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Thermal Comfort and Internal Conditions Testing of Standard Relief Tents in Cold Climates

Rawan A. Fayyad[1*] and Issam M. Ali Aljubury[2]
[1,2] Department of Mechanical Engineering, College of Engineering, University of Baghdad, 10071, Baghdad, Iraq
*Corresponding Author's Email: rawan.adnan2303@coeng.uobaghdad.edu.iq

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Abstract

To assist decision-makers in selecting the best solutions and arriving at better solutions for temporary shelter and to identify key issues related to temporary shelter methods and provide some principles and recommendations, this study presented a theoretical investigation into the measurement of thermal comfort in standard relief tents in cold climates. The results were analysed and compared using the CBE MRT and CBE Thermal Comfort tools based on field-measured values inside a tent from December 2024 to February 2025. The results on 11, 13, 14 and 18 December 2024, were selected to avoid repetition. Thermal comfort is a key factor in the design and use of tents in cold regions because of its direct impact on the safety and well-being of occupants. Factors affecting the thermal comfort of tents in cold weather include insulation, ventilation, clothing and heating. This study was applied in nature and was conducted using a descriptive analytical approach. Data were collected using library and documentation methods. This study provides important indicators in the field of thermal comfort, particularly in the design of heating, ventilation and air conditioning systems. These environmental and individual factors influence the relationship between the predicted population mean vote and the predicted dissatisfaction rate. On the basis of these factors, the study helps measure human indoor thermal comfort and determine the influencing factors in each case to reach the desired conclusions while emphasising that the tents did not provide suitable thermal conditions for their inhabitants until they were treated using an experimental model.

Keywords: *temporary shelter; thermal comfort; CBE MRT; CBE Thermal Comfort tools; PMV; PPD*

1. Introduction

The Centre for the Built Environment (CBE) Thermal Comfort Tool is a widely used tool for calculating and visualising thermal comfort in accordance with ASHRAE 55[1], ISO 7730[2], and EN 16798[3]. Other main thermal comfort models include PMV, standard effective temperature (SET), adaptive models, local discomfort models, Solar Call, and dynamic predictive clothing insulation. Our technology offers interactive and dynamic visualisations of thermal comfort zones. More than 49,000 people worldwide use the CBE Thermal Comfort Tool annually, including engineers, architects, researchers, educators, facility managers, and policymakers. The tool has many practical applications.

Currently, 45 million people have been displaced worldwide because of conflict, natural disasters or other calamities. The frequency of extreme weather and climatic occurrences adds to the complexity and intensity of the global natural disaster scenario. The affected nations and areas usually lack the capacity to handle such calamities.

Refugees are people who have been displaced and have crossed a border to seek safety in another nation. The United Nations High Commissioner for Refugees (UNHCR) has two missions under these circumstances: protection and aid. In addition to registering the refugees and giving them legal status, the UNHCR oversees the aid effort. Mass population displacements frequently result in high mortality rates. The population's quality of life and chances of survival will increase with the speed and adaptability of the response. Governments frequently use temporary buildings, such as relief tents, to distribute goods for disaster relief and to help impacted communities relocate in a transitional manner [4]. Disaster relief tents are often used as essential emergency rescue tools during temporary shelter phases. However, as with other temporary structures, the nature of their construction results in poor thermal resistance, heat loss and limited heat storage capacity. As a result, the inhabitants of these tents often suffer from severe cold during the winter and stifling, harsh conditions during the summer [5]. This problem occurs because the temperature inside the tents rises quickly in direct sunshine and falls quickly when the outside temperature drops [6] as a result of the structure's lack of thermal capacity. To improve the internal microclimate of tents, studies have been conducted on changing the structure of materials [7], adding more layers [8], and developing layer technology and external partitions [9] for the tents.

Experiments have demonstrated that adding a reflective layer to the tent's outer layer lowers the air temperature [10][11]. The thermal insulation of building walls also greatly enhanced by reflective insulation [12].

Tent partition modifications and the application of various thermal insulation layers [13] have been shown to reduce heating and cooling loads while maintaining acceptable thermal comfort levels for occupants [14]. According to Bradshaw [15], buildings are designed to create an artificial environment that is better suited for human use or specific processes than the surrounding outdoor conditions. Therefore, maintaining a distinct indoor thermal environment is essential, as it usually differs significantly from external climatic conditions. This indoor climate can be influenced through passive envelope features or actively controlled using environmental systems.

In emergency situations, addressing all factors that influence the planning of temporary housing is often impractical. Additionally, each affected region has unique characteristics that shape the suitability of different sheltering technologies. A planning model that considers human error and evaluates the interaction between existing and newly implemented infrastructure is crucial for improving preparedness in the pre-disaster phase. Crisis risks can be mitigated through proper planning, community preparedness, and enhanced resilience. This can be achieved by adopting a systematic temporary housing strategy for each location that relies on local data and outlines key actions required during pre- and post-disaster periods.

