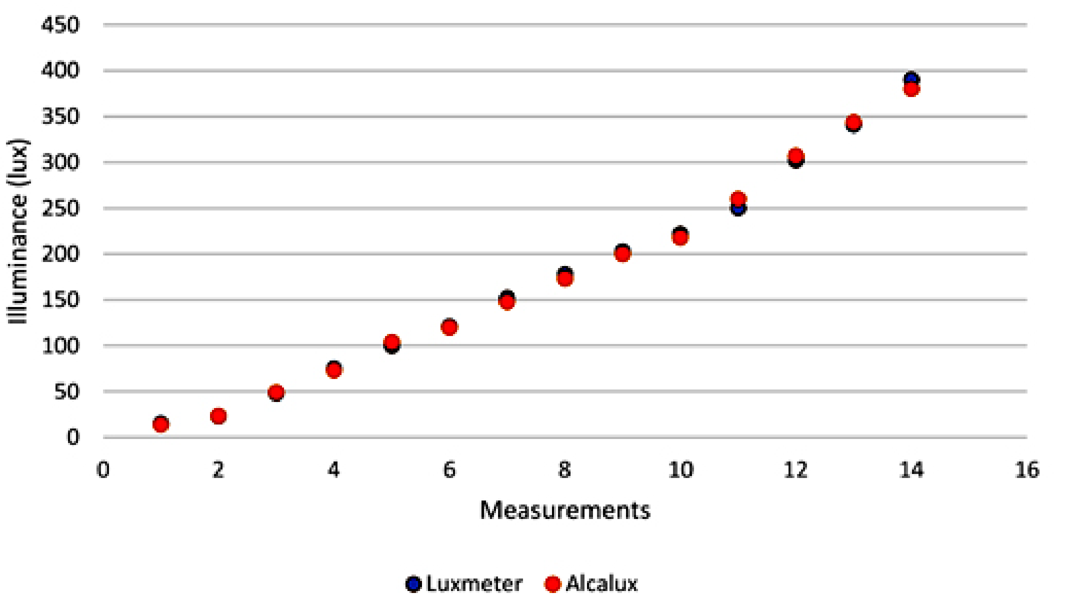


Figure 6. External sensor device (Alcalux) vs. luxmeter accuracy (Gutierrez-Martinez et al., 2017)

During daylight measurements, a 2021 model Samsung Galaxy Note 20 Ultra was used. The values at the measurement points were measured using the three highest-rated applications within smartphone applications, and then their averages were calculated. Thus, the aim was to obtain the most accurate data possible and minimize the margin of error. The window that received the most daylight from the windows in the classroom was selected, and a location marking was made. Each day, the smartphone was placed in the same location for measurements, and daylight measurement was first taken from the outdoor environment. Then, the midpoint of the student desks was calculated and determined to mark the positions of these measurement points inside the classroom. While one of the students faces the daylight (window), the other students turn their faces away from it. Observations were made regarding where the students sat in the classroom, and it was taken into consideration because it was determined to be essential by studies examining the effect of daylight on seat preferences (İzmir Tunahan et al., 2021).

3.3. Details of the Selected Classroom

The selected classroom for measurements is located in the southwest corner of the faculty building. After the initial stage of the study, the number of classes was reduced to one, and the number of days was increased. When selecting the chosen classroom, attention was paid not only to the intensity of light but also to the higher student usage. The other classroom, located northwest of the faculty building, was not selected by the institution for graduate-level courses (it was understood to be an additional classroom in case of need), and it was also understood that students did not prefer it for studying or waiting during breaks. This constitutes an important output of the pilot study. Additionally, it receives maximum daylight, especially during midday hours. The classroom is located on the ground floor of the faculty building, which makes it easily accessible (Figure 7).

Figure 7. The selected classroom's location and plan

Being close to the entrance of the architectural department building, which consists of three floors including a basement, students entering the classroom can reach it without much fatigue. Its three large windows allow direct daylight into the interior. The walls of the classroom are painted in light colours, providing a generally airy environment. The curtains of the classroom are dark red and are thick enough to almost completely block out daylight when used, especially during presentations. When these curtains are drawn during presentations, students create a dark environment, resulting in nearly 80% of the two-hour class being conducted in darkness (Figure 8).

Figure 8. The selected classroom

3.4. Participants

After the literature review of "thermal comfort", "daylight" and "mental health", a classroom was determined in the Faculty of Architecture of Dokuz Eylül University Campus. The majority of graduate students in the class are female, typically characterized by those who are accepted into the graduate program for that semester. Among the instructors teaching the selected courses, only two are male. Apart from them, there is only one male student enrolled in the class. Since the ages of the observed individuals were close to each other, it was understood that there were no noticeable differences in metabolic rate. The participants were selected from individuals admitted to postgraduate studies during the period when the educational program was conducted, including both postgraduate students and the teaching staff. Parameters for understanding thermal comfort were established through behaviour-oriented studies, and a mixed method was employed. For the final stage of the study, participants were asked to provide their age, weight, and height to generate the Predicted Mean Vote (PMV). This method aimed to achieve a more subjective outcome for the study. Moreover, as the study progressed from the beginning, the development of the methodology was also taken into consideration.

