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Thermal Comfort Assessment of Temporary Shelters Used in Türkiye by CFD Analysis

Ayca Gulten [1,*] and Seval Yolacti [2]

[1]Department of Architecture, Faculty of Architecture, Fırat University, 23119 Elazig, Türkiye

[2]Department of Architecture, Graduate School of Natural and Applied Sciences, Fırat University, 23119 Elazig, Türkiye

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ABSTRACT

This research assessed the thermal comfort conditions of temporary shelters in Türkiye using the Predicted Mean Vote (PMV) index. A typical container-type shelter was selected as the model for the analysis. Simulations were conducted on July 21 at four different times: 10:00, 12:00, 14:00, and 16:00. The Computational Fluid Dynamics (CFD) software Ansys Fluent was utilized to perform the simulations. Eight shelters positioned in various parts of a standard shelter layout were analyzed. Two ventilation scenarios were considered: one with only the doors open, and another with both doors and windows open. While PMV quantifies the average thermal sensation on a scale from -3 (cold) to +3 (hot), in Scenario 1, the general scale of PMV is hot or exceeds the hot scale; besides, the number of situations classified as warm and slightly warm in Scenario 2 increases. In Scenario 1, PMV values were generally high and surpassed the thermal comfort threshold (+3-hot), especially during the morning and midday hours, while natural ventilation improved significantly, leading to lower PMV values, which are about +2(warm), and enhanced thermal comfort in Scenario 2. As a result, it is recommended to consider site-specific orientation, prioritizing layouts that maximize exposure to prevailing wind directions, particularly for living and sleeping areas, while also minimizing the exposure of heavily occupied zones to intense solar radiation.

*Corresponding Author
Email: aycagulten@gmail.com

1. Introduction

The existence of man-made or natural disasters around the world is permanent. Depending on their magnitude and the extent of their impact, disasters create numerous problems that must be addressed in the post-disaster period. The areas where a disaster exhibits its most devastating effects are shelters. A disaster can cause many people to lose their homes in a very short time, sometimes within just a few minutes. The severe earthquakes that struck Türkiye between 2020 and 2023 are recent examples of this phenomenon. Shortly after the 6,8 magnitude earthquake in Elazığ in January 2020, a 6,9 magnitude earthquake hit İzmir on October 30, 2020. On February 6, 2023, a vast area, including Kahramanmaraş, Hatay, Adıyaman, Şanlıurfa, Gaziantep, Adana, Malatya, Osmaniye, Kilis, and Elazığ provinces, was impacted by the 7,6 and 7,7 magnitude earthquakes centered in Kahramanmaraş. This disaster, known as the disaster of the century, resulted in thousands of casualties, the collapse of city infrastructures, and damage to historical and cultural heritage. The most crucial and primary need of those who survived the disaster was, as mentioned, "shelter. "

Three different plans are put into action for post-disaster sheltering: emergency, temporary, and permanent shelter units. First, tents, which serve as emergency shelter units, come into play. It is crucial to keep the life expectancy of tents as short as possible, especially during extremely hot and cold periods. Subsequently, disaster victims must continue their lives in Temporary Shelter Units (TDUs) until permanent housing is constructed. While this period is expected to vary between 6 months and 3 years, in practice, life in temporary housing can extend up to 5 years [1]. During this prolonged period, it is essential that the shelter units are improved to provide some degree of comfort, although not comparable to a permanent home.

In Türkiye, containers are typically used as temporary shelters, and container cities are established in areas identified by prior studies (infrastructure, ground surveys, access to water, power lines, etc.) during disaster situations. For those who must live in container cities, the fundamental requirements for sustainable shelter include not only avoiding small living spaces but also having the capacity to manage climatic challenges such as summer heat and winter cold, along with improving indoor air quality. However, despite guidelines encouraging climate awareness globally and in our country, ensuring the necessary comfort conditions for individuals in emergencies and temporary shelters after disasters or conflicts remains challenging.

The number of studies on improving thermal comfort in temporary shelters is limited.

