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Thermal Comfort in Buildings: Evaluating PMV Index and ANN Model for Prediction

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Abstract

Thermal comfort refers to the psychological state in which an individual experiences satisfaction with their body temperature. The human thermal comfort is influenced by various factors of physical, physiological, and psychological nature, including but not limited to air temperature, humidity, air velocity, radiant temperature, clothing, metabolic rate, age, and heart rate. The productivity, health, and well-being of individuals occupying a building are contingent upon the level of thermal comfort provided. The level of thermal comfort experienced by building occupants may have an impact, either positive or negative, on their productivity, health, and overall well-being. The PMV index is a commonly employed metric for assessing the thermal comfort of indoor environments. The computation of PMV index is intricate and requires a significant amount of time, thereby posing a difficulty in achieving precise thermal comfort predictions. The Artificial Neural Network (ANN) model presents a feasible substitute to conventional techniques in forecasting thermal comfort. The present investigation involved a field study aimed at assessing the thermal comfort level of a pre-existing edifice through the utilization of the PMV index. Data was gathered on multiple parameters, such as air temperature, relative humidity, and air velocity, and subsequently utilized to compute the PMV index. Subsequently, an ANN model was constructed via MATLAB software to forecast thermal comfort levels by utilizing the input data. The implications of the study's findings hold great significance for the design and operation of buildings. The utilization of the ANN model presents a prompt and precise approach in forecasting thermal comfort levels. This can aid building administrators in enhancing energy consumption optimization and augmenting the comfort of the occupants. The methodology expounded in this investigation has the potential to be implemented in other edifices and can facilitate the advancement of more effective HVAC systems.

Keywords: *Thermal comfort, PMV index, Artificial Neural Network (ANN), Building design, HVAC optimization*

1.Introduction

Thermal comfort indices the human psychological effect that is pertains to the body. One accepted definition is, “Thermal Comfort is that condition of mind that expresses satisfaction with the thermal environment” (Brager & De Dear, n.d.-a) .The establishment of a pleasant indoor thermal comfort energy balance is gaining increased attention due to its potential benefits to the well-being of occupants and their productivity levels and the exploration of making the calculation through the calculations of different parameters. When viewed as a thermodynamic system, the human body uses food (fuel) and air as input to create muscular labor and low-temperature heat even if people sit idly. Our thermoregulatory system is responsible for preserving the thermal equilibrium, which is essential for ease but not adequate for life. In order to maintain the operation of vital organs like the liver, pancreas, and other tissues, this system must be kept at a steady interior temperature of around 37 degrees Celsius to maintain thermal comfort.(Butera, 1998) Air cooling devices create a pleasant temperature for people, but this is too costly, and the installation cost and maintenance cost also take into consideration in terms of money. The construction and use of our built environment account for 39% of global greenhouse gas emissions. As per study results, it is feasible to concurrently uphold thermal comfort and minimize energy consumption by regulating the air conditioning temperature in accordance with individual thermal preferences. Precisely evaluating an individual's thermal comfort is crucial in establishing a sustainable and pleasant indoor thermal comfort.(Ma et al., 2019b). The present study introduces a novel approach that integrates the BIM and ANN methodologies to evaluate individual thermal comfort and optimize energy-efficient design within an RUET office space. The enhancement of energy efficiency and comfort levels can yield substantial advantages, such as diminished energy expenditures and a built environment that is more ecologically sustainable.

3.Literature review:

Those who are actively functioning have higher core body temperatures than those who are merely sitting around. Animals that live produce energy through internal heat generation. Food conversion into energy generates heat. This heat maintains body warmth and other bodily processes. Size, exercise, and location affect metabolic heat output. Exercise boosts metabolic rate and heat generation. To sustain body warmth in cold weather, the body may boost its metabolic rate.
Indirect calorimetry anticipates energy usage based on the intake of oxygen and carbon dioxide generation, while direct calorimetry directly counts metabolic heat output. Metabolic heat generation is essential in biology, metabolism, and environmental science because it affects living creatures and their atmosphere.

BIM and ANNs, two distinct technologies, are combined in the suggested system to produce a more commodious and energy-efficient interior environment.(Ma et al., 2019a)

BIM, short for Building Information Modeling, refers to a computer-generated model that represents the structural and functional components of a building. This model can be leveraged in various stages of the building lifecycle, including design, construction, and maintenance. It contains thorough details regarding the geometry, materials, and mechanical, electrical, and plumbing systems of a building.
The application of ANNs, on the other hand, as a sort of machine learning method for complex system optimization and prediction is due to their ability to recognize patterns and relationships in data.