The parameter ranges for which the PMV index can be evaluated are as follows (Li-Xin, 2002);

- Metabolic Rate: 0.8 – 4 met
- Clothing Insulation: 0 – 2 clo
- Dry Air Temperature: 10 – 30°C
- Radiant Temperature: 10 – 40°C
- Air Velocity: 0 – 1 m/s

Collecting factors such as age, height, and weight, which are necessary for metabolic rate, is important for generating the PMV value in the study. The fact that the students in the classroom environment were young and energetic, and their weights were close to their ideal weights, is also important for the basal metabolism of a sedentary individual and for the temperature and comfort they felt at that moment (Table 2).

Table 2. Participant characteristics

Gender	Sample size	Age (y)	Height (m)	Weight (kg)
Female	14	32,1	166,5	58,2
Male	3	44	180	70,3

3.5. Methods for Collecting Thermal Responses

On the days when observations were conducted, the classroom environment was pre-ventilated and curtains were opened to achieve an optimal condition before usage commenced. In this scenario, any changes made by the individuals in the classroom were noted. After spending a certain amount of time in the space to establish thermal comfort (typically requiring a short duration like ten minutes), participants were asked, "How do you feel?" to record their initial impressions (Table 3). Following the responses from the participants, they were asked about the reasons for their choice of clothing on that day to understand the diversity of clothing preferences. This question aimed to gauge the thickness of the clothing worn. Since clothing thickness typically falls between 0 and 2, a value was assigned to represent the thickness of the clothing.

Table 3. Questions to ask during observation

Questions to Ask During Observation					
How do you feel in terms of thermal comfort? (score)	1	2	3	4	5
What should the preferred outfit be like today?	Thick (2)			Thin (0)	

The basic parameters for observing participants' behaviours were primarily established by drawing upon findings from other studies. Firstly, the parameter of clothing choice was calculated to generate a PMV (Predicted Mean Vote) value. Body movements directly related to thermal values were also deemed significant. For instance, behaviours such as waving hands to create airflow when feeling hot, swinging legs, or shifting chairs were noted. Additionally, interventions related to lighting were included as parameters. The opening and closing of curtains determined natural lighting while turning the classroom lamp on or off indicated behaviours related to artificial lighting. Changes made to door and window openings for airflow or repositioning were also recorded. At the end of the entire class session, participants were asked, "How do you feel in terms of thermal comfort today?" to understand their clothing choices or behavioural correlations.

4. Findings and Discussion

In daylighting, external environmental factors such as climate, weather conditions, and the latitude of the location are important. Additionally, the orientation and geometry of the building, daylighting strategies, the form and material properties of solar control elements, as well as the shape, position, and light transmittance properties of light-transmitting surfaces are key parameters in determining the penetration and distribution of daylight within the interior space (Çiftçi & Arpacıoğlu, 2021). After measurements and observations in the initial stage of the study, it was decided that there were deficiencies, and it was accepted as a preliminary study as a result. Subsequently, the methodology was revised to evolve into a more systematic study based on daylight measurements. As a result of this preliminary study; in this study, the thermal comfort effects of daylight on users were investigated on 5 different days in the same locations, ensuring that many variables remained constant. Throughout the observation period, the temperature balance remained consistent. The temperature fluctuated approximately 9°C, ranging between 18°C and 27°C. These temperature changes observed at the end of March and the first week of April resulted in significant fluctuations in outdoor conditions and daylight balance. It appears that students first check the weather conditions when setting out for school in the morning, and then decide on their clothing based on whether the sky is cloudy or clear. The initial data reveals that daylight can alter human subjective thermal perception from a psychological standpoint, with the effects being linked to the thermal environment in which users are exposed.

On the days when observations were conducted, the daylight values in the outdoor environment were as follows:

- The lowest daylight illuminance: 2600 ± 50 lx
- Medium daylight illuminance: 27350 ± 50 lx
- The highest daylight illuminance: 116500 ± 50 lx

The average values of daylight measured in the indoor environment are as follows:

- The lowest daylight illuminance: 33 ± 5 lx
- Medium daylight illuminance: 100 ± 5 lx
- The highest daylight illuminance: 140 ± 5 lx

When these values were measured, average values were taken as they were measured from three different applications. The presence of plus and minus indicates the quantitative difference between the applications (Mardaljevic, 2023).

On days when observations were conducted, there were instances of both cloudy skies and clear skies, as the daylight conditions varied. Although a clear sky is not directly correlated with the brightness of daylight, it significantly influences it (Dolnikova et al., 2022). Therefore, these days were chosen to minimize the effects as much as possible. However, it was understood that the presence of clouds did not necessarily correlate with lower levels of daylight. Additionally, before the observation process in the classroom began, ventilated curtains were opened, lights were turned off, and the environment was optimized. Nevertheless, it was observed that users could change these factors in the space according to their preferences.

