

EVALUATION OF THERMAL COMFORT IN RESIDENTIAL BUILDINGS IN DUHOK

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ABSTRACT

Thermal comfort is an essential factor affecting occupants' health, well-being, and overall satisfaction within residential buildings. Due to rapid urbanization, population growth, and continuous residential development in the city of Duhok, the thermal performance of residential buildings has become an important issue for sustainable urban living. This study aims to evaluate the thermal comfort conditions of ten residential houses in Duhok, Iraq, through the assessment of indoor environmental parameters and occupants' perceptions. A mixed-method approach was employed, combining field measurements and occupant questionnaires. Indoor environmental data, including air temperature, relative humidity, air velocity, and mean radiant temperature, were collected from the selected houses. In addition, a structured questionnaire was distributed to residents to assess their thermal sensation and overall satisfaction. Thermal comfort conditions were evaluated using the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices in accordance with internationally recognized thermal comfort standards. The results indicated that indoor air temperatures ranged from 27.5°C to 31.0°C, with an average temperature of 29.07°C. PMV values ranged from 0.35 to 1.70, revealing that most houses experienced slightly warm to warm thermal conditions. Occupant satisfaction ranged from 45% to 91%, with an average of 70%. The findings demonstrated that houses with lower indoor temperatures and higher air movement achieved better thermal comfort performance and higher occupant satisfaction. The study concludes that improving natural ventilation, thermal insulation, and shading strategies can significantly enhance thermal comfort in residential buildings and contribute to better indoor environmental quality in Duhok.

Keywords: Thermal Comfort, Residential Buildings, Indoor Environmental Quality, Occupant Satisfaction, Duhok

1. INTRODUCTION

Thermal comfort is a fundamental component of indoor environmental quality and plays a significant role in occupants' health, well-being, and satisfaction. Since people spend a considerable amount of time indoors, providing a comfortable thermal environment has become one of the primary objectives in residential building design. Thermal comfort influences not only the quality of life of occupants but also their productivity, health, and energy consumption patterns [1].

The concept of thermal comfort refers to a condition in which individuals feel satisfied with their surrounding thermal environment. However, thermal comfort is a complex phenomenon because it depends on both environmental and personal factors. Environmental factors include air temperature, relative humidity, air velocity, and mean radiant temperature, while personal factors include clothing insulation and metabolic activity. The interaction of these variables determines how occupants perceive thermal conditions within indoor spaces [2].

Air temperature is one of the most influential parameters affecting thermal comfort because it directly impacts the heat exchange between the human

body and the surrounding environment. Relative humidity affects the body's ability to cool itself through perspiration, while air velocity influences heat loss by convection and evaporation [3]. Mean radiant temperature represents the combined effect of the temperatures of surrounding surfaces and significantly contributes to occupants' thermal sensation. Therefore, accurate assessment of these parameters is essential for evaluating indoor thermal conditions [4].

The achievement of acceptable thermal comfort conditions has become increasingly important in modern residential buildings due to growing concerns regarding energy efficiency, sustainability, and occupant well-being [5]. Buildings that fail to provide comfortable indoor environments often require excessive use of heating and cooling systems, resulting in increased energy consumption and operational costs. Consequently, understanding thermal comfort performance can contribute to the development of more sustainable and energy-efficient residential buildings [6].

Several international standards have been developed to assess thermal comfort conditions. Among the most widely used are the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices,

which provide quantitative methods for evaluating occupants' thermal sensation and comfort levels.

These indices are based on measured environmental parameters and personal characteristics and are commonly used in thermal comfort research and building performance evaluation [7, 8].

Assessment of thermal comfort can be conducted using objective measurements, subjective surveys, or a combination of both approaches. Environmental measurements provide information about actual indoor conditions, whereas occupant surveys reflect human perceptions and satisfaction levels. Combining these methods offers a comprehensive understanding of thermal comfort performance and allows for a more accurate evaluation of indoor environmental quality.