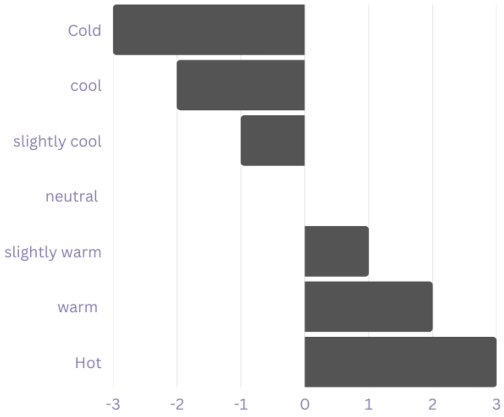

Figure 1: PMV index (SimScale, n.d.)

The PMV index is a predictive measure of the average rating assigned by a sizable population on a seven-point thermal sensation scale. This scale ranges from 3, indicating a hot sensation, to -3, indicating a cold sensation, with intermediate values representing varying degrees of warmth and coolness.(Merabet et al., 2018a)

4.Research Methodology:

The purpose of this research is to investigate the effectiveness of the PMV index and an ANN model for predicting thermal comfort in buildings. Several variables, including environmental conditions and individual characteristics, are measured and recorded. PMV values are calculated manually using equations and formulas, and then checked using software analysis to ensure precision. With the use of the acquired data, an ANN model is developed and trained to achieve optimal performance in PMV prediction. Non-training data is used to evaluate the trained ANN model by comparing its predictions to the actual PMV values. The advantages, disadvantages, and accuracy of hand computations and ANN forecasts are compared to estimate occupant thermal comfort in buildings. Calculation Formulae of Predicted Mean Vote (Brager & De Dear, n.d.-b; Butera, 1998; Merabet et al., 2018b)

$$
\boldsymbol{PMV} = \begin{aligned} & (0.303e^{-0.036M} + 0.028)\{(M - W) - 3.05 \times 10^{-3}[5733 - 6.99(M - W) - p_{\mathrm{a}}] \\ & -0.42[(M - W) - 58.15] - 1.7 \times 10^{-5}M(5867 - p_{\mathrm{a}}) - 0.0014M(34 - t_{\mathrm{a}}) \\ & -3.96 \times 10^{-8} f_{\mathrm{c}}[(t_{\mathrm{cl}} + 273)^4 - t_{\mathrm{mr}} + 273)^4 - f_{\mathrm{cl}} h_{\mathrm{c}}(t_{\mathrm{cl}} - t_a)\} \end{aligned}
$$

Here,

$$
M = \frac{21(0.23\mathrm{RQ} + 0.77)Q_{\mathrm{O}_2}}{A_D} \tag{1}
$$

$$
t_{\mathrm{cl}} = 35.7 - 0.028(M - W) - I_{\mathrm{cl}}\{3.96 \times 10^{-8} f_{\mathrm{d}}[(t_{\mathrm{cl}} + 273)^4 - t_{\mathrm{mr}} + 273^4] + f_{\mathrm{cl}} h_{\mathrm{c}}(t_{\mathrm{cd}} - t_{\mathrm{a}})\} \tag{2}
$$

$$
h_{\mathrm{c}} = \begin{bmatrix} 2.38(t_{\mathrm{cl}} - t_{\mathrm{a}})^{0.25} & \text{for } 2.38(t_{\mathrm{cl}} - t_s)^{0.25} > 12.1(v_{\mathrm{ar}})^{1/2} \\ 12.1(v_{\mathrm{ar}})^{1/2} & \text{for } 2.38(t_{\mathrm{cl}} - t_{\mathrm{x}})^{0.25} < 12.1(v_{\mathrm{ar}})^{1/2} \end{bmatrix} \tag{3}
$$

$$
v_{\mathrm{ar}} = v_{\mathrm{a}} + 0.005(M/A_{\mathrm{DU}} - 58.15) \tag{4}
$$

$$
f_{\mathrm{cl}} = \begin{bmatrix} 1.00 + 1.290 \cdot I_{\mathrm{cl}} & \text{for } I_{\mathrm{cl}} < 0.078\ \mathrm{m}^{20}\mathrm{CW}^{-1} \\ 1.05 + 0.645 \cdot I_{\mathrm{d}} & \text{for } I_{\mathrm{cl}} > 0.078\ \mathrm{m}^{20}\mathrm{CW}^{-1} \end{bmatrix} \tag{5}
$$

