

# Enhancing cognitive performance through thermal comfort: insights from classroom renovation at Diponegoro University

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**Abstract.** International Undergraduate Program (IUP) of Industrial Engineering Department classrooms face challenges when the Wet-bulb Globe Temperature (WBGT) reaches 27.09°C and a temperature of 32.69°C, primarily due to the extensive use of glass. Direct sunlight through glass windows can raise indoor temperature. A renovation project was initiated to enhance overall comfort by closing the glass surface using wooden material. This research aims to assess the WBGT in the classroom before and after renovation to analyze the effect of the thermal comfort increase on cognitive performance. Post-renovation measurements revealed a reduction in WBGT to 24.58°C, accompanied by a decrease in temperature and humidity. The cognitive performance is measured using the Montreal Cognitive Assessment (MoCA). Cognitive performance, including response time, showed improvement after the renovation, with the introduction of plants further enhancing this effect. Beyond improving classroom comfort, the renovation also presents opportunities for energy savings by reducing reliance on air conditioning. This study demonstrates how renovations can contribute to sustainable building practices, offering both immediate educational benefits and reductions in energy consumption, particularly in tropical climates.

## 1 Introduction

Buildings in universities have higher requirements in air temperature and humidity because the thermal environment inside the room largely influences learning performance [1]. The building of the Industrial Engineering Department at Diponegoro University has a modern architectural concept dominated by transparent glass materials, allowing direct sunlight into the rooms, especially during the daytime. Direct sunlight can increase room temperature,

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especially for buildings in tropical climates. However, excessive daytime heat could affect the room's thermal comfort [2].

The Industrial Engineering Building received a green building score of 52 out of a possible 121 points and was classified with a bronze based on green-ship measurement categories by the Green Building Council of Indonesia [3]. The overall performance of buildings is influenced by six primary parameters: the building envelope, interior design, operations and maintenance, climate, energy, and occupant behavior [4]. Occupants interactions with buildings lead to variations in energy use [5-6]. The building sector constitutes one-third of worldwide energy usage [7]. By focusing on thermal comfort improvements through innovative design and technology, buildings can significantly reduce their energy consumption [8]. Ensuring thermal comfort becomes vital for sustainable development, aligning with multiple Sustainable Development Goals (SDGs) such as SDG 3 (Good Health and Well-being) and SDG 7 (Affordable and Clean Energy).

This study examines the correlation between thermal comfort and physical comfort in relation to SDG 3 (Good Health and Well-Being). Several studies have postulated a relationship between physical comfort and cognitive performance. Exposure to high temperatures affects performance in various tasks, such as attention, perception, and mathematical processing [9]. Discomfort brought on by low indoor air quality and uncomfortable heat might impair cognitive function and reduce productivity [10-12].

Research conducted in the International Undergraduate Program of Industrial Engineering (IUP IE) class in which students experience discomfort in the classroom. The research on WBGT and temperature measurement of the classrooms has a WBGT value of 27.09°C and a temperature value of 32.69°C [13]. The high temperature is caused by the building being predominantly glass, allowing direct sunlight through windows measuring 46 cm x 31 cm without any filter, only using rolling glass curtains. It has previously been observed that the uncomfortable thermal environment in classrooms can affect students' learning process and motivation in academic activities, such as difficulty concentrating, learning, memorizing, and thinking during exams [14]. Based on these research findings, the program chair and staff plan to renovate the classroom to improve comfort in the teaching and learning process.

The room is located on the 2nd floor of a 4-story building so it is assumed there is no heat exposure from above and below the room and only the side walls are exposed to direct sunlight. The International Undergraduate Program (IUP) IE Classroom had dimensions of 7.50 m x 3.78 m. The two walls of the classroom are brick walls, while the other two sides facing the outside of the building are glass windows (46 cm x 31 cm) covering all the walls with a height of 3 meters (7.50 m x 3 m and 3.78 m x 3 m). The room was kept throughout the experiment without an air conditioner (AC). The renovation was done by cover the glass wall with multiplex plywood on wall side which exposed to sunlight during the day and evening. The multiplex used is around 40 mm thick with many layers of veneer.