In the literature, there are studies in which numerical analyses were made on obtaining thermal comfort with passive measures by examining a single shelter in temporary shelter units used in emergency situations. Tan and Tan [1], conducted experimental and numerical studies for temporary shelters in Taiwan's tropical climate, specifically addressing summer conditions. They found that adding a mechanical fan with an average speed of 2,75 m/s while keeping the door and window closed yielded the best user results. Yu *et al*. [2] performed field studies in areas where temporary shelters were deployed following the 8,8 magnitude Wenchuan earthquake in 2008 and the 7,7 magnitude Lushan earthquake in 2013 in China, later constructing small-scale examples of the implemented shelter models. Various additional measures were taken to enhance indoor comfort conditions in the sample shelters for cold weather, and the temperature and humidity inside the shelters were recorded. Consequently, integrating polypropylene sheets into the from a specially constructed experimental prefabricated structure. An analysis of summer heat gain based on the validated model revealed that the windows of the prefabricated structure outer walls of the shelter was identified as the most cost-effective method for blocking wind. Although this solution benefits winter conditions, it is anticipated to have negative consequences during summer because it obstructs wind and ventilation effects. Wang *et al*. [3] conducted a study on the thermal comfort of prefabricated structures utilized as temporary shelter units for disaster victims in emergencies. To explore methods for improving the thermal environment of these prefabricated structures, a simulation model was developed using EnergyPlus, and the simulated data were validated by comparison with measurements obtained contributed the most significant share to the total heat gain, followed by the roof and the east wall. The study also examined the effectiveness of various passive measures applied to the prefabricated structure. The results indicated that incorporating a thin, movable fabric layer with a reflectance ratio of 0,9 on the walls and installing roof and external window shutters would significantly enhance thermal comfort during the summer.