$$
T_{\mathrm{mrt}}^4 = T_1^4 F_{\mathrm{p-1}} + T_2^4 F_{\mathrm{p-2}} + \cdots + T_i^4 F_{\mathrm{p-i}} + \cdots T_N^4 F_{\mathrm{p-N}} \tag{6}
$$

$$
F_{\mathrm{p-i}} = F_{\mathrm{max}}\left[1 - e^{-(a/c)/\tau)}\right]\left[1 - e^{-(b/c)/\gamma)}\right] \tag{7}
$$

$$
\tau = A + B(a + b), \gamma = C + D(b/c) + E[a/c] \tag{8}
$$

$$
T_o = \frac{T_{mrt} + T_{dry-bulb}}{2} \tag{9}
$$

$$
A_D = 0.202m^{0.425}l^{0.725} \tag{10}
$$

$$
PPD = 100 - 95 \cdot \exp\left[-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)\right]
$$

Where,

M= rate of metabolic heat production, W/m^2
W= rate of mechanical work accomplished, W/m^2
m= body mass, kg
t_{cr} = temperature of core compartment, $^\circ\mathrm{C}$
t_{cr} = temperature of core compartment, $^\circ\mathrm{C}$
$M =$ metabolic rate, $\mathrm{W/m^2}$
RQ = respiratory quotient; molar ratio of Q_{CO_2} exhaled to Q_{O_2} inhaled, dimensionless
$Q_{\mathrm{O}_2} =$ volumetric rate of oxygen consumption at conditions (STPD) of $0^\circ\mathrm{C}, 101.325\mathrm{kPa}, \mathrm{mL/s}$

V= velocity (m/s)
a = is the width of the surface
b =is the height of the surface
c= distance between the person and the target surface
Coefficients *Fmax*, *A*, *B*, *C*, *D* (F(p−N)) = surrounding surfaces and the angle factor between the person
A_D = DuBois surface area, m^2
m = mass, kg
I = height, m
f_d = clothing area factor

Activities	**W/m^2**	**meta**
Seated, quiet	60	1
Reading, seated	55	1
Writing	60	1
Typing	65	1.1
Light activity while standing	90	1.6
Moderate activity while standing	130	2

Level of Exertion	**Heart Rate (bpm)**	**Oxygen consumed (mL/s)**
Light work	< 90	< 8
Moderate work	90 to 110	8 to 16
Heavy work	110 to 130	16 to 24
Very heavy work	130 to 150	24 to 32
Extremely heavy work	150 to 170	> 32

Table2: Heat Generations and metabolic rate for activities for various kinds of work (Brager & De Dear, n.d.-b)

5. Results & Discussions:

The thermal comfort indicators include air temperature, relative humidity, air velocity, mean radiant temperature, clothing type, metabolic rate, PMV and Percentage of People Dissatisfied (PPD). Each variable was measured and documented during the day. The trained artificial neural network estimated thermal comfort ratings for 68 data sets. Tables display these calculations. MATLAB and data were used to create an ANN model. The ANN predicted thermal comfort using input data. This model predicts PMV, a common thermal comfort metric.