This study aims to evaluate thermal comfort conditions in ten residential houses in Duhok by analyzing indoor environmental parameters and occupants' thermal perceptions. The study focuses on measuring key thermal comfort variables and

assessing occupant satisfaction to identify the factors influencing thermal comfort performance in residential buildings. The findings are expected to contribute to improving indoor environmental quality and supporting the design of more comfortable and energy-efficient residential buildings.

2. METHODOLOGY

2.1 Research Design

This study adopts a quantitative and descriptive field-study approach to evaluate thermal comfort conditions in residential buildings in Duhok. The assessment combines indoor environmental measurements with occupant surveys to compare actual thermal conditions with residents' comfort perceptions. The research design framework for evaluating thermal comfort in residential buildings in Duhok is shown in Figure 1.

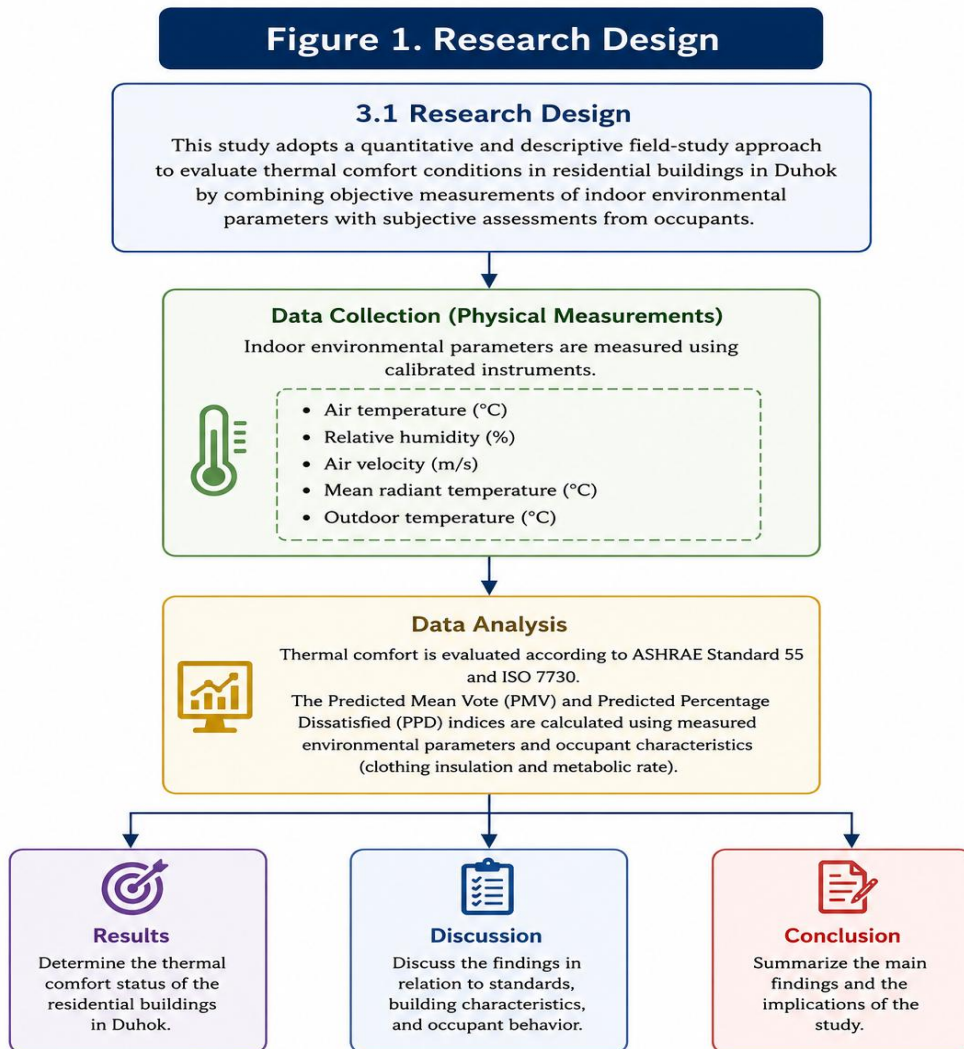


Figure 1. Research design framework for evaluating thermal comfort

2.2 Study area

This study is conducted in the city of Duhok, the administrative capital of the Duhok Governorate within the Kurdistan Region of Iraq. The city is situated in the northern highlands of Iraq at coordinates 36°52'N 43°0'E, at a mean elevation of 565 meters above sea level. The total municipal area is approximately 577 km², with an estimated population of 340,871 residents (2018).

