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Thermal Comfort in Intermediate Spaces of Educational Buildings (Case Study: Isfahan University of Technology)

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ABSTRACT

This study explores the concept of thermal comfort in intermediate (semi-enclosed or enclosed transitional) spaces at Isfahan University of Technology (IUT), located in a hot-arid climate. While most comfort standards focus on fully enclosed, mechanically controlled environments, this research aims to assess whether such standards apply to transitional architectural spaces and to what extent users adapt to these microclimates. A year-long cross-sectional survey was conducted, combining subjective questionnaires with on-site physical measurements in selected intermediate spaces across the IUT campus. The investigation evaluated thermal sensation, preference, and acceptability in relation to indoor environmental parameters such as temperature, humidity, and air velocity. The collected data were then compared to ASHRAE comfort standards and predictive models like the Adaptive Mean Vote and Predicted Mean Vote. The results revealed that occupants in intermediate spaces displayed a higher degree of thermal adaptability than predicted by conventional comfort models. The neutral temperature in enclosed intermediate zones was determined to be 23.5°C-0.35°C higher than the AMV model's prediction. Despite deviations from the ASHRAE thermal comfort zone, users still rated their thermal environment as acceptable, emphasizing the psychological and behavioral flexibility in semi-enclosed educational spaces. Laboratory-based and stable models such as PMV are inadequate for evaluating thermal comfort in enclosed intermediate spaces of educational buildings. These environments require field-based calibration of comfort expectations to reflect real-life adaptive behaviors. Establishing a unique comfort standard tailored to such spatial typologies is essential to support user satisfaction and sustainable design strategies in arid climate regions.

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INTRODUCTION

Given the substantial energy consumption within the building sector, it is crucial to focus on strategies to decrease this usage (Hesari & Shojaee, 2021). Despite the increased integration of technological and passive solutions in architectural design, achieving the anticipated reduction in energy consumption is not a straightforward task. Energy consumption is on the rise while available energy resources are diminishing. This trend is particularly evident in developing countries, including Iran, where energy usage is escalating (Heidari & Azizi, 2020). Given the significance of this issue, it is clear that identifying effective solutions for managing and controlling energy consumption is essential (Eiraji & Elmkhah, 2021). Discrepancies in building design and construction, technical and system conditions, material choices, and occupants' energy consumption behavior can lead to a notable difference between predicted (at the design stage) and actual energy consumption in buildings. Therefore, focusing on thermal compatibility, encompassing physiological, psychological, and behavioral aspects, can profoundly influence occupants' thermal comfort, decrease energy consumption, and revolutionize building design and operation. This emphasizes the need to account for occupants' behavior when striving to design energy-efficient buildings and bridge the gap between predicted and actual energy use. The initial step towards achieving more accurate simulation and design outcomes involves understanding the range of occupants' thermal comfort and their interaction with the environment (Azadkhani, 2022). Consequently, this study aims to investigate thermal compatibility in enclosed intermediate spaces within higher education settings by identifying the range of thermal comfort. So, this research endeavors to answer the following question: 1. What is the range of occupants' thermal comfort in enclosed intermediate spaces used for high-educational purposes?. This question will be addressed by determining the range of ther-

mal comfort and neutral temperature through environmental measurements and assessing users' thermal comfort. Additionally, factors leading to thermal comfort will be gathered through questionnaires and interviews. Ultimately, this research seeks to evaluate the state of comfort and thermal compatibility in enclosed intermediate spaces within universities and higher education institutions in hot-arid climate.

MATERIALS AND METHODS

Intermediate spaces

More industrialized lifestyles, the need for spaces that link human to outdoor spaces has grown. These areas, described as "intermediate spaces" in this context, are situated between the interior and exterior of a building, functioning like a bridge with varying environmental conditions. These spaces hold potential for energy conservation (Pitts, 2013). Moreover, intermediate spaces in contemporary buildings are not only as passageways but as versatile areas. They serve multiple purposes in academic, cultural, business, recreational, and transportation buildings. In addition to passage, these spaces are utilized for conversations, educational activities, meetings, or leisure time. At times, they even transform into service areas like restaurants and coffee shops. Therefore, assessing the thermal comfort of these places significantly impacts the occupants and the activities conducted within them. Intermediate spaces have multiple functions and are closely related to the occupied indoor space in non-domestic buildings. There are few specific regulations, standards, or guidelines for these spaces. Most research on intermediate spaces is derived from studies of regular interior space but these spaces are very different from the main university spaces such as classrooms and laboratories in terms of location, occupants' activity and cloths wearing. Also, the duration of using these spaces are different from main ones. Therefore, it is not possible to use the thermal comfort standards of the main spaces in these spaces, and with further research, the specific

design standards and priorities of these buffer spaces should be obtained.