4.1. Observations and Analysis of Thermal Comfort and Daylight Interaction

Shortly after exposure to daylight, participants were asked two general comfort questions. Firstly, similar to the thermal comfort question, participants were asked why they chose their clothing and for general judgements in terms of thickness, simply asking them to identify it as thick or thin (Table 3). The participants were then asked to rate their present thermal comfort on a scale of 1 to 5, with 5 meaning "very comfortable" and 1 meaning "very uncomfortable."

Understanding the impact of buildings on users alone is not sufficient; it is essential to adopt an approach that aims to improve user health. Therefore, in the design, construction, and evaluation processes of buildings, structural and spatial characteristics must be considered alongside user health as a crucial criterion (Şentürk Sipahi & Yamaçlı, 2021). When observing participants' behaviours, it was noted that their clothing choices tended to be of moderate thickness relative to the ambient temperature. However, on some days (for instance, the third day), unexpected rainfall led to rapid changes in temperature. The interaction between clothing and daylight can influence the overall aesthetic experience of spaces. Glossy surfaces have the ability to reflect and direct daylight rays in a specific direction because they maintain a consistent angle of incidence and reflection. These surfaces exhibit both a shiny and shimmering appearance, and the intensity of the illumination varies depending on our viewpoint. This indicates that the surfaces in our environment have a significant impact on our perception of daylight and contribute to shaping our luminous environment (Grønlund et al., 2024). Nevertheless, this did not significantly impact participants' thermal comfort levels, as indicated by their responses to the thermal comfort rating question, where they reported feeling comfortable. Participants indicated feeling thermally uncomfortable on days when they believed they had chosen their clothing incorrectly. Furthermore, on days when clothing thicker than level 1,5 was chosen, temperatures ranged between 25 and 26 °C. On these days, daylight values varied considerably, indicating a direct relationship between participants' clothing choices and environmental conditions (Table 4).

Table 4. Behaviour parameters

Parameters	Day 1	Day 2	Day 3	Day 4	Day5	Day 6
Outdoor Daylight (Lx)	10770	20446	4741	2667	116570	9018
Indoor Daylight (Avg. Lx)	56,6	110	50	32	129	40
Clothing Choice (Avg.)	1,8	1,5	1,5	1	1,2	1
Body Movements	+	+	+	-	-	-
Behaviour Associated with Natural Light	+	-	-	+	-	+
Behaviour Associated with Artificial Light	-	+	+	-	+	-
Behaviour Related to Airflow	+	+	-	-	-	+
Displacement Process Behaviour	+	+	-	-	+	+
Participants' Thermal Comfort Score (Avg.)	3	2	1	3	4	4

In another study by Chinazzo (2019b), the focus is on investigating the thermal and visual comfort evaluations of daylight transmitted through spectrally selective glass, as well as its overall impact on indoor comfort. However, the study primarily discusses the effects of daylight colour and temperature on comfort perceptions, without specifically addressing the influence of clothing on comfort assessments. The type of clothing individuals wear can significantly influence how they perceive and experience thermal conditions in a given environment. Therefore, there is a recognized need to develop methodologies with a tendency towards observing this aspect, as it is crucial for enhancing understanding in this area (Chinazzo et al., 2019b). Participants' clothing choices were not only measured to assess the PMV value but also to observe whether they changed their clothing based on daylight when exhibiting behaviour to leave the environment. This formed a sub-question of the study. The importance of participants bringing a jacket with them is significant in this regard.

Participants' hand and foot movements during class were also observed. Some conscious or unconscious movements, such as swinging legs when feeling warm, moving hands to feel air, or tying up hair, were noted. Particularly on the first, second, and third days, intense body movements were observed, correlating with lower thermal comfort ratings.

- First day, on 25th March, the daylight value of 10770 is considered acceptable as an average value for outdoor conditions, but its reflection in the indoor environment is considerably low. In a classroom setting, an average of 56.6 lux falls below the daylight value that an individual should ideally receive.
- Second day, on 26th March, compared to the first day, a higher value of 20446 lux was measured in the outdoor environment on the second day, resulting in an effect indoors that was twice as much as the outdoor value. However, despite the expected minimum daylight value of 100 lux on the second day, it was observed that artificial lighting was turned on and the perceived level of comfort decreased to 2 in terms of thermal comfort compared to the first day. One of the main reasons for this was that participants wore lighter clothing, mistakenly assuming the thermal comfort from the previous day.
- Third day, on 29th March, the daylight value outdoors was measured quite low at 4741 lux compared to previous days. However, due to lighter clothing choices compared to previous days, the thermal comfort decreased to 1 point. Additionally, since the daylight value indoors was less than the expected 50 lux, a change in artificial lighting was observed.
- Fourth day, on 1st April, which recorded the minimum daylight value of 2667 lux, the value measured indoors naturally was the lowest at 32 lux. Therefore, artificial lighting was turned on. However, thermal comfort was mostly considered as 3.
- Fifth day, on 2nd April, which had the highest daylight value of 116570 lux, the indoor value was also the highest on average at 129 lux. It was observed that participants exhibited leaving the classroom behaviour, with thermal comfort being considered as 4. This behaviour could be considered as an attempt to balance the outdoor daylight with the indoor environment.
- Sixth day, on 5th April, the daylight value was measured at 9018 lux, similar to the first day. It was observed that participants exhibited leaving the classroom behaviour, despite the indoor value being 40 lux.