This article introduces a structured approach to temporary housing design, viewed as a sequence of steps aimed at addressing occupant needs and improving the internal conditions inside tents. The discussion highlights that relying solely on solar energy is insufficient for maintaining adequate heating in lightweight shelters unless an integrated solar heating system is implemented.

Haiqal et al. [16] evaluated the thermal comfort performance of refugee tents by combining ANSYS Fluent simulations with field observations in a humid tropical region. Their study tested two design improvements rooftop vents and a double-skin roof with a 10 cm air gap. Ventilation alone reduced indoor air temperature by approximately 0.5 K, while the double-skin design further decreased indoor temperature by about 2.9 K relative to the outdoors. These modifications also enhanced airflow, demonstrating the value of improved insulation and ventilation strategies for shelters in humid climates [21].

Using local high-thermal-mass materials, Eltaweel et al. created an inverted-box-rib modular shelter known as Makazi. Compared to lightweight alternatives, these shelters exhibited smaller temperature fluctuations an important advantage in regions with large diurnal temperature variability, as confirmed by EnergyPlus simulations. This approach balances rapid construction, cultural compatibility, and improved occupant comfort [22].

Through IDA-ICE simulations and field measurements, Ibrahim et al. examined evolving design strategies across multiple phases of prototype refugee housing. Their findings indicated that passive approaches such as solar shading and thermal insulation significantly improved indoor thermal performance. Although later prototypes achieved substantial reductions in heating and cooling demands and enhanced thermal comfort, active systems were still required during winter in cold climates [23].

Rupp, Vásquez, and Lamberts reviewed a large number of thermal comfort studies although not specific to temporary shelters. Their analysis highlighted the influence of local controls, occupant adaptability, air movement, and mean radiant temperature on comfort. They concluded that thermal comfort is shaped by a combination of passive design features, occupant behaviour, and adaptive management, especially in low-performance temporary structures [24].

Overall, this study aims to evaluate the internal thermal conditions of emergency shelters and assess the thermal comfort performance of standard relief tents to inform design improvements suited for various climate conditions.

2. Methodology

Thermal environment and thermal comfort tests of standard relief tents were conducted in a low-temperature environment to determine the heat transfer coefficient value of the thermal cover of the air tent. These data can be used in case of plans to use heating inside the tent (Fig. 1). The study was conducted under cold climatic conditions in December in Thi-Qar/Nasiriyah, Iraq. The relationships between The Predicted Percentage of Dissatisfied (PPD) you can just write PPD. and predicted mean vote (PMV) were adopted, and their values were calculated mathematically and compared with their values obtained by using CBE and CBE 3D MRT software.

3. Climate of Nasiriyah City

Nasiriyah is a city in Iraq situated along the banks of the Euphrates River, about 360 km southeast of Baghdad at 46.26 longitude, 31.7 latitude and an elevation of 10 m above sea level. The winter months are December, January and February.

4. Thermal Comfort

The design and operation of indoor environments and the assessment of indoor thermal environments depend heavily on thermal comfort. Thermal comfort is defined as the "state of mind which reflects happiness with the thermal environment" according to ISO standard 7730 [2]. Over the past few decades, academics have thoroughly examined and discussed two kinds of thermal comfort techniques. Globally, indoor thermal comfort in buildings is predicted and evaluated using Fanger's PPD and PMV indices [19]. The indicators are derived from laboratory research and supported by the idea that the body's heat balance and metabolic heat generation indicate how people react to their thermal surroundings in terms of heat transfer physics and physiology. According to the steady-state heat balance model, the effects of thermal load on the human thermoregulatory system's effect mechanisms are strongly linked to thermal sensation. This method is reliable because it allows HVAC engineers to create an indoor environment by calculating radiant temperature for radiant heating and cooling system design and indoor thermal design parameters such as air temperature, humidity, and air speed for heating and cooling load calculations.

5. Thermal Comfort Indices

With air speed, air temperature, humidity, metabolic rate, clothing levels and global temperature taken into account, the thermal comfort indices can be calculated as follows:

PMV (predictive mean vote)

The percentage of thermally unsatisfied individ uals who feel either too warm or too chilly is deter mined by the PPD index. It forecasts how many pe ople in a bigger group will be thermally displeased.

Draught risk is the proportion of people who are expected to experience discomfort due to draught.

6. PMV and PPD

PMV is a metric used in the field of thermal comfort and indoor environmental quality to estimate the thermal perception of a group of occupants in a given indoor space. The PMV model was developed by Fanger in the 1970s [4] and is based on the heat balance of the human body. The PMV index utilises six key factors to determine the thermal sensation: air temperature, MRT, air velocity, humidity, clothing insulation and metabolic rate [16].

The model is based on the idea of thermal sensation, which is quantified on a scale ranging from -3 (representing cold) to +3 (representing heat), with 0 denoting a neutral or pleasant condition [17].