Despite the implementation of comfort guidelines based on laboratory research, like ISO-7730, there is a rising body of evidence suggesting that occupant contentment with the actual thermal conditions in buildings doesn't consistently align with strict adherence to these standards. In many cases, occupants seem to exhibit a higher level of tolerance for deviations from commonly accepted comfort temperature ranges than what might be anticipated. The theory employed in this research is the theory of thermal adaptation. According to this theory, individuals, when exposed to thermal discomfort, adapt and adjust to the thermal environment by making changes in their conditions. This adaptation and adjustment continue until the individual reaches a level of satisfaction with the thermal conditions of the environment. The theory identifies three categories of factors influencing changes in thermal conditions, including: 1- Personal factors such as age, gender, weight, and economic background; 2- Environmental factors like building design, building performance, season, climate, and regional social conditions; 3- Perceptual factors such as expectations and thermal preferences (Xu & Li, 2021). It is with the assistance of these factors that individuals make adjustments to their thermal conditions. In the next stage, if individuals are unable to alter their thermal conditions with these factors, they attempt to achieve this through behavioral reactions. Behaviors such as changing clothing and coverings, altering activities, changing posture, modifying eating and drinking habits, or changing location, opening and closing windows, turning mechanical devices on and off, are types of behavioral reactions (Zhao et al., 2023). It is important to note that sometimes these behavioral reactions are influenced by societal culture, such as an individual's attire or type of activity. Another category of individual adaptive responses to the environment are physiological, meaning that individuals gradually adapt and become

compatible with the environment they are in over time, becoming, in a sense, "accustomed" to it. The final category of individual environmental adjustment methods are psychological adjustments, such as expectations and personal experiences. In this paper, behavioral responses of individuals were recorded and documented through questionnaires and observations. Behavioral adjustments refer to changes individuals make to themselves (like clothing, activities, eating, or drinking) and their environment (like opening windows or using fans). Making behavioral adjustments to regulate the body's temperature provides the most effective means for people to actively ensure their comfort. For instance, altering clothing insulation can result in a difference of up to 3 degrees Celsius in preferred temperatures (Fountain et al., 1996).

One of the earliest studies in this field was conducted by Jitkhajornwanich et al. in 1998 which focused on the thermal comfort of intermediate spaces in schools in Bangkok during the cold season. Through field measurements and questionnaires, they concluded that the neutral temperature for all samples was 27.1 degrees Celsius, and the acceptable temperature ranged from 25.5 to 31.5 degrees Celsius (Jitkhajornwanich et al., 1998).

In 2004, Chun and colleagues conducted a review article. For this, three categories of intermediate spaces (including two lobbies, two balconies, and two open pavilions) in Japanese yukamis were selected. Physical variables such as temperature, relative humidity, globe temperature, solar radiation, and air velocity in both long-term periods of three days and short-term periods on an hourly basis were examined. Additionally, the behavior of individuals was recorded. They used a weather station outside the study site to measure external temperatures. To assess thermal comfort, they utilized the PMV and SET* indices, claiming that although these indices are used to predict indoor thermal comfort. They also applied them to compare environmental conditions in these spaces in order to

propose a new method for thermal comfort in such spaces in this climate. They also recorded the values of clothing insulation (CLO) and metabolic rate (Met) based on observations. Ultimately, they concluded that the PMV index may not be suitable for predicting thermal comfort in intermediate spaces(Chun et al., 2004).

Furthermore, Kwong et al.,2009 examined thermal comfort in intermediate spaces. They chose a lobby space in a government building in Malaysia for this purpose and explained the reason for choosing this space as follows: it was selected due to its unique features, one of which is the common form and plan of administrative buildings in Malaysia, and another reason is its frequent use due to its connection to important internal spaces and the presence of many people in this area. Additionally, this space is extensively utilized during special occasions(Kwong et al.,2009).

In 2014, Hu and Jiang selected semi-open spaces, semi-enclosed spaces, and fully enclosed corridors on the campus of a university in Hong Kong to investigate thermal comfort. They cited the high usage of these spaces by users throughout the day as the reason for their selection(Hu&Jiang, 2014).

Vargas and Stevenson, in 2016, aimed to examine the seasonal thermal comfort experience in terms of thermal comfort perception and short-term experience of the space. As a result, they chose three schools with naturally ventilated lobbies. Their research showed that long-term mental experience of different seasons and temperature expectations also influence the perception of thermal comfort in the present space. These researchers claimed that thermal perception patterns can be identified in fieldwork and that logical use of lobby spaces can positively change occupant's thermal perception(Vargas & Stevenson, 2016).

