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Analysis of Thermal Comfort in the Environment of a Tourist Guide Classroom in Central Taiwan

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Abstract

The inadequate temperature environment in tour guide classrooms can not only affect the health of visitors but also reduce their concentration during learning. In Taiwan, temperatures often exceed 30°C during certain seasons. Learning in overheated environments not only affects physiological comfort but may also significantly decrease concentration levels. To lower the temperature, extensive use of air conditioning is required to enhance indoor comfort. However, this may lead to excessively cold learning environments, thereby hindering effective learning. The thermal comfort of tour guide classrooms directly impacts the health and concentration of visitors. This study investigates the thermal comfort of tour guide classrooms in Miaoli Leisure Farm with two objectives: first, to understand visitors' comfort perceptions, and second, to identify a predictive model for thermal comfort in the classroom to set optimal indoor air conditioning conditions in the future. Data for this study were collected through on-site measurements of temperature, wind speed, humidity, and physical parameters, as well as on-site questionnaire surveys on visitors' clothing, height, weight, gender, and subjective perception of thermal comfort. Through correlation and regression analyses, it was found that thermal comfort is moderately to highly correlated with indoor and outdoor temperatures and clothing insulation, while correlations with other parameters such as wind speed, humidity, and Body Mass Index are relatively low. Considering the practical feasibility of parameters, this study employs outdoor temperature as the sole variable in the optimal thermal comfort control equation. During the measurement period (May 2024), the optimal thermal comfort control equation for tour guide classrooms was found to be: $T = 17.45 + 0.32\ T_{out}$ *，Where T represents indoor comfortable temperature and* T_{out} *represents outdoor temperature (°C). The coefficient of determination is 0.567(correlation coefficient +0.753), with the optimal comfortable temperature being 24.5°C.*

Keywords: *Thermal comfort, predictive model, questionnaire survey.*

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I. INTRODUCTION

Inadequate temperature conditions in tour guide classrooms not only affect the health of visiting tourists but also diminish their ability to concentrate on learning [1,2,3,4]. In Taiwan, temperatures often exceed 30°C during the summer and surrounding seasons. Learning in excessively hot environments not only affects physiological comfort but also significantly reduces concentration levels [5,6,7,8,9]. To lower the temperature, extensive use of air conditioning is required to enhance indoor comfort. However, this may lead to overly cold learning environments, resulting in suboptimal learning outcomes.

While air conditioning alleviates stuffiness, improper design or operation can cause indoor temperatures to become too cold or too hot, leading to discomfort. If indoor temperatures are too low, it not only fails to regulate comfort but also wastes energy. Inappropriately lowering the indoor temperature of tour guide classrooms not only creates poor thermal comfort but also contributes to energy wastage [10,11,12,13,14]. The Taiwanese government vigorously promotes energy conservation and carbon reduction, recommending an air conditioning set temperature of 26°C. Local governments even conduct indoor temperature inspections in major department stores and retail chains [2,15,16,17]. However, this initiative has sparked complaints from the public and business owners because people's perception of thermal comfort is influenced by various factors such as temperature, humidity, airflow, wind speed, clothing insulation, and physical activity [4,16,18,19,20].

Furthermore, excessively cold environments may cause discomfort among tourists and even compromise their immune systems, increasing the risk of illness. Studies show that prolonged exposure to excessively cold environments reduces the body's metabolic rate, thereby affecting learning and work efficiency. Therefore, maintaining appropriate indoor temperatures is crucial for enhancing learning outcomes and safeguarding health [1,15,19].

This study aims to identify the optimal indoor comfort operation mode for tour guide classrooms through on-site measurements and questionnaire surveys. Subsequently, it seeks to establish an effective thermal comfort operating mechanism to ensure that indoor learning activities occur in healthy and comfortable environments, thereby improving learning outcomes and achieving energy conservation and carbon reduction goals.