The cognitive examinations use the Montreal Cognitive Assessment (MoCA) and response time. Response time is chosen because reaction time data is more reliable [15]. MoCA scores range from 0 to 30 points, with a cut-off point of 26, where scores exceeding 26 are deemed normal. The IUP IE students were the research respondents. The MoCA scores of the IUP students were below 26 for 75% of the respondents, signifying an abnormal condition linked to the high WBGT values [13].

This study specifically examines the effect of building renovation on occupant behavior by examining the relationship between thermal comfort and cognitive performance to see how effective the impact of renovation by covering the glass surface with wooden material is in reducing the room temperature. The present study utilizes the WBGT parameter to evaluate heat stress before and after the renovation and MoCA to test cognitive performance before and after renovation. The presence of plants in the class was used to greenen the class,

and response time was used to assess student cognitive performance with and without plants in the class.

## **2 Literature Review**

### **2.1 The effect of thermal comfort on cognitive performance**

Classroom buildings are essential facilities in education infrastructure, providing a conducive space for learning and student productivity [16]. A well-designed classroom integrates educational technology to enhance capabilities and facilitate learning [17]. The classroom environment profoundly impacts student performance, with thermal and air quality conditions influencing task performance and learning motivation. Students spend time in the classroom for the learning process, making it imperative for educational institutions to ensure health and comfort [18].

Thermal comfort in university classrooms primarily aims to maximize learning performance and productivity. Room conditions, including temperature, airflow, lighting intensity, humidity, activity, occupancy, and operating hours, influence a comfortable room zone. The number of people in the room, the size of the room, the activities carried out in the room, the length of time using the room, and the heat output from lights and other electronic equipment also influence the heat associated with the room's thermal comfort [19]. Classrooms in tropical areas face more thermal comfort challenges due to extreme weather conditions and increased internal and external heat [14]. Four fundamental thermal environmental factors, indoor air temperature, average radiation temperature, airspeed, and relative humidity, would help determine the WBGT value in addition to the objective measurement.

MoCA was used to conduct cognitive assessment in this study. MoCA is a newer screening measurement assessing a broader range of domains and was specifically developed to help detect mild cognitive changes. MoCA has several advantages over the Mini-Mental State Exam (MMSE). MoCA resulted in a broader range of scores than the MMSE, and scores on the MoCA were more frequent than on the MMSE, reflecting higher sensitivity to cognitive impairment. MoCA may also be a better tool when tracking cognitive status and decline over time [20].

### **2.2 The effect of plants on thermal condition**

The International Center for Indoor Environment and Energy (ICIEE) proves that indoor air quality impacts a person's comfort and health. Many classrooms are closed and have limited areas with poor ventilation and electronic equipment, causing low humidity and increased temperatures; carbon dioxide and organic compounds will quickly evaporate [21]. Adding plants and green walls can help increase relative humidity and reduce temperature, carbon dioxide, and other volatile organic compounds [16-18]. Plants can serve as symbolic cues as if they were outside. In summer, plants can remind residents of the cooling effect provided by the shade of the vegetation canopy, especially if there is overhead vegetation. Moreover, because plants positively affect people's evaluation of space, these positive effects of plants may have a greater influence on people's sense of thermal comfort than the negative effects of uncomfortable temperatures [25].

Several short-term studies have shown that plants may improve occupant thermal comfort, but more research is needed. During the quasi-experiment, the test rooms' indoor operative temperatures were controlled between typical and extreme ranges. The presence of a substantial quantity of plants in the work environment was found to have a significant effect

on the participants' thermal comfort. For example, the occupants of the two rooms in which the presence of plants was alternated were both, on average, approximately 12.0% more thermally comfortable when plants were present in the room. In addition, they were approximately 1.79 and 1.95 times more likely to be thermally comfortable when plants were present in the room, respectively. Incorporating plants into the work environment can consume building energy by providing insulation and temporarily reducing the building's cooling load.