In 2016, Efeoma investigated the impact of clothing on adaptive thermal comfort in the warm and humid climate of Nigeria. This researcher points out that factors such as budget,

time, and human resources create limitations for studies and research expansion in all similar studies(Efeoma, 2016).

In 2016, Hou based his work on fieldwork and questionnaires in intermediate spaces, stating that the reason for choosing this method is its applicability to similar climates and conditions, allowing for easy extension and use of the results. This is in contrast to studies conducted in controlled laboratory rooms, which lack this capability. Three public buildings with air conditioning and natural ventilation were selected for study of intermediate spaces. Two of the buildings were educational institutions, and one was a cultural institution. The common feature of these intermediate spaces is their connection to the main hall, as well as having large windows connected to the outside space, along with the presence of cafes and shops. Therefore, these three intermediate spaces are essentially multi-purpose and, in addition to being used as transit spaces, serve as relaxation, eating, drinking, meeting, reading, or even working spaces. Users in these spaces have no control over climatic factors, meaning that opening or closing windows or adjusting heating and cooling temperatures is not possible for them(Hou, 2016).

Kotopouleas and Nikolopoulou, 2016, examined three airports for thermal comfort between two groups: employees and passengers. They concluded that the neutral temperature for passengers is lower than for employees(Kotopouleas & Nikolopoulou, 2016)

In 2018, Deliahmedova investigated an adaptive comfort model for assessing thermal comfort in enclosed and semi-open intermediate spaces at Lund University in Sweden. She presented a model for assessing thermal comfort in enclosed and semi-open spaces in this climate, using field measurements and standard thermal comfort criteria, and stated that further research is needed to provide a standard(Deliahmedova, 2018).

In 2019, M.Y.Tse and Jones conducted a field study using field measurements and question-

naires regarding thermal comfort in three public enclosed intermediate spaces in Cardiff, England. During this study, a strong correlation was found between clothing value and the actual temperature inside the building. People's adaptability to the thermal environment was confirmed. They concluded that close to 80% of respondents choose self-adaptive actions to overcome uncomfortable situations (M.Y.Tse & Jones, 2019).

Jiao et al., 2023, had assessed the effects of intermediate space temperatures on elderly thermal comfort and their behaviors in residential care facilities. They performed a field study using questionnaires and physical measurements and concluded that the greatest enhancement in indoor thermal comfort for the elderly occurred when the temperature contrast between the intermediate area and indoor setting was 6 °C during winter and 2 °C during summer (Jiao et al., 2023). Also, assessing influence of occupant actions on energy conservation and comfort in harsh cold climates done by Bian et al., 2023. Doing this, using DeST-h software, simulations were performed to assess the energy usage associated with various behavioral patterns. The results indicate that the energy-saving impact outweighs any decrease in thermal comfort, based on these assessments (Bian et al., 2023).

FINDINGS AND DISCUSSION

Case study buildings and climate

Three typical three-story faculty buildings at the Isfahan University of Technology (IUT) in Isfahan, IRAN is selected as a reference buildings for this study. All of these faculties are situated in the northernmost part of the university campus, aligned in the same direction, parallel to each other (Fig. 1).

Isfahan city is 1,590 meters (5,217 ft.) above sea level. It has located in 32.65°N latitude and 51.67°E longitude. The average maximum temperature is 36 °C in July, and the average minimum temperature is 9 °C in January. There are about 29 sunny days in August and September.

Most precipitation amounts are from November to May for about 2-5mm, and the minimum is from July to October (Fig. 2).

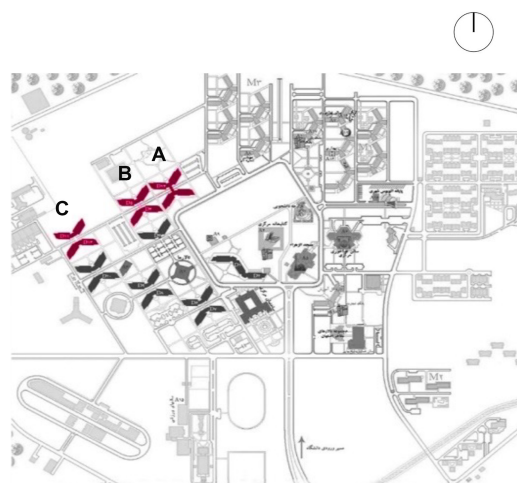


Figure 1: The location of the studied faculties on the website of Isfahan University of Technology is marked with red color. A: Faculty of Agricultural Engineering. B: Faculty of Mining and Physics Engineering. C: Faculty of Materials and Natural Resources Engineering (Central Office of Isfahan University of Technology, 2022)