II. LITERATURE REVIEW

2.1 Thermal Comfort

Thermal comfort refers to the sensation of temperature in a specific environment and the state of comfort experienced within that environment. This concept encompasses various factors such as human responses to environmental temperature, humidity, airflow, and thermal radiation [21,22]. Thermal comfort not only affects the quality of daily life but also has significant implications for work efficiency, learning outcomes, and health conditions. Factors influencing thermal comfort include [4,9,14,16,17,18,19, 22]:

- Environmental temperature: Temperature is the most direct factor affecting thermal comfort. Extreme temperatures, whether high or low, can cause discomfort and health issues such as heatstroke or hypothermia.
- Humidity: Humidity affects the body's ability to dissipate heat. High humidity reduces sweat evaporation, decreasing heat dissipation efficiency, while low humidity may lead to dry skin and respiratory discomfort.
- Airflow: Adequate airflow facilitates sweat evaporation, enhancing heat dissipation and creating a cooling sensation. However, excessive airflow may cause a sensation of coldness, especially in winter or with strong indoor air conditioning.
- Thermal radiation: Heat radiation from sources such as sunlight and mechanical equipment increases the heat in the environment, affecting thermal comfort.
- Anthropogenic factors: Factors such as clothing insulation, activity level, and individual physique also influence an individual's perception of environmental temperature. Heavy clothing or intense physical activity can increase the body's heat load, leading to a sensation of warmth.

2.2 Evaluation Criteria for Thermal Comfort

Internationally, thermal comfort assessment typically refers to two main standards: ISO 7730 and ASHRAE Standard 55 [14,23]. These standards provide guidance for evaluating and designing comfortable environments. However, due to climate, cultural, and racial differences, the applicability of these standards may need adjustments in different regions. Thermal comfort in practical applications includes [4,9,19,21,22,]:

- Workplace: Adequate thermal comfort in offices or factories can improve employee efficiency and satisfaction while reducing the incidence of work-related accidents.
- Learning environments: In schools or training institutions, suitable thermal comfort contributes to enhanced learning outcomes and concentration, creating a better educational environment.
- Residential environments: Good thermal comfort at home enhances the quality of life and ensures the health of family members.
- Public spaces: In places like malls and museums, appropriate thermal comfort enhances visitor comfort and dwell time, thereby promoting consumption and visitation.

2.3 Thermal Comfort Temperature

Lin [17] and Lin et al. [16] noted that environmental temperature, humidity, airflow, wind speed, and anthropogenic factors such as clothing insulation, activity level, and physique influence indoor thermal comfort and must be regulated by air conditioning equipment. Currently, thermal comfort largely references ISO 7730 and ASHRAE Standard 55 [23]. However, these standards may not be universally applicable to Taiwan due to differences in climate, humidity, race, and culture. As thermal comfort perception involves subjective sensations, evaluating thermal comfort requires establishing relationships between subjective sensations and relevant physiological responses. Thermal Environmental Index (TEI) encompasses dozens of indices that integrate parameters affecting thermal sensation or physiological responses, representing human thermal comfort in the environment. Fanger [20] introduced the Predicted Mean Vote (PMV) to describe the relationship between the body's net heat and its surrounding thermal balance. Thermal comfort sensation is a subjective response that varies among individuals in the same space, so PMV presents degrees of satisfaction and dissatisfaction proportionally [17,21,22,24]. The main influencing factors of PMV include temperature, humidity, thermal radiation, wind speed, clothing insulation, and activity level [4,14]. Given the different conditions worldwide, tailored approaches are necessary. Considering many scholars' research, key factors influencing thermal comfort are mainly indoor temperature and thermal radiation, although some studies suggest that workplace characteristics play a more crucial role.