PPD is a metric used to predict the level of dissatisfaction in a population on the basis of certain factors, such as environmental conditions, personal preferences or specific criteria of interest. It is widely used in fields such as building performance, architecture and environmental science, particularly in the context of indoor environmental quality.

In indoor climate assessment (such as thermal comfort), PPD is calculated the basis of the PMV model, which estimates the average response of a population to a certain set of environmental conditions such as temperature, humidity, air velocity and clothing insulation.

PPD: On the basis of the PMV value, the PPD estimates the percentage of people who are likely to be dissatisfied with the thermal conditions. A higher PPD indicates a higher likelihood of dissatisfaction.

PMV model considers six main factors that affect human thermal comfort:

Air temperature: the temperature of the air surrounding a person.

MRT: the average temperature of surfaces that radiate heat towards the person (e.g. walls, windows or floors).

Air velocity: the speed of the air moving around a person, which can influence how heat is dissipated from the body.

Relative humidity: the quantity of moisture in the air that influences the body's capacity to cool itself through evaporation.

Clothing insulation: the amount of thermal insulation provided by the clothing a person is wearing.

Metabolic rate: the amount of heat produced by the human body due to physical activity.

Relationship between PMV and PPD:

As PMV moves away from 0 (neutral), PPD increases.

For instance:

PMV = 0 → PPD ≈ 5% (comfortably neutral)

PMV = −1 or +1 → PPD ≈ 25%

PMV = −2 or +2 → PPD ≈ 50%

PPD calculation:

PPD is mathematically linked to PMV, as in Equation (1). As PMV moves further from zero (i.e. the neutral comfort zone), PPD increases. The relationship between PMV and PPD is described by the following equation [25]:

$$PPD=100-95e^{(-0.0335(PMV))4}-0.2179(PMV)^2 \quad ... (1)$$

where e is the mathematical constant (Euler's number).

This formula illustrates how PPD grows exponentially in either the positive (hot) or negative (cold) direction as PMV travels farther from zero.

PPD is the predicted percentage of dissatisfied people (in%), and PMV is the predicted mean vote on the thermal sensation scale.

7. Experimental work

7.1 Testing the properties of standard relief tents

The shelter consists of the following parts:

Roof panels: polyolefin foam panels treated with UV protection.

Door: highly resistant door and hinges with locks, which can be padlocked from both sides for added safety for women and children.

Floor sheet: height-adjustable, flood-preventing tarpaulin made of woven high-density polyethylene fibres.

Window: intrusion prevention window with mosquito net and shade made of UV- and heat-resistant polymer plastic

Wall panels: polyolefin foam panels treated with fire retardant and UV protection.

Ventilation: UV- and heat-resistant polymer plastic.

Figure (1) shows the tent features.

7.2. Tent Features

Table 1,
Tent features

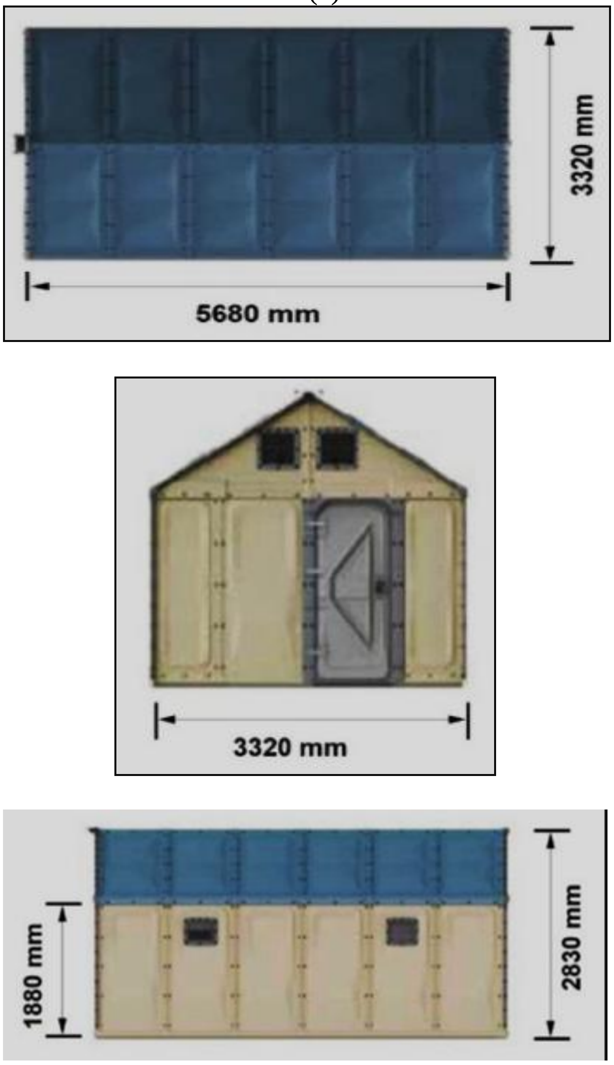
No.	Part
1	Lockable door
2	Four windows
3	Four ventilations
4	Semi-rigid, opaque roof and wall panels
5	Steel frame mounted with ground anchors
6	PV system and portable lamp
7	Flat-packed
8	Five-year shelf life
9	Minimum three-year life span for panels
10	Minimum 10 years for frame
11	Four to six hours assembly time by a team of four