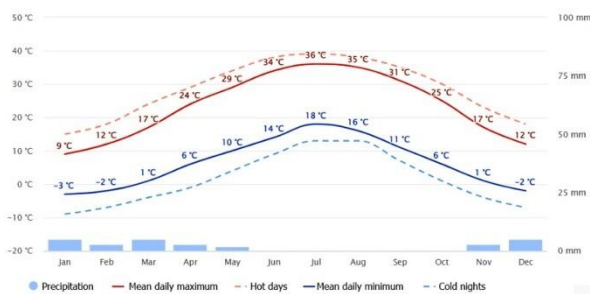


Figure 2: Average temperatures and precipitation of Isfahan, IRAN (Weather Isfahan Organization, n.d).

These faculties were chosen for the following reasons:

- The orientation of all these buildings is the same.
- Other educational buildings are being built or operated near these faculties. As a result, the university's development on this site is ongoing, and the information obtained from the research

can be applied to early designs of buildings or the construction stage.

•It represents typical high educational and non-domestic building materials in hot and dry climate of IRAN. So, construction techniques for walls, floors, openings, and architectural features can demonstrate typical construction types of these buildings. In this situation, the energy assessment results in this type of intermediate space can be used in similar non-domestic buildings with the same climate. This item can be both a feature of this type of intermediate space and also it is one of the limitations of case sample selection.

•There is a synoptic meteorological station on this university campus where weather data can be used.

•All of these buildings have an X-form base. Therefore, the discrepancies caused by the effect of volume can be controlled (Fig. 3).

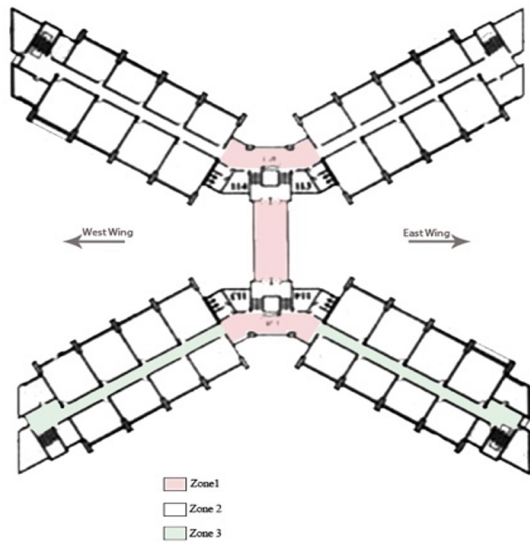


Figure 3: Typical Floor Plan of Main Intermediate Spaces of Agriculture Engineering, Physics and Mine Engineering College in IUT (Central Office of IUT, 2022).

Main intermediate spaces in these buildings consist of two flat parts on the 2nd and 3rd floors. It connects the two parts of the volume suspended over the street crossing space. Other intermediate spaces in natural ventilation

faculties (Agriculture Engineering, Physics and Mine Engineering) are entrance or elevator lobby spaces and, an almost wide space between two corridors can be used for meetings, talking, resting, etc. (Fig. 4). Also, mechanical ventilation faculties have an entrance lobby with large windows, a central atrium and, a wide interface space between two part of X-form that it is used for studying space (Fig. 5 & Fig. 6).



Figure 4: Main Intermediate Spaces of : A-Agriculture Engineering and, B-Physics and Mine Engineering College in IUT (Authors, 2022)

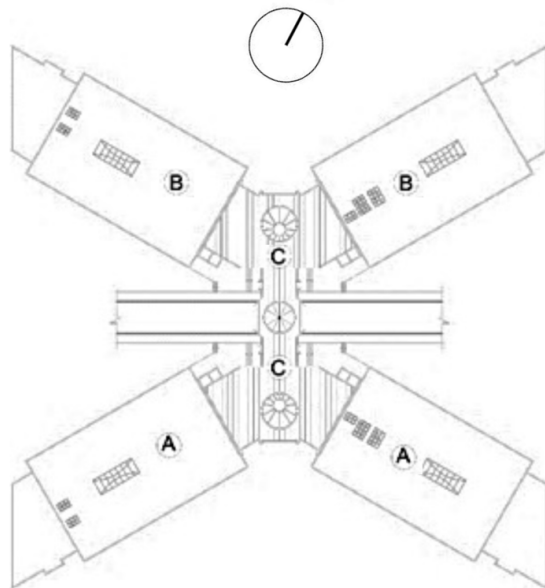


Figure 5: Typical Floor Plan of Main Intermediate Spaces of Materials and Natural Resources Engineering in IUT. A: main Spaces of Natural Resources college, B: main spaces of Material college, and C: Intermediate Spaces (Central Office of IUT, 2022).