III. RESEARCH METHODOLOGY

This study conducted on-site measurements of physical factors, including outdoor temperature, indoor temperature, humidity, wind speed, and carbon dioxide concentration. Additionally, it integrated real-time questionnaire surveys to understand respondents' perceptions of the thermal environment. The research was conducted in the tour guide classroom of Miaoli Leisure Farm, measuring 7.62 m x 13.46 m x 5.95 m in size, equipped with a central air conditioning system for cooling. The classroom was divided into six zones for on-site measurements, collecting data on indoor temperature, humidity, and wind speed at a height of 100 centimeters from the ground. Simultaneously, regular records of temperature and humidity in the open outdoor space were taken. Furthermore, subjective comfort perception questionnaire surveys were conducted when visitors completed the tour. The questionnaire included information on gender, age, height, weight, physical condition, clothing insulation, etc. Additionally, respondents rated their perception of the indoor environment based on a seven-level comfort index scale (table 1).

Table 1: Thermal Comfort Scale [25]

Value	Thermal Sensation Description	Comfort Satisfaction Description
3	Hot	Very Satisfied
2	Warm	Satisfied
1	Slightly Warm	Acceptable
0	Comfortable	Neutral
-1	Slightly Cool	Unsatisfied
-2	Cool	Very Unsatisfied
-3	Cold	Extremely Unsatisfied

IV. RESULTS AND DISCUSSION

4.1 Analysis of Measurement Results of Environmental Factors

According to the heat balance theory, factors directly affecting indoor thermal comfort primarily include anthropogenic factors such as clothing insulation and activity level, as well as indoor physical factors like air temperature, wind speed, and relative humidity. Indirect influencing factors encompass outdoor radiation temperature, cold airflow effects, and floor temperature. The calculation method of PMV thermal comfort index involves parameters such as clothing insulation, activity level, indoor temperature, wind speed, relative humidity, and radiation temperature. Following the method outlined by Lin et al. [17], this study substituted outdoor temperature for radiation temperature. Table 2 displays the measured values of various physical environmental factors. The measured indoor temperature ranged from 21.5°C to 27.3°C on average, with indoor temperature gradually rising as the duration of visitors' stay indoors increased.

Table 2: Measurement Results of Environmental Physical Factors

Measurement	Outdoor Temperature (°C)		Indoor Temperature (°C)		Relative Humidity (%)		Carbon Dioxide (ppm)		Airflow Speed (m/s)	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
1	26.8	2.5	24	1.2	62.1	1.2	862.1	48.6	0.21	0.03
2	25.3	2.4	22.4	1.0	57.3	0.9	811.2	68.1	0.33	0.04
3	27.4	1.8	25.2	0.8	60.1	1.8	756.1	98.5	0.09	0.03
4	30.2	2.4	27.1	1.7	71.8	0.6	932.3	68.1	0.09	0.02
5	29.1	2.4	27.1	1.3	55.5	2.1	712.3	75	0.14	0.04
6	24.3	2.1	22.2	1.9	61.1	1.3	771.1	67.8	0.22	0.06
7	29.5	2.2	27.1	1.2	73.2	1.4	889.3	57.1	0.16	0.04
8	23.9	1.8	21.5	1.5	59.5	2.6	798.2	47.9	0.18	0.08
9	29.7	1.3	27.3	1.3	69.8	1.8	914.3	63.2	0.31	0.07
10	24.8	2.4	23.3	1.1	66.1	2.5	886.6	58.6	0.29	0.08