When evaluating daylight quality and glare sensation indoors, it indirectly emphasizes the importance of artificial lighting measurements and standards (Garretón et al., 2016). The relationship established by participants between natural and artificial light was also examined. This was because presentations are sometimes given in the classroom environment, leading to the closure of curtains. However, on days when natural light was not bright, it was observed that the curtains remained open during presentations. Additionally, it was noteworthy that on the fourth day, for example, when natural light was at its lowest, curtains were open and artificial lighting was used despite no presentations taking place. According to IESNA standards, the recommended brightness ratio for optimal lighting conditions indoors is 1:20. The 1:20 brightness ratio guide serves as a practical criterion for lighting designers and architects to enhance artificial lighting quality in various indoor spaces, ultimately improving the overall visual environment for occupants. A direct relationship between the use of natural and artificial light was identified (Samiou et al., 2022). Additionally, the importance of curtains inside the classroom is significant due to the shading that will be implemented. The installation of shading devices can provide solutions to glare issues; however, glare reduction measures may further restrict daylight penetration into the deeper areas of the room (Cılasun Kunduracı & Kızılörenli, 2024). Furthermore, it was noticed that participants generally only fully closed one of the two curtains in the classroom while leaving the other partially open.

Similarly to the direct relationship established with light, some changes related to airflow are among the parameters affecting the classroom environment. Yang & Shekar (2014) conducted several experiments in their studies on airflow, investigating both turbulent and stagnant airflow conditions. According to their study, the behaviour of opening windows provides significant information about users' thermal comfort (Yang & Sekhar, 2014). On days with intense daylight, compared to other days when it was measured lower, the preference for opening windows was not observed. However, airflow was considered important on days with average brightness measured between 9000 and 21000 lux. One reason for this might be associated with users' tendency to move away from windows on days with intense daylight. Additionally, it is understood that participants' desire to go outside decreases on days with low daylight brightness, leading to a reduced need to move away from windows and towards artificial light, thereby exhibiting such behaviours.

After observing these parameters, the PMV value was calculated. Firstly, the metabolic rate (M) of the participants was calculated. For this purpose, participants were asked for their age, height, and weight values. Upon examining the participants' characteristics, it was found that their physical attributes were similar, with no extreme differences. However, after calculating the metabolic rates of individual participants, an average value was obtained. Metabolic rate is a value used to calculate the calories burned by a person at rest. Taking into account light levels, activity, and food intake, it can be hypothesized that the higher metabolic rate observed in individuals exposed to light levels above 500 lux during the day may contribute to this result (te Kulve et al., 2016)

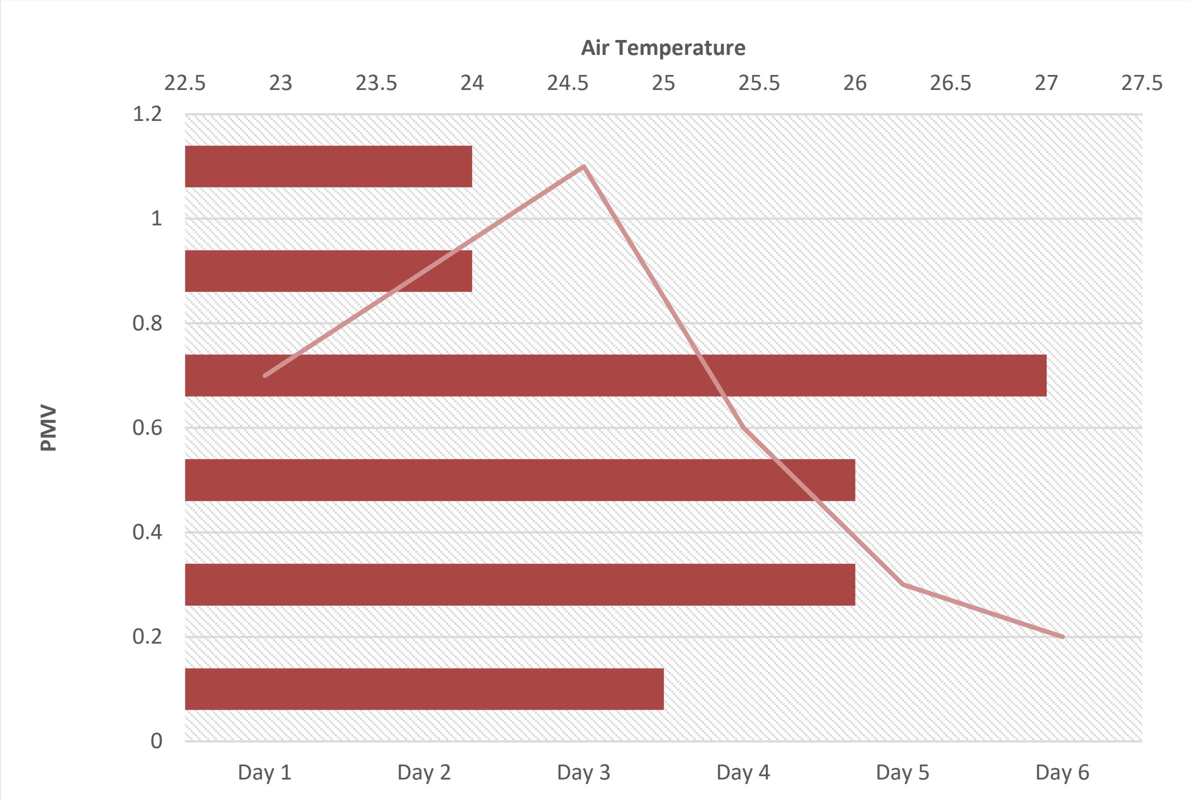
Taking into account that participants were exposed to a maximum of 140 lux in the classroom environment, it is understood that the variability of a metabolic value is not of significant importance for this study. However, it is still important to gather information about an individual's physical characteristics to understand changes in their behaviour (Haddad et al., 2013). Therefore, this value has been considered, but it has not been accepted as a parameter with intense sensitivity. One reason for the thermal comfort responses given by individuals in the classroom environment being so close to each other is also that the importance of this variable is less influential compared to other variables.