Figure 6: Typical Floor Plan and Main Intermediate Spaces of Materials and Natural Resources Engineering in IUT. (Authors, 2021)

The aims of the current study are to investigate the thermal compatibility and comfort range of occupants in enclosed intermediate spaces of higher education buildings, particularly within a hot-arid climate. This includes identifying the neutral temperature, assessing environmental variables, and analyzing behavioral adaptations of users through field measurements and surveys. The ultimate goal is to evaluate the suitability of existing thermal comfort models for these transitional zones and to propose more context-specific guidelines. This study has been carried out at the Isfahan University of Technology (IUT), located in Isfahan, Iran, a region characterized by its hot-arid climate and specific architectural typologies relevant to public academic institutions. The fieldwork and data collection for this study were conducted throughout the year 2022, covering different seasons to ensure a comprehensive understanding of thermal perceptions and environmental variations across time.

Methodology

This research was conducted in Isfahan University of Technology (IUT), located in a hot-arid climate in IRAN. The study was field-based and did not interfere with the temperature conditions of the spaces under investigation. The thermal responses of individuals using these spaces were studied and collected during a year summer

2021 to spring 2022, including the period of the post-COVID19 pandemic.

According to Adaptive Model (AM) studies, the field study method by Nicol (1993) - Level 3¹, was selected as the basis and foundation of the methodology. Its basis lies in creating thermal comfort conditions consistent with the thermal experiences of normal individuals in their daily lives. This method is based on real-world observations, where experimental results are compared with theoretical models. The findings represent a range of desirable and tolerable conditions for individuals, which are used as the comfort range for building design (Nicol, 1993).

In Nicol approach, the findings are comparable to other studies, and it can be extended to other regions related to the climatic characteristics of that area. Therefore, parallel to the previous stage, the measurement of key environmental parameters and their effect on thermal comfort in the research was conducted based on field studies (Pitts, 2013), including air temperature, globe temperature, relative humidity, and wind speed, both in enclosed intermediate spaces and in outdoor sample areas, which are educational buildings of the university (Table 1). Mean radiant temperature (T_{mrt}) was also recorded using mathematical calculations (Appendix 1). At the same time, coded questionnaires regarding architectural factors were provided to the users of the space. The measurements and distribution of questionnaires were carried out. Enclosed intermediate spaces in the campus of Isfahan University of Technology include entrance spaces (lobby), corridors, and hallways, as well as interconnecting bridges (Sabat) of different faculties, and two samples of these spaces were selected for each type of space from various faculties for examination. The selection of these enclosed intermediate spaces aimed to allow for additional functions beyond movement within

¹ At this level, alongside measuring environmental variables, personal variables (clothing rate and activity rate), and other factors such as age, gender, eating, drinking, thermal experience, physical condition, or other variables depending on the research design and objectives, are measured.

these types of spaces. Therefore, the main focus was on selecting the intermediate spaces between the faculties and the intersection points of corridors, which have suitable entrance spaces as well as lobbies. It is worth mentioning that for the optimal placement of temperature measuring equipment, it was necessary to select the best location closer to the average ambient temperature through trial and error before the main fieldwork. During the measurements of environmental variables, in addition to pre-set questionnaires, personal and individual information such as age, their activity level before entering the designated place, the individual's health status, and factors of this nature were also asked, along with their satisfaction with the ambient temperature and their thermal preference. The level and type of individual activity during the use of the studied intermediate spaces, as well as their clothing, were recorded by observation

and according to the ASHREA standard (Pitts & Saleh ,2006). Furthermore, the climate data of the outdoor environment were obtained from the synoptic weather station at the university. In addition, due to the need for more accurate results of the climatic factors in the human height range, these factors were also assessed in the outdoor areas of the faculties by a portable weather station (Chun & Tamura, 2004).So, in case of discrepancy with the data obtained from the weather station, their average statistics were taken into account. As a result, the data of this research are both quantitative and qualitative. Subsequently, the data were analyzed and examined using statistical software, and the type of relationship and correlation between the variables was assessed.

Based on this, the present study has an applied orientation and its method is a case study based on field studies.