Indoor relative humidity showed minimal fluctuations, with average relative humidity ranging from 55.5% to 73.2%. These data closely align with the optimal relative humidity levels (according to regulations for labor workplaces, indoor temperature maintained by central air conditioning systems should be within 23°C to 28°C, relative humidity should be between 60% to 75%, and wind speed should not exceed an average of 0.5 m/s). Under air conditioning, indoor relative humidity tends to be lower than normal outdoor levels. The measured wind speeds ranged from 0.09 to 0.33 m/s, approaching a static state and remaining below the prescribed 0.5 m/s limit for labor workplaces. With the entry of visitors participating in the tour, the total indoor carbon dioxide levels increased due to metabolic processes. In the absence of individuals, measured carbon dioxide concentrations ranged from 448 to 509 ppm, while with visitors present, concentrations ranged from 702.3 to 948.3 ppm. According to Ovando Chacon et al. [21] and Özdamar Seitablaiev and Umaroğulları [22] carbon dioxide is a byproduct of human metabolism, and its impact on human thermal balance is indirect. If the concentration of carbon dioxide in the air exceeds 800 ppm, people may feel stuffy. When indoor carbon dioxide levels reach a certain threshold and ventilation is poor, visitors may experience discomfort, feeling stuffy and fatigued. Effectively venting carbon dioxide outdoors can improve indoor air quality, enhance comfort, and increase satisfaction [7,17,21,22,23].

4.2 Analysis of Anthropogenic Factors Measurement Results

In order to understand visitors' subjective thermal comfort in specific environments, this study conducted subjective thermal comfort surveys alongside measurements of indoor environmental physical factors. A total of 148 respondents participated in the survey, including 78 males (52.7%) and 70 females (47.3%). Since the measurement was conducted in May 2024, participants wore summer clothing with thin outerwear, resulting in calculated clothing insulation values of 0.57±0.13 clo for males and 0.67±0.19 clo for females [23]. According to ASHRAE Standard 55, thermal comfort is defined as 80% of occupants finding the environment acceptable as a standard for thermal conditions. In this study, the acceptability of the environment was assessed through a questionnaire, revealing that 78.38% of participants found the indoor environment acceptable, while 8.11% felt somewhat cold or very cold, and 13.52% felt warm or very hot. Thus, it can be observed that although the air conditioning system in the classroom is close to the 80% thermal comfort standard, there is still room for improvement.