Furthermore, uncomfortable heat reduces productivity [10-11]. Besides improving indoor air quality, using plants also increases the psychological and physiological comfort of humans indoors [26]. The evaluation of plants on the psychological impact on residents stated that plants in a room could provide a more stable and dynamic feeling effect. Similarly, [27-28] stated that plants improve stress management by maintaining psychological and physiological stability.

### 3 Research Methodology

#### 3.1 The effect of renovation on temperature

The design of this research adopts a field experiment approach. Field experiments are a way to collect information based on original field experiments and represent what is in the field. Field experimental research is carried out in natural conditions without strict control of variables. This research uses counterbalance or balance on both sides. This pattern is known as a rotation, crossover, or transition pattern. This design is used to compensate for the weakness of designs that do not include a control group, especially if the sample size is small. Research with a counterbalanced design does not use a pre-test but instead uses a post-test to assess student performance in the actual physical classroom environment. Work climate data was collected by measuring temperature, humidity, and room temperature using the WBGT Meter 8778 (Figure 1).



**Fig. 1.** WBGT Meter 8778.

Respondents will be asked to carry out a MOCA test in post-renovation conditions. The collected data will be compared with historical MOCA test data before the renovation. The MoCA method is presented in a paper-and-pencil format, organized with a single-page test, and requires brief administration time. The IUP IE students were the research participants for the MOCA test. For acclimatization purposes, the research participants must be in Semarang, Central Java, for the last 14 days. Generally, humans take 7 to 14 days to adapt to hot temperatures, with 75% of physiological adjustments occurring in the first 4-6 days of heat exposure. Additionally, participants should be in good health and not have engaged in strenuous activities such as sports.

### 3.2 Experiment The Effect of Indoor Plants on Thermal Perception

The experiment on post-renovation conditions, both without plants and with plants, was assessed using a within-subject design. Alternative plants used in this experiment are given in Table 1.

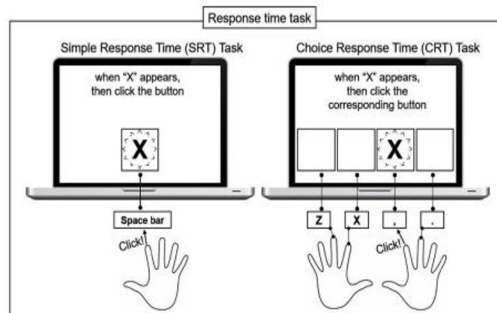
**Table 1.** Interior plants and green walls.

Latin name	Amount
Peach Lily	1
Spathiphyllum	1
Montreal	1
Sansevieria	1
Dieffenbachia	1
Philodendrons,	1
Chlorophytum Comosum	8
Philodendron Burlemarx	8
Tradescantia Spathacea	24

This design involved providing each respondent with multiple treatments, allowing for a comparison of responses within the same group of participants. The measurements were conducted during the dry season when the sun shone intensely. This within-subject design ensures that each participant experiences both conditions, reducing variability and enabling a more robust assessment of the impact of the renovation with and without plants.

Green walls and indoor plants are implemented in intervention efforts through an environmental approach. The research design used a field experiment in classroom conditions after renovation. Green walls are made of modular panels and are not permanent. The structures used to make green walls are as follows: (a) the frame measures 100 cm x 45 cm; (b) polycarbonate; (c) coconut fiber or coconut powder.