Table 1: Measurement method of climatic variables by the desired time period (Authors Based on Chun, 2004)

Measurement Method	Studied Variables	Time	Placement of Measurement Equipment	Time Period
Long-term	Air temperature Relative humidity	Three-day average (72 hours)	120 centimeters above ground level (ASHREA Standard 55)	Continuous with a 5-minute interval using a temperature and humidity data logger during working hours
Short-term	Air temperature Relative humidity Wind speed	9:00 AM - 12:00 PM 3:00 PM - 6:00 PM	120 centimeters above ground level (ASHREA Standard 55)	Momentary measurement after three minutes of placing the sensor of the multifunctional device in the studied environment

Field measurements were conducted using temperature and humidity data loggers, an anemometer, and a globe thermometer for evaluation.

In thermal comfort studies, three main devices should be used for environmental data measurement: A- Temperature and humidity measuring device - B- Globe temperature measuring device - C- Wind velocity measuring device. These devices should be installed at an ap-




propriate height and distance from the ceiling, floor, and walls. The most suitable height is 1.1 meters above the floor and at an equal distance from two adjacent walls (Dahlan et al., 2009). The selected devices were based on their availability in the IRAN market and the reliability and accuracy of the data. The used devices are shown in (Fig. 7). Additionally, the installation positions of the devices are shown in (Fig. 8).

The validation of the devices was conducted

by placing the measuring instruments under test for three days, and the results of multiple devices were compared. The differences between the devices did not exceed 0.5 to 1 degree Celsius. This difference in measured relative humidity was less than 5 percent. The temperature measurement range specified by the manufacturer

was from zero to 50 degrees Celsius for indoor environments and from minus 20 to plus 70 degrees Celsius for outdoor data loggers. It indicated a relative humidity range from 10% to 95%. Approximately 20 minutes were considered for the devices to equilibrate with the environment.

Figure 7: Specifications of Climate Measurement Devices in the Research Field Study (Authors, 2023)

Device Name / Model	Measured Parameters	Device Image	Method Time Location
Wintact Humidity & Temperature Meter	<ul style="list-style-type: none"> •Air Temperature •Relative Humidity 		Recording data by placing the device in hand after 3 minutes of exposure to climatic factors
BENETECH Digital Anemometer	<ul style="list-style-type: none"> •Air Flow Velocity •Air Temperature 		6 AM, 8 AM, 10 AM, 12 PM, 2 PM.
Heat Index WBGT Meter	<ul style="list-style-type: none"> •Globe Temperature •Air Temperature 		110 centimeters from the ground

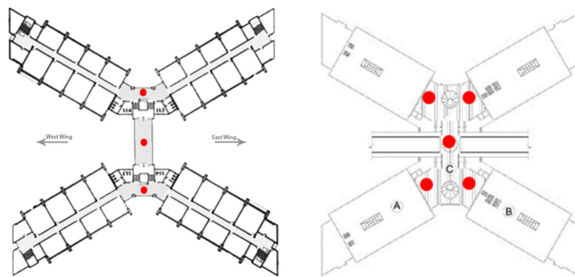


Figure 8: Installation Locations of Climate Measurement Devices on the Plan (Right: Faculty of Textile Engineering and Natural Resources, Left: Faculty of Agricultural Engineering, Mining, and Physics)

The physical variables in this study include environmental parameters such as air temperature (T_a), globe temperature (T_g), relative hu-

midity (RH%), and air velocity (V), which were recorded in the enclosed intermediate spaces under investigation using temperature, humidity, and anemometer devices. The mean radiant temperature (TMRT) was also calculated mathematically and recorded in Appendix 1. Additionally, outdoor temperature data was obtained from the synoptic weather station located at the university site and was also recorded on-site using portable sensors. These recorded data was cross-referenced and compared with the data obtained from the weather station.

The temperature, relative humidity, and air velocity conditions in both enclosed intermediate spaces and the external environment are presented in (Tab. 2).

Table 2: Temperature, Relative Humidity, and Air Velocity Conditions in the Outdoor Space on Field Measurement Days (Authors, 2023)

Time of Measurement	Temperature ($^{\circ}$ C)			Relative Humidity (%)			Air Velocity (m/s)		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Summer 2021	34	31.9	36	15.2	22.1	30.5	0	0.3	1.5
Autumn 2021	14	23	34	12	29.1	58	0.9	1.7	3
Winter 2022	11.1	11.9	13	19.5	23	27.2	0.5	1.1	2.5
Spring 2022	13.7	16.8	22.3	11.8	15.5	19.1	0.2	0.6	1.7

Furthermore, the climatic-environmental specifications of the enclosed intermediate spaces were documented based on the examined buildings during the data collection period, and are outlined in (Appendix1).