The clothing insulation value was measured by considering the material of the fabric used in the garment. If the participant wears a t-shirt without any garment on their arms, it is given a value of 0, while if they wear a wool sweater providing the highest insulation, it is given a value of 2. The values found are determined according to these clothing layers. The metabolic rate was measured electronically using a website (https://www.calculator.net/bmr-calculator.html) that calculates basal metabolism. PMV (Predicted Mean Vote) measures comfort on a 7-point scale from +3 ("Very Hot") to -3 ("Very Cold"), with 0 indicating "Neutral."

Table 5. Average predicted mean vote value (Quadco Engineering BV, 2024)

Days	Air Temperature (ta)	Mean Radiant Temperature (tr)	Air Velocity (VA)	Relative Humidity (RH)	Clothing (clo)	Metabolic Rate (M)	PMV
Day 1	25	28	0,1	30	1,8	1,3	0,7
Day 2	26	27	0,5	50	1,5	1,3	0,9
Day 3	26	28	0,8	50	1,5	1,3	1,1
Day 4	27	25	0,5	30	1	1,3	0,6
Day 5	24	26	0,5	30	1,2	1,3	0,3
Day 6	24	25	0,5	30	1	1,3	0,2

Considering the temperatures and the value of daylight over the six days, it was observed that the weather was not excessively hot, which directly influenced thermal comfort (Table 5). The PMV value did not exceed 2 or fall below 0, indicating that the environment was neither too hot nor too cold. The proximity of the PMV value to zero corresponds closely with the ratings given by users for each day (Figure 9).



	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Air Temp.	25	26	26	27	24	24
PMV	0.7	0.9	1.1	0.6	0.3	0.2

Figure 9. Comparing the calculated PMV values across days

Understanding the effects of thermal comfort perception can lead to improved building and environmental design strategies that enhance occupants' well-being and productivity. (Laouadi, 2022). In this context, the sixth day, with a daylight level above 9000 lux, was closest to optimum thermal comfort, with the majority of participants giving a rating of 4 (comfortable) (Figure 10). According to the results of many studies, it has been determined that the lighting level should not be below 550 lux and the highest satisfaction level is achieved between 600 and 650 lux (Fakhari et al., 2021). However, in this study, the light falling on the classroom being below these lux values implies that it could negatively affect the individuals in the classroom. This indicates that even on days when daylight is not excessively bright, participants can feel comfortable. In this regard, it was observed that on days when daylight was not too bright, participants balanced the temperature between the outdoor and indoor environments. Participants formed a perception of temperature based on the brightness level of daylight, and they began to feel comfortable as a result of expectations that fell below this perception.