7.3. Tent measurements

Table 2,
Tent measurements

Size	17.5 m^3/188.4 ft^3
Length	5.68 m or 18.6 ft.
Width	3.32 m or 10.9 ft.
Height	2.83 m or 9.2 ft.
Weight	160 kg or 352.7 lb. (shelter 140 kg/packaging 20 kg)

(a)



(b)

Fig. 1. (a) SRTs (b) top, front and side view [20]

7.4. Tent specification

- 101 km/h or 28 m/s wind resistance
- Withstands 10 kg/m^2 snow load
- Minimum 2-minute escape time
- Passes artificial rain test with no leakage

7.5. Thermal comfort test of the tent

The most important measuring devices utilised in this study before the thermal comfort assessment of the tent was conducted are listed below.

7.5.1. Measuring Instrument (Digital Beehive Thermometer)

a) Temperature sensors: Digital thermometers or temperature data loggers were used inside and outside the tent to monitor the internal and external temperature as temperature plays an important role in determining the suitability of thermal conditions. The temperature measurement range was from −50 °C to 70 °C, and the temperature measurement accuracy was ±1 °C.

b) Humidity sensors: Hygrometers help monitor the relative humidity inside the tent. Thus, humidity monitoring devices were installed inside the tent, and the values were compared with the external humidity. The humidity measurement range was (10% _ 95%)RH, and the humidity measurement accuracy was ±5%.

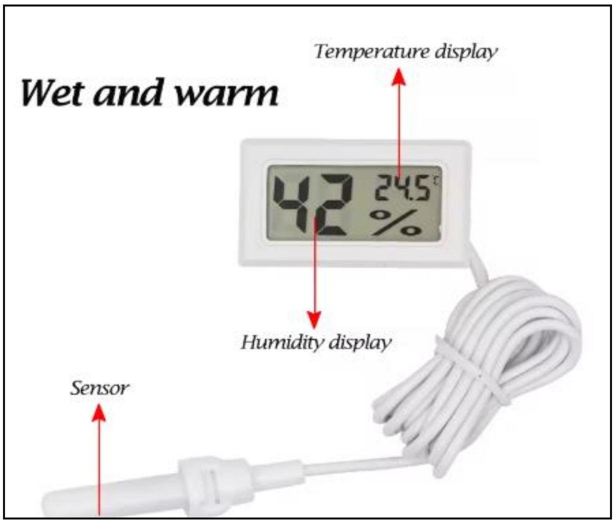


Fig. 2. Temperature and humidity sensor

7.5.2. Test procedures

Initial condition setup: The tent was set up according to the manufacturer's instructions (e.g. proper installation, tensioning). In particular, the environment surrounding the tent had to be stable and documented.

Preconditioning: The tent had to be preconditioned by exposing it to certain temperatures or humidity levels before testing.

This step was conducted in November before the start of testing.

Testing of various parameters:

- Without occupants: The thermal performance of the tent was verified in empty conditions without occupants.
- With occupants: Temperature sensors or body simulators were used inside the tent to assess how the presence of people affected temperature and comfort, with the manufacturer allowing four occupants.

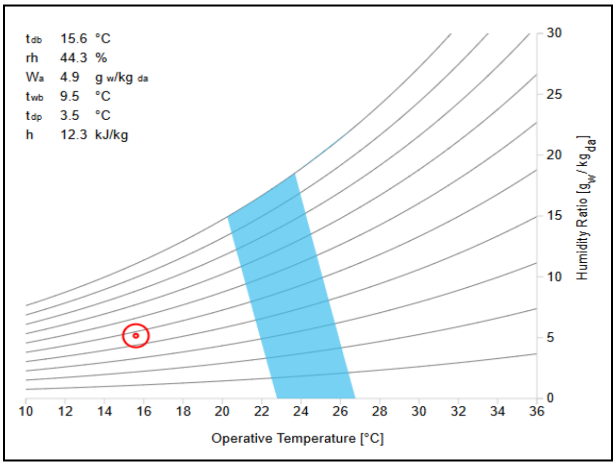
Temperature gradients: The temperature difference between inside and outside the tent was monitored on 11–18 December 2024, which were extremely cold days, with temperatures reaching below 0 °C at night while being slightly higher during the day.