According to the Köppen-Geiger climate classification system, Duhok has a hot-summer Mediterranean climate (Csa), featuring hot, dry summers and cool, wet winters. During summer, daytime temperatures frequently exceed 40°C in July and August. Winter is cold and wet, with average January daytime temperatures around 11°C and nighttime lows near freezing at 1°C [10].

The rapid urban development and spatial expansion of Duhok have fundamentally altered its residential fabric, making the evaluation of thermal comfort increasingly urgent. As the city continues to grow with little consideration for local climate conditions, many

new residential buildings fail to provide adequate indoor comfort during Duhok's extreme summers and cold winters. Therefore, this study is necessary to assess current thermal comfort levels and inform future climate-responsive residential design.

2.3 Data Collection

Data collection was carried out through field measurements and occupant questionnaires in ten residential houses. A mixed-method approach was employed to obtain objective environmental data and subjective occupant perceptions regarding thermal comfort.

2.3.1 Selection of Residential Houses

Ten occupied residential houses were selected as the study sample. The houses were chosen to represent different residential characteristics, including building age, construction materials, orientation, and cooling systems. The selected houses were distributed across different residential neighborhoods to provide a representative assessment of thermal comfort conditions. Table 1 presents the characteristics of the selected houses.

Table 1. Selected Residential Houses Characteristics

House Code	Building Type	No. of Occupants	Building Age (Years)	Cooling System
H1	Detached House	5	8	Split AC
H2	Detached House	6	12	Split AC
H3	Apartment	4	6	Split AC
H4	Detached House	7	15	Split AC
H5	Apartment	3	5	Split AC
H6	Detached House	5	10	Split AC
H7	Detached House	6	18	Split AC
H8	Apartment	4	7	Split AC
H9	Detached House	5	11	Split AC
H10	Apartment	3	9	Split AC

2.3.2 Environmental Measurements

Indoor environmental monitoring was carried out in all selected houses to evaluate the thermal conditions inside the dwellings. Measurements were performed in the living room, as it is considered the main occupied area of the house. The thermal comfort indicators assessed during the study included the following parameters:

- ✓ Air temperature (°C)
- ✓ Relative humidity (%)
- ✓ Air velocity (m/s)

- ✓ Mean radiant temperature (°C)
- ✓ Outdoor temperature (°C)

All measurements were conducted at a height of approximately 1.1 m above the floor, representing the typical seated position of an occupant. To account for variations in indoor thermal conditions throughout the day, data were collected during three different periods: morning, afternoon, and evening. The measured environmental parameters used for the thermal comfort assessment are presented in Table 2.

Table 2. Environmental Parameters Measured

Parameter	Instrument	Unit
Air Temperature	Digital Thermometer	°C
Relative Humidity	Hygrometer	%
Air Velocity	Anemometer	m/s
Mean Radiant Temperature	Globe Thermometer	°C
Outdoor Temperature	Weather Meter	°C

2.3.3 Occupant Questionnaire

A structured questionnaire was distributed to one adult occupant per selected house, consisting of three sections: demographic information (age, gender, occupation), building information (housing type, building age, cooling/heating systems), and thermal comfort [12]. Thermal comfort section included votes on thermal sensation, preference, acceptability, and overall satisfaction, by ASHRAE's seven-point scale from -3 (Cold) to +3 (Hot), where 0 represents neutral [13, 14].

This section presents the assessment results of the thermal comfort conducted in ten residential houses. The analysis is based on the environmental measurements and occupants' thermal comfort responses collected during the field survey. The results are discussed with reference to thermal comfort standards and occupants' satisfaction levels.