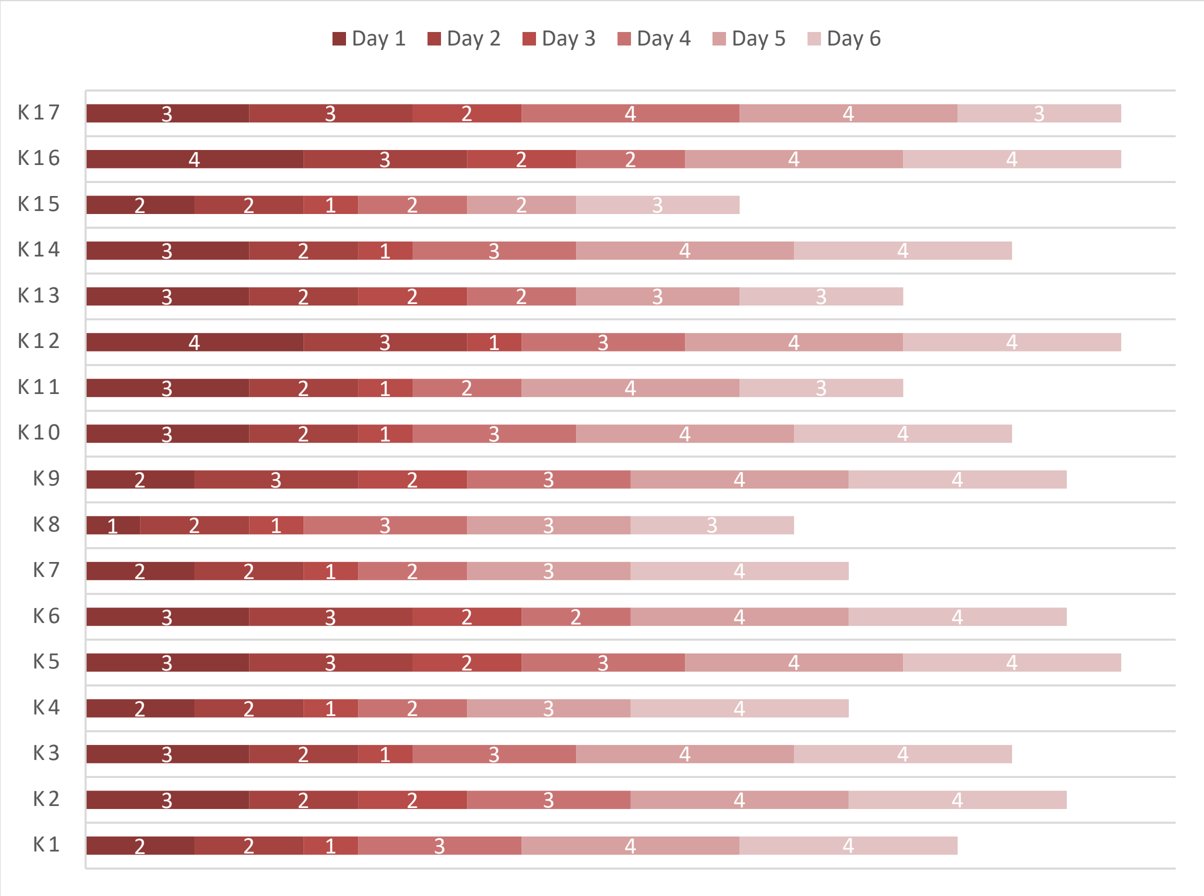


Figure 10. Participants' thermal comfort score

4.2. Limitations and Future Research

This study has several limitations regarding occupants' daylight perception and thermal comfort. First, the measurement of illuminance levels was conducted using a mobile phone's light sensor due to the lack of access to a lux meter. While mobile phone sensors can generally indicate light levels, they are not as precise or calibrated as dedicated lux meters, potentially affecting the accuracy and reliability of the illuminance data collected. This limitation may introduce some degree of variability or error in the assessment of occupants' daylight perception.

Furthermore, the sample size and diversity of the participants influenced the generalizability of the findings. Since the study was conducted in a specific type of building or with a particular group of occupants, the results may not be representative of other settings or populations. Future research should consider using standardized and calibrated equipment for measuring illuminance, expanding the participant pool to include a more diverse population, and controlling for external environmental variables. Despite these limitations, the study provides valuable insights into the interplay between daylight perception and thermal comfort in building environments.

5. Conclusion

User satisfaction is the most crucial outcome to consider in design. During the design process, an architect must consider both energy efficiency and the creation of the most functional and comfortable environment for users. Therefore, attention should be paid to daylight, and careful consideration should be given to the orientation of the building and the choice of materials. In this study, daylight was observed to impact user satisfaction regarding thermal comfort, and users' thermal behaviours were examined according to daylight brightness levels. No experimental environment was created; instead, a classroom environment was naturally selected, and an experimental methodology was developed beforehand. During the observation period, while the temperature balance remained unchanged, daylight values varied between 2000 and 116,000 lux on different days of the study. Maintaining a similar number of students in the classroom throughout the observation process helped achieve more accurate results. Observations revealed that participants checked the weather before coming to school and made clothing choices based on whether the sky was cloudy or clear.