8. Result and Conclusion

Table 3,
Results of the CBE tool

December day	PMV	PPD	Sensation	SET
12	−2.25	87%	cool	17.9
13	−2.2	85%	cool	18
14	−1.92	73%	cool	19.2
15	−4.05	100%	cold	11.9

The data gathered via the CBE interface and shown in Table (3) indicated that the thermal performance within the tent was insufficient because the inside temperature was almost similar to the outside temperature and the th ermal conditions were not appropriate for adequate housing. The CBE and CBE 3D MRT results show that the tents in the cold environment did not meet the needs of their inhabitants. The indoor thermal comfort conditions were also unsuitable in cold weather as the indoor and outdoor conditions were almost equal, which means that displaced people would continue to experience the same problem. This problem can only be solved with the development of an advanced solar system. Figures 3(a–d) show the relationship between humidity and operating temperature on 11–18 December and their effects on PPD, PMV, sensation and SET on the basis of other variables used in CBE, such as MRT, air temperature, metabolic rate and clothing level. Overall, thermal comfort was observed on the basis of the variable values and their effects on PMV and PPD. The PMV values ranged from 2.2 to 4. According to the PMV scale, thermal sensation indicates that indoor conditions were cool to very cold. PPD values are based on PMV values, with PMV resulting in a PPD of approximately 75%, meaning that most people felt uncomfortable. Figures 4(a–d) show the thermal comfort through the relationship between relative humidity and dry-bulb temperature for the same days and variables.



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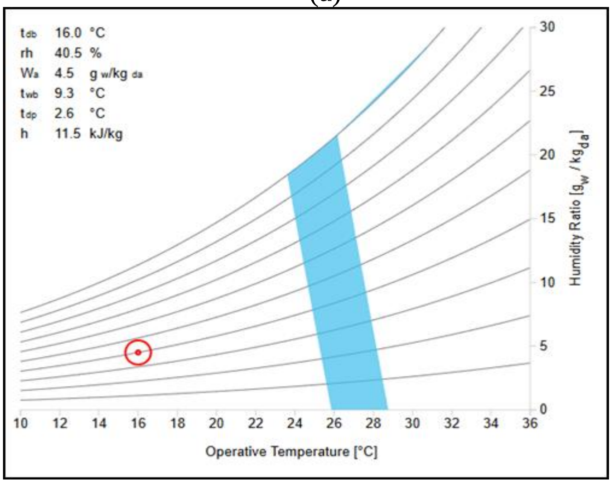

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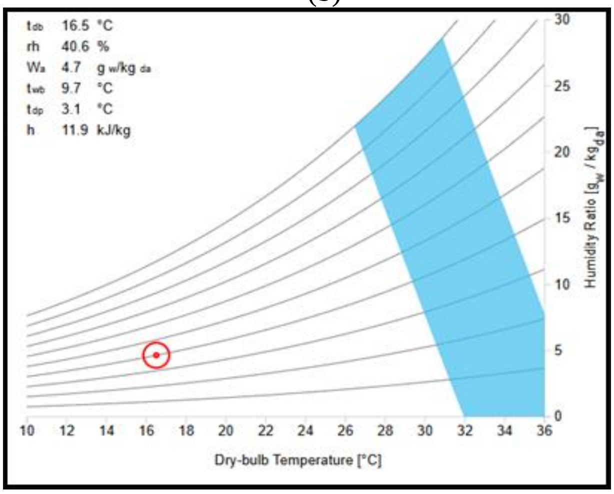

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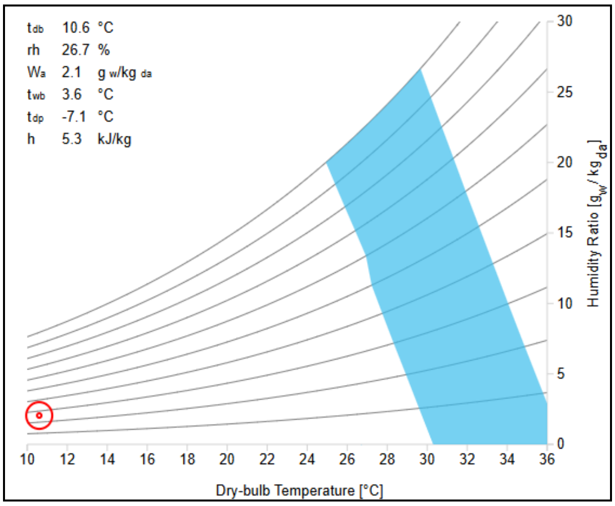
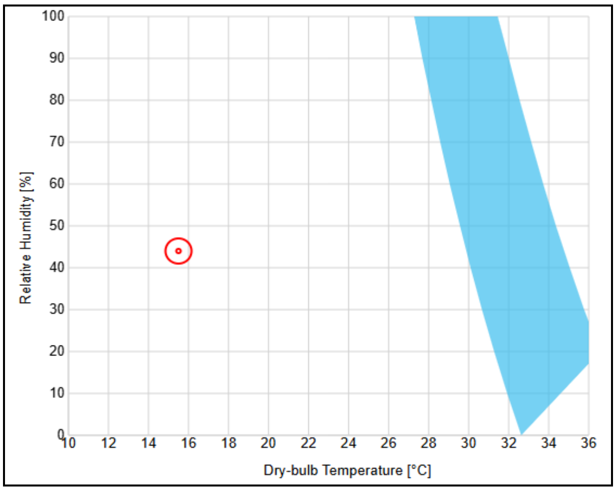


(d)

Fig. 3. Comfort zone for thermal comfort based on operating temperature and humidity ratio values, as defined by ASHRAE 55 standard, showing the range of acceptable indoor conditions.