Also, to examine the respondents' mental perceptions and thermal sensations, a questionnaire based on ISO-7730 standard and ASHREA was prepared. This questionnaire is attached in the appendix 2. The questionnaire assessing respondents' thermal perceptions during their use of enclosed intermediate spaces was distributed among occupants. Approximately 10-15 minutes were allocated for completing the questionnaire, while simultaneously recording climatic data obtained from environmental sensors. The thermal perceptions of the occupants were collected in a cross-sectional manner. In cross-sectional research, the statistical population usually includes a large number of individuals, and in this case, the individual is not the measure; rather, the primary importance is based on different individuals' sensations of their thermal environment. Cross-sectional research helps to generalize the results to similar cases. In order to measure thermal perceptions, the questionnaire was prepared based on existing standards, consisting of the following main sections. The first section includes general information about individuals. The other section was arranged in order to estimate thermal behaviors of occupants. In fact, the purpose of this questionnaire was to gather information about respondents' thermal behaviors.

In the Nicol method, a hundred questionnaires are sufficient for field studies, which can be completed in both longitudinal and cross-sectional methods (Heidari, 2000). In practical terms, the questionnaires were conducted to theoretical saturation, and they were completed in a cross-sectional method. Therefore, a total of 160 questionnaires were distributed in the seasons under study from summer 2021 to spring 2022.

The data obtained from field studies and

questionnaires are analyzed and examined in terms of physical and non-physical factors. Physical factors include climatic-environmental data obtained by sensors and the synoptic meteorological station located at the site. These factors undoubtedly have a direct impact on the thermal sensation of space users. Non-physical factors include actions, behaviors, and strategies that individuals can use to adjust their thermal status and even achieve their desired thermal comfort. SPSS version 26 analytical software was used for analyzing data.

RESULTS AND CONCLUSION

The correlation between indoor air temperature and individuals' thermal comfort perception

The Spearman correlation coefficient between indoor air temperature and thermal preference in the specified enclosed space is ($r=0.564$), indicating a positive relationship between the two variables. The significance coefficient (sig.) is less than 0.001, confirming the meaningful relationship between these two variables. Additionally, the determination coefficient is 0.32, suggesting that indoor temperature can account for 32% of the variance in individuals' thermal preference in the specified space.

Fig.9 illustrates the correlation equation between indoor air temperature and thermal comfort perception according to the real preferences of individuals. Based on this graph, the minimum neutral indoor temperature for the study participants in intermediate educational spaces is 14.4 degrees Celsius, while the maximum is 31 degrees Celsius. The neutral temperature in intermediate spaces is 22.7 degrees Celsius.

Also, the neutral temperature was determined using the PMV model, utilizing the CBE Thermal Comfort Tool, for all individuals who completed the questionnaire. To achieve this, the operational air temperature was inputted into the software, matching the indoor air temperature. Additionally, air humidity, air flow velocity, clothing insulation rate, and the overall

metabolic rate of all participants in the questionnaire, were entered into the software according to the data recording time. In the next step, the data obtained from the software, in accordance with the PMV model, the PPD model, and the SET temperature, were imported into statistical software such as Excel and SPSS. Subsequently, a correlation chart between indoor air temperature and individuals' thermal sensation was drawn using the PMV model, and the linear equation was obtained (Fig. 10). Using the correlation chart and comfort point, the neutral temperature in intermediate spaces was determined using this model.

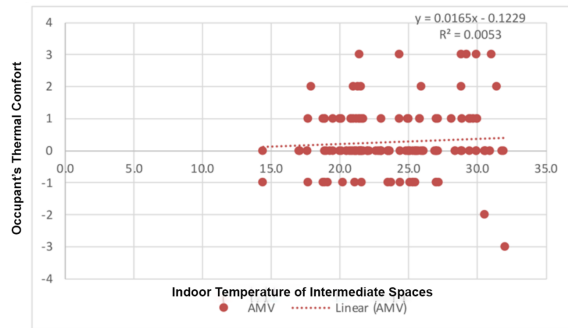


Figure 9: The correlation and linear equation between indoor air temperature and individuals' thermal comfort perception based on their actual preferences. (Authors, 2023)