Cognitive performance is measured in response time, using PsyToolkit to carry out the Deary-Liewald experiment. The experiment consisted of a simple response time (SRT) task and a choice response time (CRT) task. The SRT task has only one stimulus on the laptop screen. Respondents must respond by pressing the space bar as quickly as possible when it appears. Meanwhile, the CRT task consists of several stimuli. When a stimulus appears in one of the boxes on the laptop screen, the respondent must respond by pressing the appropriate button (Figure 2). If the respondent does not respond within 150 milliseconds (ms), it is considered too fast; if the respondent responds within 700 ms, it is considered too long.



**Fig. 2.** Response time.

The IUP IE students were the research participants for the response time test, conducted under the same conditioning as the MOCA test, as discussed in the previous sub-chapter.

## 4 Result and Discussion

### 4.1 The Impact of Renovation

There are six factors in choosing higher education, including academics, facilities, campus life, reputation, industry linkage and access [29]. Therefore, providing comfortable learning facilities is important, such as for IUP classrooms which are special classes. Measurements of IUP classroom temperature were carried out in rooms that had been renovated. Thermal measurements are conducted continuously for an 8-hour work period or at specific times. Data was collected from 12:00 PM to 2:00 PM WIB during the peak temperature. The WBGT threshold value used in this research is 31°C (Minister of Manpower Regulation Number 5 of 2018). The measurement results on WBGT for the IUP IE classroom showed that no WBGT value exceeds the predetermined threshold. Other parameters influencing thermal comfort besides the WBGT value are humidity and temperature. However, the temperature measurement results before renovation have values that exceed the comfortable limit [13].

The renovation covered the glass windows with multiplex, layered wood sheets consisting of 3 layers of wood with a total thickness of 18 mm. This wood is used because it has cavities, which can reduce the sun's heat that penetrates the glass windows. After collecting WBGT data on room temperature and humidity after renovation, the data was tested to prove whether significant differences were found between WBGT, temperature, and humidity before and after renovation.

The processed data in the Wilcoxon Test yielded a result of  $0.04 < 0.05$ , indicating a significant difference between WBGT values before and after the renovation. The measured WBGT value before the renovation was 27.09°C, whereas, after the renovation, it was 24.58°C. There was a decrease in WBGT after the renovation because the glass material was replaced with a facade, preventing direct sunlight from passing through the windows. It can be concluded that the classroom renovation contributed to a reduction in room temperature. The average humidity value before renovation is 48.99%, decreasing to 40.98% after renovation. A comparison between WBGT, temperature, and humidity before and after renovation is given in Table 2.

**Table 2.** WBGT, temperature, and humidity before and after renovation.

The Climate Indicators	Before Renovation	After Renovation
WBGT	27.09	24.58
Temperature	32.69	28.86
Humidity	48.99	40.98

The elevated Wet Bulb Globe Temperature (WBGT) values observed prior to the renovation can be primarily attributed to the building's extensive use of windows and glass facades. These elements allow significant solar radiation to penetrate, leading to higher indoor temperatures. According to the Jakarta Green Building user guide, the characteristics of glass materials are determined based on solar transmittance, solar absorptance, solar reflectance, and visible transmittance. Generally, the transmission of solar radiation through glass is much greater than through walls. Therefore, the post-renovation design prioritized minimizing solar heat gain by replacing the windows with walls, thus mitigating excessive temperature increases.

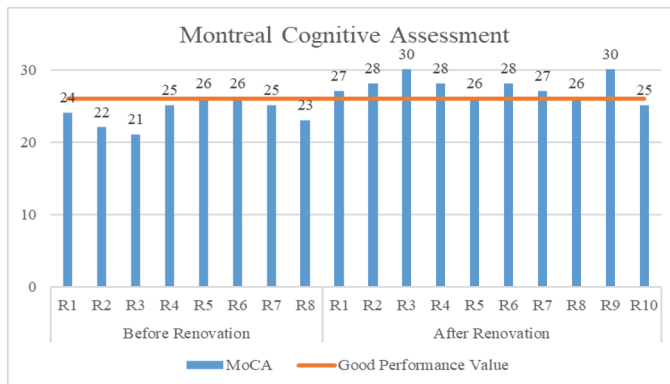
In addition to the building design, the thermal adaptive behavior of occupants plays a crucial role in maintaining indoor thermal comfort. This behavior includes actions such as opening doors or windows and turning on air conditioning (AC) units when thermal discomfort is experienced. When occupants experience thermal discomfort, occupant behavior tends to react to restore thermal comfort in the environment [30]. Occupants'