The operating temperature is represented by the abscissa in this psychrometric chart (Fig. 3), and the MRT (DBT = MRT) is equal to the dry-bulb temperature for each location. According to the standard, the comfort zone is the set of circumstances with the same DBT and MRT for which the PMV falls between −0.5 and +0.5.

The standard has limited applicability, covering only healthy people. Occupants who are sleeping, reclined while in contact with bedding or able to alter blankets or bedding wearing extremely impermeable clothes or whose clothing insulation exceeds 1.5 clo are exempt from this guideline.



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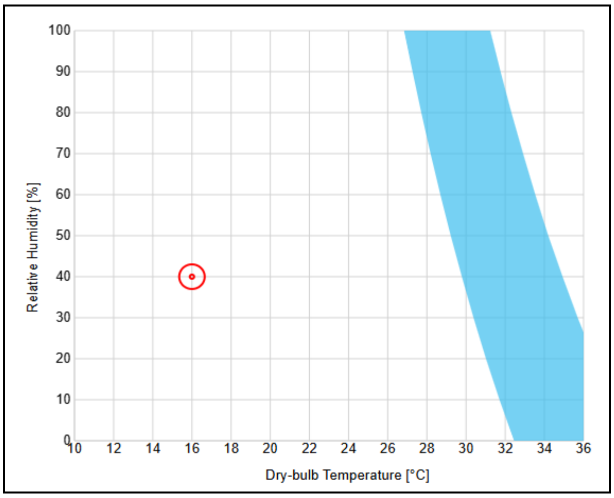

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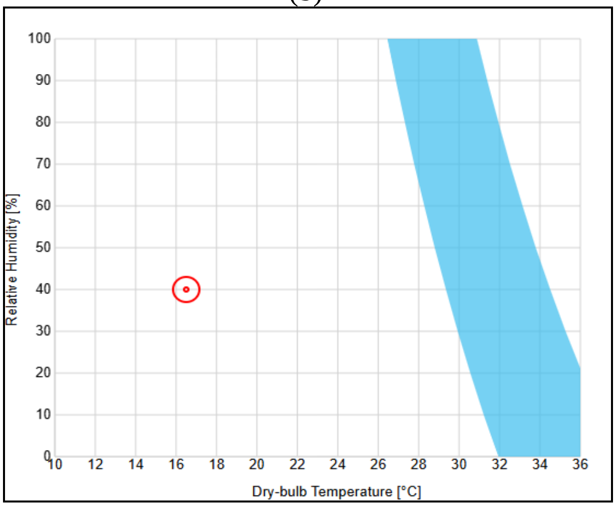

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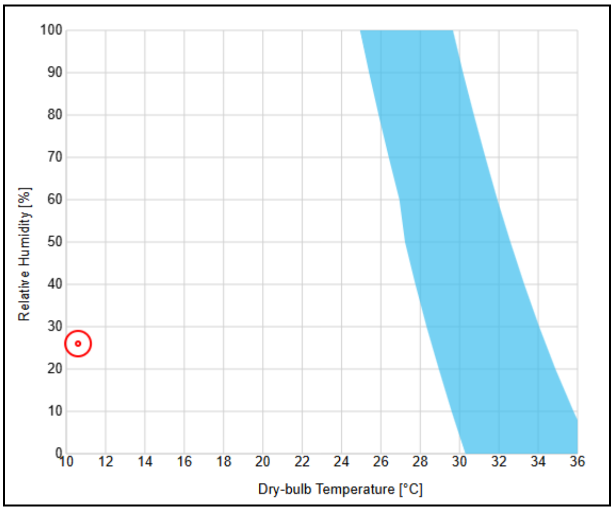
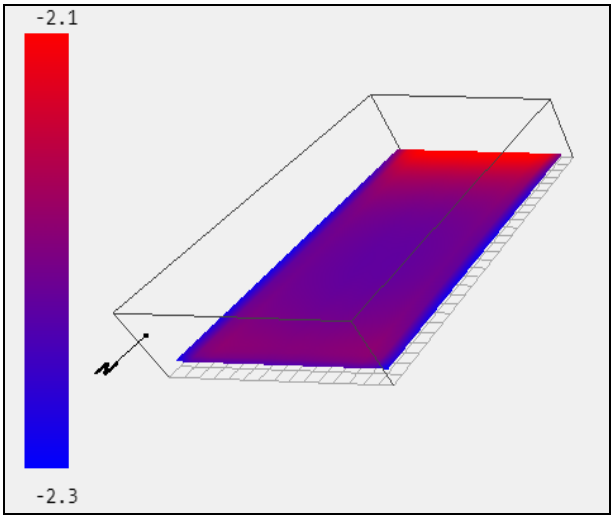


(d)

Fig. 4. Comfort zone according to the dry-bulb temperature and humidity ratio values based on EN 16798-1.