3.1 Indoor Environmental Conditions

Table 3 presents the average measured indoor environmental parameters for the selected residential houses

3. RESULTS AND DISCUSSION

Table 3. Average measured indoor Environmental Parameters

House	Air Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)	Mean Radiant Temperature (°C)
H1	28.5	42	0.20	29.0
H2	30.1	38	0.15	30.7
H3	27.8	45	0.25	28.2
H4	31.0	35	0.12	31.6
H5	29.2	40	0.18	29.8
H6	28.0	47	0.28	28.5
H7	30.5	37	0.14	31.0
H8	27.5	48	0.30	28.0
H9	29.8	39	0.16	30.2
H10	28.3	43	0.22	28.8

The results of the assessment indicate that indoor air temperatures ranged from 27.5°C to 31.0°C, averaged 29.07°C. Relative humidity values ranged between 35% and 48%, while air velocity varied from 0.12 m/s to 0.30 m/s.

The highest indoor recorded temperature was in House H4 (31.0°C), whereas House H8 recorded the lowest temperature (27.5°C). Houses with higher temperatures generally exhibited lower air movement, which negatively influenced thermal comfort.

3.2 Assessment of Thermal Comfort

Thermal comfort was evaluated using the Predicted Mean Vote (PMV) and Predicted Percentage

Dissatisfied (PPD) indices. Assessment of Thermal Comfort Results is shown in Table 4.

The PMV values ranged from 0.35 to 1.70. According to thermal comfort standards, PMV values between -0.5 and +0.5 are generally considered acceptable. Only House H8 achieved a PMV value close to or within the comfort zone. The remaining houses exhibited slightly warm to warm thermal conditions.

Highest PMV house H4 is recorded with a value of 1.70, and the highest PPD value (61%), indicating a significant level of thermal discomfort among occupants. In contrast, House H8 recorded the lowest (PMV) and (PPD) values, suggesting the most comfortable indoor environment among the surveyed houses.

Table 4. Thermal Comfort Assessment Results

House	PMV	PPD (%)	Thermal Sensation
H1	0.85	20	Slightly Warm
H2	1.35	42	Warm
H3	0.55	11	Slightly Warm
H4	1.70	61	Warm
H5	1.00	27	Slightly Warm
H6	0.50	10	Slightly Warm
H7	1.45	48	Warm
H8	0.35	7	Neutral-Slightly Warm
H9	1.20	35	Warm
H10	0.70	15	Slightly Warm

3.3 Occupants' Thermal Satisfaction

The questionnaire responses were analyzed the occupants' determination, overall thermal satisfaction, shown in Figure 2.

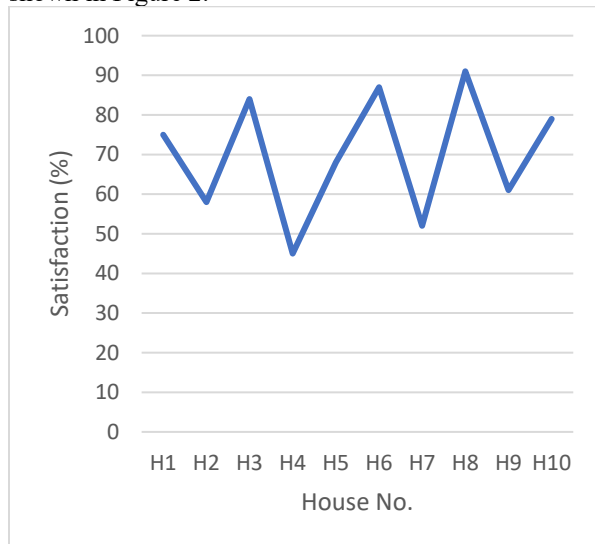


Figure 2 Occupants' Thermal Satisfaction

The results showed that levels of thermal satisfaction varied considerably among the surveyed houses. Satisfaction levels ranged from 45% to 91%, with an overall average of 70%.