adaptive responses can be classified into three main categories: personal adaptation, technical or environmental adjustments, and psychological adjustments. Personal adaptation involves changes in clothing or activity to cope with environmental changes. In contrast, environmental adjustments typically involve the use of mechanical systems such as AC to reduce indoor temperatures or manually opening windows to enhance ventilation. Psychological adaptation, on the other hand, refers to a cognitive reappraisal of the environment where occupants perceive the conditions as acceptable, even if they deviate from typical comfort standards.

Data from Table 2 indicate that the classroom renovation resulted in a decrease in room WBGT, humidity, and temperature. The findings support the argument that renovations aimed at improving energy efficiency and thermal management not only lower energy demands but also create a healthier and more comfortable indoor environment for occupants. The renovation of buildings in sectors like education offers a pathway toward more sustainable and resilient infrastructure. Scaling up these renovation strategies across educational institutions presents a significant opportunity for large-scale energy reduction and greenhouse gas (GHG) emission mitigation. Thus, The renovation of educational buildings not only improves the quality of indoor environments but also serves as a strategies against climate change. It reduces energy consumption and provides a better indoor environment for occupants [31].

## 4.2 Impact Renovation on Cognitive Performance

The MoCA examination is employed to evaluate respondent attention in a physical environment. MoCA scores range from 0 to 30 points, where the total score is obtained by adding points from each completed task. The highest score is 30 points, and a score of 26 or above is considered normal, as several studies suggest a MoCA cutoff point of 26. Various cognitive tasks were assigned to measure cognitive performance using the MoCA, including executive functions, naming, memory, attention, language, abstraction, delayed memory, and orientation—the result of the MOCA test presented in Figure 3.



**Fig. 3.** MoCA examination.

Regarding the MoCA examination comparison before and after renovation, MoCA scores are better after the renovation compared to the pre-renovation condition. Before renovation, 75% of occupants scored below 26, whereas 80% scored above 26 after renovation. The research result is the same as the findings of the Wilcoxon test results before and after renovation, with an Asymp. Sig (2-tailed) value of  $0.048 < 0.05$ , indicating a significant difference.

Based on cognitive performance measurements using MoCA in the post-renovation condition, visuospatial executive function, attention, language, abstraction, and delayed recall were better compared to the pre-renovation condition. This improvement is attributed to the pre-renovation room having a high WBGT value of 27.09°C and a temperature of 32.69°C. The temperature difference can impact performance on various tasks, as a WBGT value of 26.67°C negatively affects tasks such as attention, perception, and mathematical processing [9]. Field studies in classrooms and elementary school offices have shown higher scores in attention tasks, self-reported attention, and productivity [26].

The renovation achieved energy efficiency and created a more sustainable and efficient building. The introduction of green elements and a thoughtful design process demonstrated positive outcomes regarding both environmental and cognitive aspects. In summary, the research highlights the multifaceted benefits of a holistic and sustainable approach to renovation, positively influencing thermal comfort, cognitive performance, and overall well-being in educational spaces.

### 4.3 Impact of the indoor plant on response time

Objective cognitive assessment in the post-renovation condition was conducted through response time experiments, comparing the actual condition without plants and the treatment condition with plants—web-based response time testing using PsyToolkit with the Dearly Liwead experiment. The experiment included two tasks: SRT and CRT.