The dry-bulb temperature is the abscissa in this psychrometric chart (Fig. 4), and the input box controls the fixed MRT. The comfort zone boundary is defined by the same MRT at each place on the chart. illustrates how modifications to MRT impact thermal comfort. Each point will have the same MRT, but the operational temperature button can still be used. While the CBE Thermal Comfort tool computes the relative air speed automatically, it does not compute the dynamic insulating properties of clothing as required by ISO 7730 Section C.2. Therefore, the user should compute this value and enter it into the CBE Thermal Comfort tool.

Figures 5(a–d) illustrate CBE's 3D MRT tool, an interactive tool that uses room surface temperatures, solar gain from windows and skylights, and the MRT to determine and display the expected comfort level in a given space. This tool allows for the input of variables related to thermal comfort, including clothing levels and metabolic rates. The figures model a 3D space, including windows and skylights, and then display graphical outputs showing the average radiant temperature, or comfort, represented by the predicted MRT, spread over the space. This tool shows how radiant heat is distributed within the tent, thus helping identify areas of excessive coldness or heat. It enables researchers to test the effect of design modifications, such as adding insulation, curtains or vents, on improving thermal comfort.



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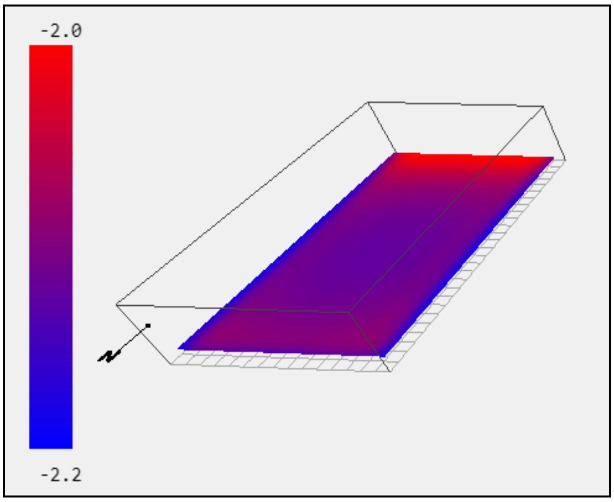

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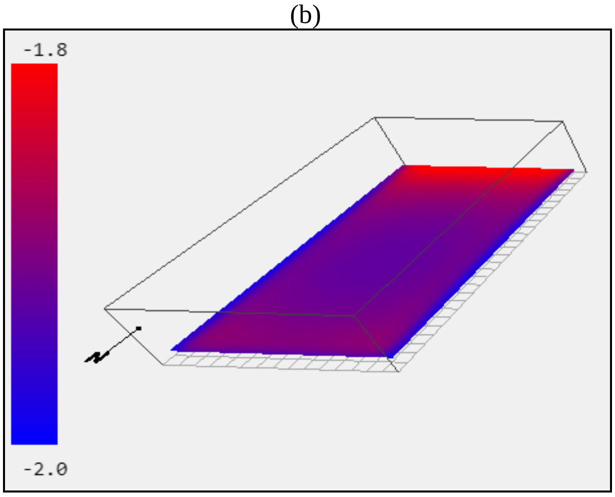

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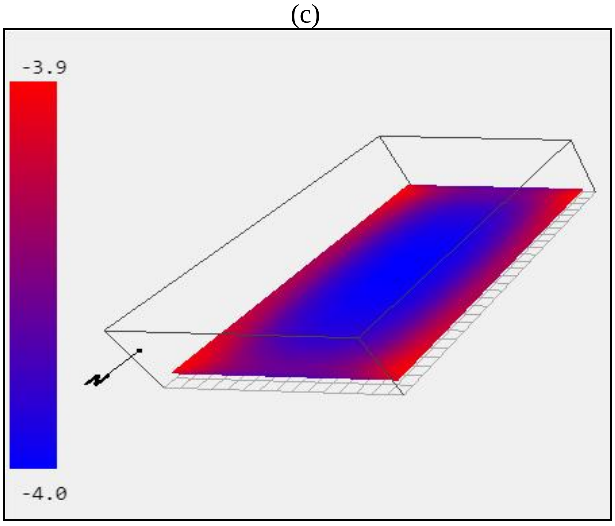

(d)