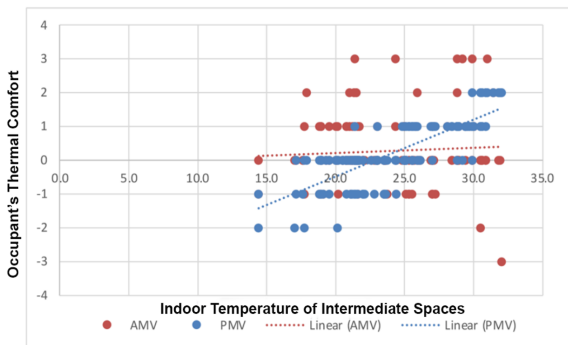


Figure 10: The correlation between indoor temperature in enclosed intermediate spaces and thermal sensation using the laboratory PMV model (Authors, 2023)

According to the PMV model, the neutral temperature in enclosed intermediate spaces was found to be 23.5 degrees Celsius, which is 0.35

higher than the neutral temperature obtained from the AMV model. Fig.9 illustrates the disparity in results between laboratory studies using the PMV model and field studies using the AMV method.

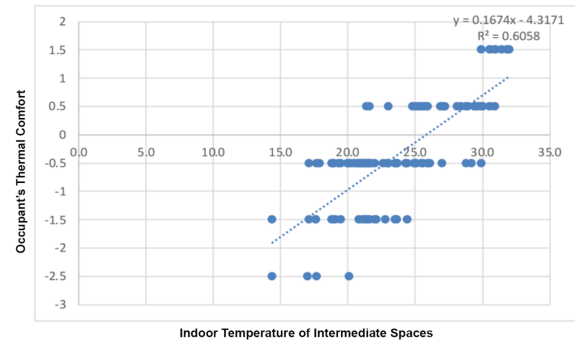


Figure 11: Discrepancy in the Results of PMV Laboratory Studies and AMV Field Studies.NB. (Authors, 2023)

In Fig.11, the PMV model line has a much steeper slope compared to the AMV model and is considered more responsive. This indicates that users in real conditions experience a wider range of thermal comfort compared to laboratory conditions. The results of this chart show that the laboratory model cannot accurately describe and predict the thermal comfort conditions for individuals in enclosed intermediate spaces. In real conditions, individuals, based on their past thermal experiences, personal conditions, and changes in clothing or activities, can achieve thermal comfort. With a 0.35 decrease in neutral temperature, almost 3% energy savings can be achieved(Appendix 3), and conversely, increasing the neutral temperature based on the laboratory model in enclosed intermediate spaces not only does not help with thermal comfort, but many individuals feel discomfort and achieve thermal comfort by activities such as opening windows or reducing outer clothing in cold seasons. Additionally, the value of p is reported to be less than 0.005. Furthermore, the Pearson correlation coefficient between the results of laboratory PMV studies and field AMV studies is 0.346.

A covariance analysis was performed to examine the effectiveness of using the PMV model on individuals' thermal comfort in enclosed intermediate spaces. The independent variable is the internal temperature in enclosed intermediate spaces. The dependent variable is the field study model (AMV), and the auxiliary variable is the laboratory study model (PMV). The effect size between these two variables is 0.107, and the PMV model can predict 10.7% of the AMV model. Preliminary checks were performed to ensure no violation of assumptions of normality, linearity, variance homogeneity, regression slope homogeneity, and measurement reliability of covarying variables. The results of the Levene's test show that $\text{sig} > 0.05$, indicating no violation of the assumption of equal variances. It is worth noting that among the data related to "occupants' thermal perception" in intermediate spaces in Fig.9, two samples exhibited significantly lower values compared to the rest of the observations. These two points are clearly identifiable as outliers on the chart. Preliminary assessment suggests that these anomalies may have resulted from unusual environmental conditions such as inadequate ventilation, direct solar radiation, or occupants' short-term presence in the space, leading to extreme thermal discomfort. Nevertheless, in order to preserve the integrity of the collected dataset, these points have been retained in the analysis. Given their potential impact on the results, it is recommended that future studies conduct a more detailed investigation into the causes of such occurrences.

Overall, the PMV model indicates that the neutral temperature in enclosed intermediate spaces is 23.5 degrees Celsius, which is 0.35 degrees higher compared to the neutral temperature derived from the AMV model. So in fact, the PMV model cannot accurately determine the thermal comfort of individuals in enclosed intermediate spaces. Many people adapt themselves to environmental conditions and achieve thermal comfort through adaptive behaviors.

The results of this study indicate that the neutral temperature in enclosed intermediate spaces should be considered lower than in main spaces with mechanical systems. This is because, as found in this research, individuals in these types of spaces can achieve thermal comfort through active changes in activity, clothing, or location. This way, annual energy consumption for heating and cooling in similar educational buildings with the climate of the studied building can be saved.

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