Initial findings suggest that daylight may alter people's subjective thermal perception from a psychological standpoint, and these effects are related to the thermal environment they are exposed to. This behaviour-focused study primarily considers participants' responses, with the diversity of behaviours observed alongside their responses allowing for an assessment of thermal comfort in terms of daylight. It was observed that on days with lower daylight values, participants tended to balance their thermal comfort by adjusting their clothing choices, effectively changing their comfort levels and almost deactivating the impact of daylight. Consequently, the influence of daylight on thermal comfort and thermal behaviour varies with participants' perceptions. On bright daylight days, participants seemed to associate this with warmth, influencing their clothing choices and even classroom movement levels. Ultimately, it was found that participants' behaviours were shaped by daylight, though it's important to note that behaviour is not solely related to daylight. When participants' thermal comfort was observed objectively and subjectively, daylight alone was not found to be the determining factor.

Various factors, such as participants' preparation for presentations and class, as well as their level of engagement, also contributed to changes in body temperature. Additionally, while daylight does not have a physiological effect on participants, it appears that there is a psychological desire for warmth when exposed to bright daylight levels. Among factors affecting thermal comfort, the importance of daylight is relatively low; however, it should still be taken into consideration. This is mainly due to the relationship between thermal comfort and behavioural responses based on environmental perception. Future studies that increase the number of days observed and conduct comparative measurements across different seasons will allow for a more detailed examination of the effect of daylight on thermal comfort.

Acknowledgements

This research article was derived from an assignment completed as part of the MSc course on Seminars on Architecture II under the supervision of Dr. Gizem İzmir Tunahan at Dokuz Eylül University. The information and documents in this article have been written under national and international research and publication ethics. This study was approved by the Dokuz Eylul University (Approval Number: [E-873447630-659-1003901]). All participants provided informed consent prior to their inclusion in the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

References

Bahar, Z. & Yalçınkaya, Ş. (2021). Daylight as a design element: Jean Nouvel. *Düzce University Journal of Science and Technology*, 9(5), 1724-1738. https://doi.org/10.29130/dubited.894120

Bellia, L., d'Ambrosio Alfano, F. R., Fragliasso, F., Palella, B. I. & Riccio, G. (2021). On the interaction between lighting and thermal comfort: An integrated approach to IEQ. *Energy and Buildings*, 231. https://doi.org/10.1016/j.enbuild.2020.110570

Cılasun Kunduracı, A. & Kızılörenli, E. (2024). A design proposal for improving daylight performance of a deep-plan classroom by using tubular daylight guidance systems and movable shading devices. *Journal of Polytechnic*, 27(4): 1305-1316. DOI: 10.2339/politeknik.1266467.

Chinazzo, G. Wienold, J. & Andersen, M. (2019a). Daylight affects human thermal perception. *Scientific Reports*, 9, 13690. https://doi.org/10.1038/s41598-019-48963-y

Chinazzo, G. Wienold, J. & Andersen, M. (2019b). Variation in thermal, visual and overall comfort evaluation under coloured glazing at different temperature levels. *JAIC - Journal of the International Colour Association*, 23:45-54.

Çiftçi, M. E. & Arpacıoğlu, Ü. (2021). Daylight Guidance Systems. *Journal of Architectural Sciences and Applications*, 6(1), 59-76. https://doi.org/10.30785/mbud.794257

Erdem, Y. D., Yılmaz Erten, Ş., & Umaroğulları, F. (2023). The Effect of Vertical Skylights Designed in Buildings on Daylight Illumination. *Gazi University Journal of Science Part C: Design and Technology*, 11(2), 561-571. https://doi.org/10.29109/gujsc.1265787

Dolnikova, E., Katunsky, D. & Lopusniak, M. (2022). Evaluation of daylight comfort in industrial building. *IOP Conference Series: Materials Science and Engineering*, 1252(1), 012031. https://doi.org/10.1088/1757-899x/1252/1/012031

Fakhari, M., Fayaz, R. & Asadi, S. (2021). Lighting preferences in office spaces concerning the indoor thermal environment. *Frontiers of Architectural Research*, 10(3), 639–651. https://doi.org/10.1016/j.foar.2021.03.003

Ganesh, G. A., Sinha, S. L., Verma, T. N. & Dewangan, S. K. (2021, October 15). Investigation of indoor environment quality and factors affecting human comfort: A critical review. *Building and Environment*, Vol. 204. Elsevier Ltd. https://doi.org/10.1016/j.buildenv.2021.108146

Garretón, J. Y., Rodriguez, R. & Pattini, A. (2016). Effects of perceived indoor temperature on daylight glare perception. *Building Research and Information*, 44(8), 907–919. https://doi.org/10.1080/09613218.2016.1103116

Geng, Y., Ji, W., Lin, B. & Zhu, Y. (2017). The impact of thermal environment on occupant IEQ perception and productivity. *Building and Environment*, 121, 158-167. https://doi.org/10.1016/j.buildenv.2017.05.022

Grønlund, L., Mathiasen, N., Sørensen P. & Frandsen A., K. (2024). Poetic Daylight – a pavilion for the perception of daylight. Doi: 10.1088/1755-1315/1320/1/012006

Gutierrez-Martinez, J. M., Castillo-Martinez, A., Medina-Merodio, J. A., Aguado-Delgado, J. & Martinez-Herraiz, J. J. (2017). Smartphones as a light measurement tool: Case of study. *Applied Sciences (Switzerland),* 7(6). https://doi.org/10.3390/app7060616

Haddad, S., Osmond, P. & King, S. (2013). Metabolic Rate Estimation in The Calcula-Tion of The PMV for Children.