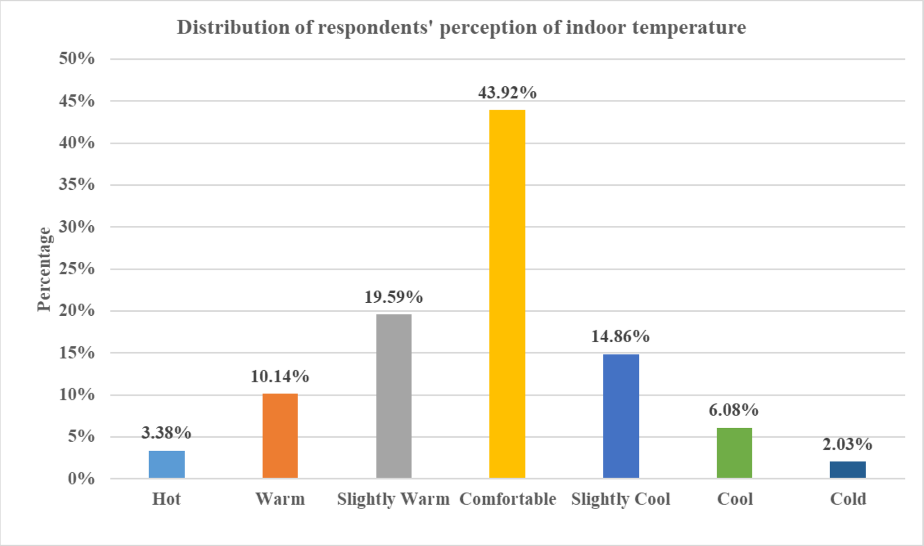

Figure 1: Distribution of respondents' perceptions of indoor temperature

Human beings feel most comfortable with relative humidity between 60% and 70%. If humidity is too high, it can feel uncomfortably damp as sweat does not evaporate easily, while too low humidity can lead to dry and cracked skin due to moisture loss. According to the survey analysis, 72.8% of respondents felt comfortable with the humidity, while 12.2% reported feeling dry or extremely dry. According to the ASHRAE Standard 55, for individuals with low physical activity levels, the optimal indoor air velocity should be kept below 0.2 m/s. Olesen [26] and Lin et al. [17] stated that increasing indoor air velocity can enhance comfort temperature, but it should be controlled below 1.0 m/s to avoid negative effects. Based on measurement results, indoor air velocity ranged from 0.09 to 0.22 m/s, with 84% of respondents reporting comfortable air velocity or good ventilation. From the analysis of the returned questionnaires, overall satisfaction with comfort, including responses of very satisfied, satisfied, and acceptable, accounted for 86.7% of the total. Only 13.3% of respondents expressed dissatisfaction, including responses of dissatisfied, very dissatisfied, or extremely dissatisfied. This indicates that the majority of respondents find the classroom's air conditioning settings acceptable.

4.3 Analysis of Parameters Influencing Thermal Comfort

Through correlation analysis, this study identified the relationships between various parameters. Table 3 presents the results of the correlation analysis among these parameters. Among these parameters, we found that indoor temperature, outdoor temperature, and clothing insulation have moderate to high correlations with indoor thermal comfort temperature (according to the equation proposed by Auliciems[27] in 1986) (correlation coefficients of 0.942, 0.778, and -0.587, respectively). Therefore, conducting multiple regression analysis with indoor temperature, outdoor temperature, and clothing insulation as independent variables and indoor thermal comfort as the dependent variable is feasible. However, in practical applications, indoor temperature is influenced by classroom air conditioning activation, and clothing insulation is influenced by visitors. Therefore, the multiple regression equation obtained may not be meaningful in practical operations. Thus, when seeking the optimal comfort temperature equation, only outdoor temperature is considered as an independent variable. Through regression analysis, the equation for indoor thermal comfort temperature obtained is $T = 17.45 + 0.32T_{out}$, with a determination coefficient of 0.567, where T_{out} represents outdoor temperature (°C). In order to meet the thermal comfort needs of visitors, we sought the optimal control temperature model for the guided tour classroom. Considering practical feasibility, conducting regression analysis with outdoor temperature as the sole variable is reasonable. Through calculation, the optimal comfort temperature obtained is 24.5°C.

Table 3: Pearson correlation coefficients for each parameter

	Comfort Temperature	Indoor Temperature	Outdoor Temperature	Clothing Insulation	Humidity	Wind Speed	CO_2 Level	BMI
Comfort Temperature	1							
Indoor Temperature	0.942	1						
Outdoor Temperature	0.778	0.799	1					
Clothing Insulation	-0.587	0.132	-0.689	1				
Humidity	-0.213	-0.241	-0.287	0.287	1			
Wind Speed	0.011	-0.333	-0.214	0.398	0.314	1		
CO_2 Level	0.098	-0.168	0.011	-0.219	-0.298	-0.445	1	
BMI	0.199	0.085	0.099	0.347	-0.064	-0.119	-0.078	1

V. CONCLUSION

Through the measurement of environmental factors and the survey of visitors' subjective feelings, it was found that visitors had a good sense of comfort in the guided classroom, with 78.38% of respondents indicating comfort. This indicates that the current control of comfort is still acceptable. However, through correlation analysis and multiple regression analysis, it was found that there is a moderate to high correlation between indoor temperature, outdoor temperature, clothing insulation, and indoor thermal comfort temperature (correlation coefficients of 0.942, 0.778, -0.587, respectively). Therefore, conducting multiple regression analysis with indoor temperature, outdoor temperature, and clothing insulation as independent variables and thermal comfort as the dependent variable is feasible. However, in practical operations, considering only outdoor temperature as the independent variable is more realistic. Based on multiple regression analysis, the equation for indoor thermal comfort temperature obtained is as follows: $T = 17.45 + 0.32T_{out}$, with a coefficient of determination of 0.567 (correlation coefficient +0.753), where T_{out} represents the outdoor temperature (°C).

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