The highest satisfaction level was observed in House H8 (91%), which also demonstrated the lowest temperature and highest air velocity. Conversely, House H4 reported the lowest satisfaction level (45%), followed by the highest indoor temperature and lowest air movement.

These findings shown a clear relationship between indoor environmental conditions and occupant satisfaction. Houses with lower temperatures and better ventilation generally achieved higher satisfaction scores.

3.4 Discussion

The results indicated that the thermal comfort conditions in the investigated residential buildings were mainly affected by indoor air temperature and ventilation rates. In several houses, the recorded temperatures exceeded 30°C, leading to PMV values above +1.0 and higher levels of occupant dissatisfaction. These findings suggest that residents perceived the indoor environment as relatively hot and thermally uncomfortable.

The results also highlight the positive effect of air velocity. Houses H6 and H8 recorded higher air movement values (0.28–0.30 m/s), which contributed to improved comfort despite relatively warm climatic conditions. Furthermore, the comparison between

PMV values and questionnaire responses showed a strong agreement between predicted thermal comfort and actual occupant perceptions. Houses with lower PMV and PPD values consistently reported higher satisfaction levels. Overall, the findings suggest that thermal comfort, especially in residential buildings, can be improved through enhanced natural ventilation, effective shading devices, improved building insulation, and the use of energy-efficient cooling systems.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This study evaluated thermal comfort situations in ten residential houses through a combination of indoor environmental measurements and occupant surveys. The assessment focused on key thermal comfort parameters, including air temperature, air velocity, relative humidity, and mean radiant temperature, together with occupants' thermal perceptions and satisfaction levels. The results revealed that the average indoor air temperature of the surveyed houses was 29.07°C, indicating relatively warm indoor conditions. Thermal comfort assessment using the (PMV) and (PPD) indices showed that most houses were outside the recommended thermal comfort range. PMV values ranged from 0.35 to 1.70, suggesting that occupants generally perceived their indoor environment as slightly warm to warm.

Among the investigated houses, House H8 demonstrated the best results of thermal comfort, recording the lowest PMV and PPD values and the highest occupant satisfaction level (91%). In contrast, House H4 exhibited the poorest thermal comfort situations, characterized by the highest indoor temperature, the highest dissatisfaction level, and the lowest occupant satisfaction score (45%). The findings also indicated a strong relationship between indoor environmental conditions and occupants' thermal perceptions. Houses with lower indoor temperatures and higher air movement achieved better levels of thermal comfort and greater occupant satisfaction. Increased air velocity was found to improve comfort conditions even when indoor temperatures remained relatively high.

In addition, the analysis revealed a strong correlation between the environmental measurements collected and the occupants' survey responses, indicating that the estimated thermal comfort levels closely matched residents' perceptions. This finding highlights the effectiveness of integrating quantitative data with subjective evaluations when examining thermal comfort in residential settings.

The study further suggests that residential indoor comfort can be enhanced by increasing natural airflow, upgrading thermal insulation, incorporating appropriate shading solutions, and adopting energy-efficient cooling technologies. The application of these strategies can help minimize thermal stress, promote occupant health and satisfaction, and improve the overall quality of the indoor environment in residential buildings.

4.2 Recommendations

The results of this study indicate several practical approaches for enhancing thermal comfort in residential buildings. As dwellings with cooler indoor environments and greater air circulation were associated with higher levels of comfort and occupant satisfaction, increasing natural ventilation should be a key consideration. This can be achieved through the strategic placement of windows, the implementation of cross-ventilation techniques, and the use of shading elements that limit solar heat gain while encouraging airflow.

Furthermore, upgrading the thermal insulation of building envelopes, particularly roofs and walls, can help stabilize indoor temperatures and decrease reliance on mechanical cooling. Homeowners and building professionals are also encouraged to adopt energy-efficient cooling technologies and climate-sensitive design solutions to improve indoor environmental conditions. Together, these interventions can enhance occupant well-being, reduce discomfort, and support the development of more sustainable and energy-conscious residential buildings.

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