İzmir Tunahan, G., Altamirano, H. & Teji, J. U. (2021). The Role of Daylight in Library Users' Seat Preferences. *CIE Conference.* (pp.1-11). London, England.

İzmir Tunahan, G., Altamirano, H., Teji, J., U. & Ticleanu, C. (2022). Evaluation of daylight perception assessment methods. *Front Psychol*. 13:805796. Doi: 10.3389/fpsyg.2022.805796

Jiang, Y., Li, N., Yongga, A. & Yan, W. (2022). Short-term effects of natural view and daylight from windows on thermal perception, health, and energy-saving potential. *Building and Environment*, 208, 108575. https://doi.org/10.1016/j.buildenv.2021.108575

Kılıç, Z., A. & Yener, A. (2017). Investigating Daylight Performance Metrics Used to Evaluate Daily. Retrieved from https://www.researchgate.net/publication/330039410

Kutlu, R. (2019). Daylight as a Design Element. *The Turkish Online Journal of Design, Art and Communication – TOJDAC*. ISSN: 2146-5193, April 2019, 9(2), p. 226-233.

Lala, B. & Hagishima, A. (2022). A Review of thermal comfort in primary schools and future challenges in machine learning based prediction for children. *Buildings*. 12 (11), 2007. https://doi.org/10.3390/buildings12112007

Laouadi, A. (2022). A new general formulation for the PMV thermal comfort index. *Buildings*, 12(10), 1572. https://doi.org/10.3390/buildings12101572

Li-xin, G. (2002). Prediction of PMV index using neural network. *Journal of Harbin University of Civil Engineering and Architecture*.

Mardaljevic, J. & Nabil, A. (2005). The useful daylight illuminance paradigm: A replacement for daylight factors. *Lighting Research and Technology*, 37, 41-59.

Mardaljevic, J. (2023). Editorial: Daylight and illuminance measurement. *Lighting Research & Technology*, 55(6), 501–501. doi:10.1177/14771535231198564

Menteşe, S. & Koca, S. (2023). Investigation of outdoor thermal comfort levels of Bilecik Central District. *Eastern Geography Journal*, 28(50), 57-63. https://doi.org/10.5152/EGJ.2023.22024

Münch, M., Wirz-Justice, A., Brown, S. A., Kantermann, T., Martiny, K., Stefani, O., … Skene, D. J. (2020). The role of daylight for humans: Gaps in current knowledge. *Clocks and Sleep*, 2(1), 61–85. https://doi.org/10.3390/clockssleep2010008

Quadco Engineering. (2024). Determination of PMV and PPD and specification of the conditions for thermal comfort. Access Address (10.05.2024): https://www.quadco.engineering/en/know-how/cfd-calculate-pmv-and-ppd.htm

Samiou, A. I., Doulos, L. T. & Zerefos, S. (2022). Daylighting and artificial lighting criteria that promote performance and optical comfort in preschool classrooms. *Energy and Buildings*, 258. https://doi.org/10.1016/j.enbuild.2021.111819

Şentürk Sipahi, G. & Yamaçlı, R. (2021). Building the future: an assessment on daylighting and COVID-19 in residential buildings. *Journal of Architectural Sciences and Applications*, 6(1), 374-383. DOI: 10.30785/mbud.874426

Toussakoe, K., Ouedraogo, E., Kossi Imbga, B., Nana, G., Compaore, A., Pelega Kieno, F. & Kam, S. (2023). Prediction of Thermal Comfort from Operating Temperature and the Predicted Mean Vote / Predicted Percentage Dissatisfied (PMV/PPD) Indices in a Nubian Vault. *Advances in Materials*. https://doi.org/10.11648/j.am.20231201.12

Tatar, E. (2014). A Proposal for the use of daylight in workspaces within the scope of sustainable architecture. *Journal of the Institute of Science and Technology of Süleyman Demirel University*, 17(1), 147-162.

te Kulve, M., Schellen, L., Schlangen, L. J. & van Marken Lichtenbelt, W. D. (2016). The influence of light on thermal responses. *Acta Physiologica* (Oxford, England), 216(2), 163–185. https://doi.org/10.1111/apha.12552

Yang, B., & Sekhar, C. (2014). Human Perception Relation between Thermal Comfort and Air Movement for Ceiling Mounted Personalized Ventilation System. *In Advanced Materials Research* (Vol. 935, pp. 329–332). Trans Tech Publications, Ltd. https://doi.org/10.4028/www.scientific.net/amr.935.329

Zhang S., Yao, R. & Li, B. (2024). An improved approach for solving the adaptive coefficient in the aPMV (adaptive predictive mean vote) index. *Building and Environment*, 256:111481-111481. DOI: 10.1016/j.buildenv.2024.111481