Fig. 5. Comfort zone in the CBE 3D MRT Tool

9. Conclusion

The comfort finding was based on the idea that the key input for thermal sensation and comfort perception is provided by thermoreceptors, which are sensitive to core and skin temperatures. Fanger's PMV model (Fanger, 1972) and the current approach have been shown to predict similar comfort zones for non-stratified situations, even though the latter relies on a general thermal balance between the environment and the human body. However, the CBE model's prediction of the chilly limit of the comfort zone was less accurate than that of the PMV model. The tent's thermal comfort was tested by creating a variety of environmental scenarios and measuring interior and external variables that influence comfort, including temperature, humidity and airflow, using a variety of sensors. The outcomes were used to evaluate how well the tent maintained a cozy interior atmosphere. Additionally, a variety of factors influenced the tents' interior conditions, and findings indicate that depending solely on solar energy was not enough to guarantee suitable comfort levels, especially in the winter. The walls, floors, tent insulation and the precise places where the tents were erected were all deemed crucial components in the study. SRTs were tested during winter, specifically on 11–18 December 2024, when daytime and nighttime temperatures were extremely low. The CBE tool, which is intended to compute and show thermal comfort in compliance with ASHRAE standards, was used to simulate the thermal comfort conditions. On the basis of the results of this study, the following conclusions can be drawn:

1. Relying on solar radiation alone in building the heating system is insufficient because it does not provide the required thermal comfort, especially in cloudy weather, and the problem of providing suitable housing is not solved.
2. The parameters that PMV and PPD rely on, such as temperature, humidity, air velocity, clothing insulation and metabolic rate, can greatly impro ve the interior conditions, according to the PM V and PPD readings that were used to determin e the tent's internal thermal comfort level in acc ordance with the CBE tool.
3. The proposed theoretical model was mainly based on the values obtained experimentally during certain days in December.

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Data Availability

The data supporting the findings of this study were obtained by the corresponding author. The authors thank the United Nations High Commissioner for Refugees in Iraq for providing tents for the purpose of conducting the study, the University of Baghdad for providing laboratory support, colleagues who assisted in the experimental work, and Professor Dr. Issam Mohammed Ali for his continuous follow-up and supervision of the completion of the work.

Nomenclature

SRTs	standard relief tents
HVAC	heating, ventilation, and air conditioning
PMV	predicted population mean vote
PPD	predicted dissatisfaction rate (in %)
SET	standard effective temperature
CBE	Center for the Built Environment
UNHCR	United Nations High Commissioner for Refugees
e	mathematical constant (Euler's number)

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اختبار الراحة الحرارية والظروف الداخلية لخيام الإغاثة القياسية (SRTs) في المناخات الباردة

روان عدنان فياض[١]*، عصام محمد علي الجبوري[٢]

[١،٢] قسم الهندسة الميكانيكية، كلية الهندسة، جامعة بغداد، بغداد، العراق

*البريد الالكتروني: rawan.adnan2303@coeng.uobaghdad.edu.iq

المستخلص

لمساعدة صانعي القرار في اختيار أفضل الحلول والتوصل إلى حلول أفضل للمأوى المؤقت، تهدف الدراسة إلى تحديد القضايا الرئيسية المتعلقة بأساليب المأوى المؤقت وتقديم بعض المبادئ والتوصيات. قدمت هذه الدراسة بحثًا نظريًا في قياس الراحة الحرارية في خيام الإغاثة القياسية (SRTs) في المناخات الباردة. تم تحليل النتائج ومقارنتها باستخدام أدوات CBE MRT و CBE Thermal Comfort بناءً على القيم المقاسة ميدانيًا داخل الخيمة في ١٢ و١٣ و١٤ و١٥ ديسمبر ٢٠٢٤. نظرًا لتأثيرها المباشر على سلامة ورفاهية شاغليها، تُعد الراحة الحرارية عاملاً رئيسيًا في تصميم واستخدام الخيام في المناطق الباردة. تشمل العوامل المؤثرة على الراحة الحرارية للخيام في الطقس البارد العزل والتهوية والملابس والتدفئة. هذه الدراسة تطبيقية في الطبيعة وأُجريت باستخدام نهج تحليلي وصفي. تم جمع البيانات باستخدام أساليب المكتبة والتوثيق. توفر هذه الدراسة مؤشرات مهمة في مجال الراحة الحرارية، وخاصة في تصميم أنظمة التدفئة والتهوية وتكييف الهواء (HVAC). تؤثر هذه العوامل البيئية والفردية على العلاقة بين متوسط تصويت السكان المتوقع (PMV) ومعدل عدم الرضا المتوقع (PPD). بناءً على هذه العوامل، تساعد الدراسة على قياس الراحة الحرارية الداخلية للإنسان وتحديد العوامل المؤثرة في كل حالة للوصول إلى الاستنتاجات المرجوة، مع التأكيد على أن الخيام لم توفر ظروفًا حرارية مناسبة لساكنيها إلا بعد معالجتها باستخدام نموذج تجريبي.