User ID	Time	Distance (d)	Mass (kg)	Length (l)	Heart Rate	Air Temperature (°C)	Mean Radiant Temperature (°C)	Relative Air Velocity (m/s)	Relative Humidity (%)	Clothing type	Metabolic Rate (met)	PMV	PPD (%)
1501	8:00	2.5	70	1.8	75	24	23	0.15	50	Light clothing	1.2	-0.3	15
1502	9:30	3.2	65	1.7	82	26	24	0.2	45	Moderate clothing	1.4	0.1	8
1503	11:45	1.8	80	1.9	79	20	19	0.1	55	Heavy clothing	1.8	-0.5	16
1504	14:15	2.7	68	1.75	80	22	20	0.25	40	Moderate clothing	1.6	0.2	6
1505	16:45	2.4	72	1.85	77	21	20	0.15	60	Light clothing	1.7	-0.2	12
1506	8:30	2.2	75	1.78	85	23	21	0.3	45	Moderate clothing	1.9	0.3	5
1507	10:15	3.5	63	1.73	78	22	20	0.2	50	Light clothing	1.4	-0.6	18
1508	13:00	2.1	71	1.79	88	24	22	0.25	40	Heavy clothing	2.1	-0.8	22
1509	15:45	2.8	67	1.76	80	21	19	0.1	55	Moderate clothing	1.5	0.4	9
1510	17:30	2.3	73	1.84	76	20	18	0.15	60	Light clothing	1.65	-0.1	11
1511	9:00	2.6	68	1.72	70	25	23	0.2	45	Heavy clothing	1.7	0	10
1512	8:15	2.4	72	1.78	79	23	21	0.2	55	Moderate clothing	1.5	0.3	9
1513	9:45	3.1	66	1.75	81	24	22	0.15	50	Light clothing	1.6	-0.1	14
1514	11:30	1.9	79	1.9	77	21	20	0.1	60	Heavy clothing	1.7	-0.2	12
1515	14:00	2.8	67	1.76	78	22	20	0.25	45	Moderate clothing	1.8	0.1	8
1516	16:30	2.3	73	1.84	76	20	18	0.2	55	Heavy clothing	1.9	0	10
1517	8:45	2.7	68	1.72	70	25	23	0.15	50	Light clothing	1.4	-0.3	15
1518	10:30	3.4	64	1.7	83	26	24	0.2	45	Moderate clothing	1.5	0.2	6
1519	13:15	2	70	1.8	85	23	21	0.3	40	Heavy clothing	1.6	-0.5	16
1520	15:45	2.9	66	1.75	79	21	19	0.1	60	Moderate clothing	1.7	0.3	5

Table 3: Calculation of Thermal Comfort

The distances covered by the users range from 1.8 m to 3.5 m. The mass of the users varies from 63 kg to 80 kg. The length of the users ranges from 1.7 m to 1.9 m. The heart rates recorded for the users range from 70 beats per minute to 88 beats per minute. The air temperature varies between 20°C and 26°C.The mean radiant temperature ranges from 18°C to 24°C. The relative air velocity recorded ranges from 0.1 m/s to 0.3 m/s. The relative humidity varies between 40% and 60%. The metabolic rates recorded range from 0.5 met to 1.9 met. The Predicted Mean Vote (PMV) values range from -0.8 to 2.1. By analyzing these parameters, we can observe the variations in different factors that contribute to the thermal comfort of the users

We can further explore the relationship between the PMV and PPD values. By analyzing these values, we can assess the comfort levels experienced by the users and determine if there are any significant deviations from thermal neutrality. By examining the data across different time points, we can identify any patterns related to the variation of metabolic rate, PMV, and PPD throughout the day. This analysis can help understand if there are specific time periods where thermal comfort is more challenging to achieve. In addition to supporting software analysis, the software platform also facilitates the hand calculation of PMV (Predicted Mean Vote). This means that users have the flexibility to manually calculate PMV values based on established equations and principles