The response time in the condition without plants for simple response time testing average speed is 527,9 milliseconds, while for choice task response time testing, the average is 589,5 milliseconds. In the response time condition with plants, the average speed for simple tasks is 301.4 milliseconds; for choice tasks, it is 439.1 milliseconds. Response time recapitulation data for experiments with ten respondents are given in Table 3.

**Table 3.** Response time.

Respondents	Conditions Without Plants		Conditions With Plants	
	Simple task (ms)	Choice Task (ms)	Simple task (ms)	Choice Task (ms)
R1	698	581	289	428
R2	293	389	260	374
R3	1059	880	292	412
R4	287	407	294	460
R5	292	492	325	477
R6	287	468	239	409
R7	1278	1318	429	625
R8	311	447	299	379
R9	251	416	250	397
R10	355	497	337	400

The average speed of simple response time is faster than choice response time because respondents use their right hand when given a stimulus, where the right hand is significantly higher than the left hand in transferring motor skills [34]. Natural elements are related to productivity and effectively reduce response time, so this can validate the conclusion of increasing work productivity [35]. However, it has only been applied to tasks involving visual concentration, mental processing, and manual dexterity [34]. If response times are slower in a particular condition, the condition may distract participants; otherwise, the condition may help the subject to concentrate on the task. Response time tasks show that indoor plants in underground environments reduce response time [36].

Recommendations for improvements include implementing interior plants and green walls in building floor corridors, such as the student waiting corridor at Harvard University. Green walls can reduce room temperature due to reduced heat transfer by plants and polycarbonate reports, where the temperature with a green wall is 31.17°C lower than without a green wall, namely 37.53°C [37]. Applying the greening classroom concept, several large and medium-sized interior plants in classrooms with large space capacity, such as the Vrije University Amsterdam study [38].

The selection of plants and the platforms used to create variations in height ensure that the plants are at eye level. A study conducted at Harvard University conducted experiments with various plant species adopted by the Smith Campus Center Interior Designers. The research presents 12 indoor interior plants that influence the perception of air quality and well-being, reporting that four plants are most preferred for their benefits in improving subjective well-being (SWB) and Indoor air quality (IAQ). Ficus Benjamina, with various shapes, such as Ficus Sphere, Ficus Column, and Pyramid Ficus, achieved a much higher score for indoor air quality than all other plants [39]. Pachira Aquatic plants effectively reduce Volatile Organic Compounds (VOCs) [40].

Green wall maintenance is more manageable because planting media can be used other than soil, such as geotextiles, and the irrigation system uses hydroponic techniques. One of the advantages of a living wall is compared to a green facade [41]. Green wall maintenance supplies require irrigation for water as much as 8.75 litres/day for 1 room measuring 1 m<sup>2</sup> [42].

## 5 Conclusion

The renovation of buildings exposed to heat by installing wooden facades over glass walls has demonstrated significant success in reducing Wet Bulb Globe Temperature (WBGT), room temperature, and humidity. Specifically, the WBGT was reduced from 27.09°C to 24.58°C, and the indoor temperature decreased from 32.69°C to 28.86°C. Additionally, the incorporation of plants in classrooms was found to significantly improve cognitive performance, with the average response time for simple tasks decreasing from 527.9 milliseconds to 301.4 milliseconds and for choice tasks, from 589.5 milliseconds to 439.1 milliseconds. These results emphasize the role of thermal comfort and biophilic design elements in enhancing occupant well-being and cognitive function.

While the study successfully demonstrated the impact of building renovations on thermal comfort and cognitive performance, the broader environmental and sustainability implications should also be considered. By reducing indoor temperatures and humidity, these interventions can decrease the reliance on mechanical cooling systems, leading to lower energy consumption and greenhouse gas emissions. Future research should focus on exploring the long-term environmental and economic benefits of renovations across educational buildings. The application of these renovations across educational facilities could serve as a model for energy conservation in the building sector, contributing to broader climate change mitigation goals.

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