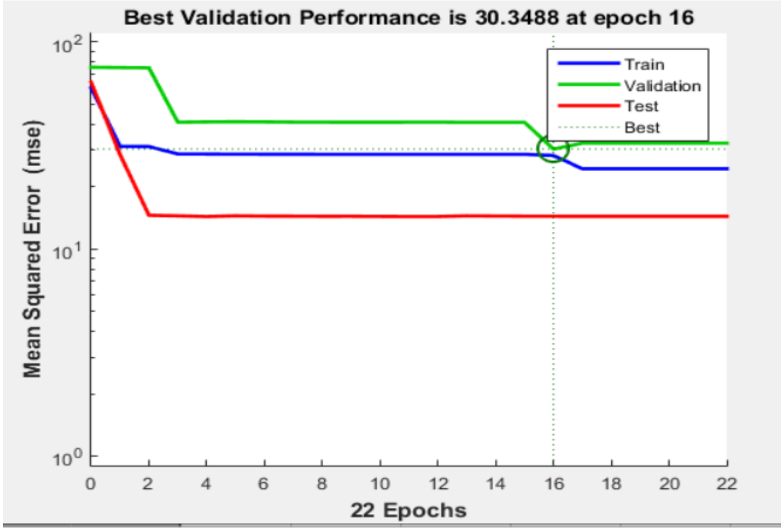

Figure 2: Network training error rate

Mass (kg)	Length (l)	Heart Rate	Air Temperature (°C)	Mean Radiant Temperature (°C)	Relative Air Velocity (m/s)	Relative Humidity (%)	Clothing type	Metabolic Rate (met)	PMV	PREDICTED VALUES
70	1.8	75	24	23	0.15	50	0.5	1.2	-0.3	0.3
65	1.7	82	26	24	0.2	45	0.9	1.4	0.1	-0.6
80	1.9	79	20	19	0.1	55	1.2	1.8	-0.5	0.4
68	1.75	80	22	20	0.25	40	0.9	1.6	0.2	0.0
72	1.85	77	21	20	0.15	60	0.5	1.7	-0.2	-0.6
75	1.78	85	23	21	0.3	45	0.9	1.9	0.3	-0.8
63	1.73	78	22	20	0.2	50	0.5	1.4	-0.6	0.2
71	1.79	88	24	22	0.25	40	1.2	2.1	-0.8	0.4
67	1.76	80	21	19	0.1	55	0.9	1.5	0.4	0.0
73	1.84	76	20	18	0.15	60	0.5	1.65	-0.1	0.4
68	1.72	70	25	23	0.2	45	1.2	1.7	0	0.0
72	1.78	79	23	21	0.2	55	0.9	1.5	0.3	-0.1
66	1.75	81	24	22	0.15	50	0.5	1.6	-0.1	-0.7
79	1.9	77	21	20	0.1	60	1.2	1.7	-0.2	-0.6
67	1.76	78	22	20	0.25	45	0.9	1.8	0.1	-0.6
73	1.84	76	20	18	0.2	55	1.2	1.9	0	0.1
68	1.72	70	25	23	0.15	50	0.5	1.4	-0.3	-0.5
64	1.7	83	26	24	0.2	45	0.9	1.5	0.2	0.4

Table 1:prediction of thermal comfort

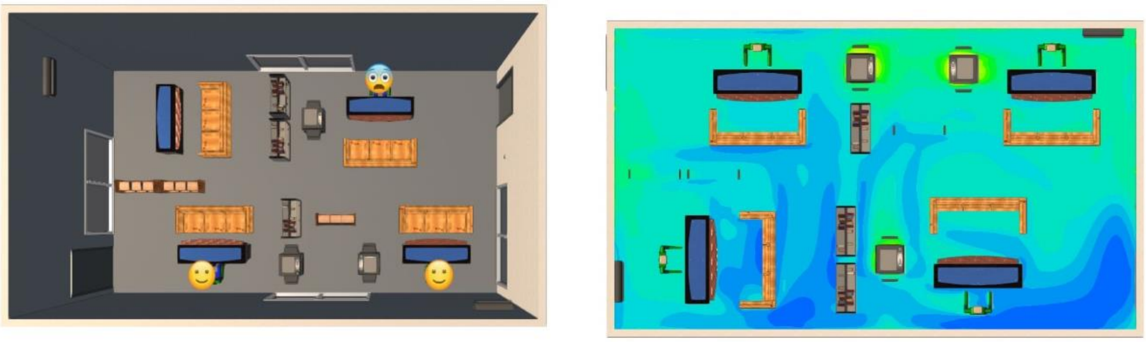

Figure 4: Software analysis for individual thermal comfort

This software analysis enables us to efficiently assess the level of comfort within the space, providing a comprehensive understanding of comfort zones. Furthermore, it empowers us to visually represent the existing conditions inside the space, facilitating a clear visualization of the comfort levels experienced by occupants. In the PMV chart, the dark blue condition represents the zone of extreme cold conditions, indicating that individuals in this region may experience discomfort due to the cold environment. On the other hand, the green zone represents the neutrality zone, indicating that individuals within this range are expected to perceive the thermal environment as comfortable or near-neutral in terms of temperature. The PMV chart visually represents the thermal comfort conditions across the space, allowing for a quick assessment of areas that may require adjustments or interventions to improve comfort levels.

6.Conclusion

This paper evaluated thermal comfort levels in an existing structure and developed an Artificial Neural Network (ANN) model to forecast thermal comfort based on numerous characteristics. Air temperature, relative humidity, and air velocity were used to quantify thermal comfort using the PMV index. The ANN model accurately predicted thermal comfort levels quickly. This paper's thermal comfort assessment and prediction approach may be used in different structures. The ANN model may be improved by adding thermal comfort characteristics in future study. This may improve building performance and HVAC system efficiency. In conclusion, using an ANN model to evaluate and anticipate thermal comfort levels is a potential method for building design optimization and HVAC system efficiency improvement.

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