There are studies in the literature comparing the thermal comfort conditions provided by different temporary shelter units with numerical analyses. Tuladhar *et al*. [4] analyzed the thermal comfort limits provided by 14 commonly used temporary shelters in various countries across 13 climatic zones, establishing 35 °C as the upper limit and 12°C as the lower limit. The analyses were conducted through simulations. Many simulations revealed that the shelters maintained indoor conditions outside the established thermal safety limit values, failing to ensure thermal comfort. Thapa *et al*. [5] evaluated indoor thermal comfort for five different temporary shelter types after the 2015 earthquake in Lalitpur, Nepal. The average indoor and outdoor temperatures recorded during the night were 10,3°C and 7,6°C, respectively, with the indoor air temperature remaining below the minimum acceptable temperature of 11°C. The study presented suggestions based on numerical analyses using various materials to minimize heat losses. Moran *et al*. [6] conducted a study in which users applied their methods to enhance thermal comfort in 12 temporary shelters located in a desert climate. Meanwhile, thermal modeling was performed for the same shelters, and the results were compared. Ultimately, while modeling is a quicker and less labor-intensive method, it was highlighted that users' efforts to improve thermal comfort through personal labor are more advantageous for process adaptation. Susanti [7] conducted a study examining the thermal conditions of temporary shelters used by displaced people in Indonesia, a country frequently affected by natural disasters and characterized by hot and humid climate conditions. The study aimed to evaluate to which single-layer and double-layer temporary shelters used after disasters could provide thermal comfort, using the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) thermal comfort indices. The data used in the thermal comfort models were compared with experimental measurements and information obtained from interviews with users. The results showed that the double-layer temporary shelter provided better PMV and PPD index values compared to the single-layer shelter. However, the results obtained from both types of shelters still did not fall within Fanger's acceptable thermal comfort range. Costa *et al*. [8] proposed the idea of repurposing containers that are decommissioned each year into shelters as a solution to the housing problem faced by people displaced due to various causes such as natural disasters and wars around the world. Although steel containers offer advantages such as rapid installation and easy transportation, they are weak in terms of energy performance and pose climate control challenges. The study aimed to address this issue by integrating two thermal insulation materials into a container structure used for temporary shelter purposes and analyzing its performance. Building Information Modeling (BIM) software was utilized for modeling, and simulations were conducted using the Building Energy Simulation (BES) software. The results showed that among the tested insulation materials, mineral wool exhibited better energy performance, and thermal insulation can significantly contribute to energy savings. Dabaieh and Serageldin [9] conducted a study that explores the integration of passive heating and cooling strategies into temporary shelter units (TSUs) located in temperate and hot climate regions to enhance energy efficiency. The research involved the implementation of three passive systems—an Earth-to-Air Heat Exchanger, a Trombe wall, and a green wall—into a TSU deployed in Sweden. These systems were designed to reduce the shelter's energy demand and promote a passive design approach. The findings indicate that the application of passive solutions such as Trombe walls and green façades can significantly decrease energy consumption and CO_2 emissions while improving indoor environmental comfort in TSUs situated in temperate and hot climates. Zemitis *et al*. [10] conducted a study aimed at analyzing the thermal comfort conditions within tent structures, which saw increased use following the outbreak of pandemics such as COVID-19. A series of measurements were carried out inside one such tent structure between May 27 and September 28, 2020, using various monitoring devices. The measurement results revealed that indoor temperatures could reach up to 40 °C during the day and rapidly drop to as low as 10 °C. These extreme and rapid temperature fluctuations were attributed to stagnant air conditions and insufficient ventilation within the tent. Furthermore, the recorded PMV (Predicted Mean Vote) values indicated that approximately 57% of the time spent inside the tent fell well outside the acceptable thermal comfort range. Akeila *et al*. [11] conducted a numerical study aimed at improving shelter conditions in response to the housing crisis caused by the refugee situation in the Middle East. The authors criticized the solutions proposed by international organizations as insufficient in terms of environmental performance and energy consumption. To address this issue, an alternative shelter design—matching the dimensional characteristics of steel shelters currently used in camps for Syrian refugees in Jordan—was developed using Building Information Modeling (BIM) technologies. The proposed design's thermal insulation, acoustic performance, ventilation, and energy consumption were evaluated and simulated using Green Building Studio and Insight software. The simulation results indicated that the newly developed model outperforms standard steel shelters in terms of thermal insulation and environmental performance, while also reducing overall energy demand. Qin *et al*. [12] emphasized that the temporary housing provided for displaced refugees often fails to meet adequate indoor thermal comfort conditions, exacerbating the psychological distress experienced by individuals who have already endured significant trauma. In order to develop a deeper understanding of this critical issue and to inform appropriate interventions, the authors conducted an extensive review of 75 academic articles and 15 reports. The findings revealed that the thermal comfort compliance rate in currently used temporary shelters stands at only 26.47%, highlighting the challenges refugees face in thermally adapting to these environments and the resulting difficulties in achieving psychological adjustment. Liang *et al*. [13] conducted a study aimed at identifying and addressing thermal deficiencies in prefabricated buildings—widely used across various sectors—that lead to inadequate thermal comfort and increased energy demand. The research focused on a standard prefabricated house, analyzing thermal weaknesses in the building envelope using infrared thermography. The analysis revealed that major heat losses were primarily due to thermal bridges at structural joints and air leakage around windows. The energy consumption associated with these losses was calculated, along with the potential energy savings that could be achieved by mitigating them. The results showed that insulating thermal bridges could reduce energy consumption by approximately 40%, while eliminating air leakage through windows could yield a similar 40% reduction. Overall, addressing all identified thermal deficiencies was found to reduce the total energy consumption of prefabricated houses by approximately 25.9%.

As a result of wars, migrations, and natural disasters (fires, floods, and earthquakes) caused by global warming, the need for temporary shelters in the world has increased dramatically in recent years. Studies show that there are many interrelated variables that ensure thermal comfort in temporary shelters. These variables include building shell, orientation logic of temporary shelters within the layout plan, natural ventilation, window sizes, shading elements, etc. [14]. The biggest obstacle for local governments operating in this field to ensure thermal comfort in temporary shelters is the lack of clear definition of the essential factors affecting them and the interactions of these factors with each other. For example, while it is important to provide passive natural ventilation within the settlement area in hot, humid climate regions, the thermophysical properties of the shell elements of the buildings gain importance in cold climate regions. Turkiye uses a standard layout scheme and temporary shelter model in most container cities without considering the climate region. For example, rectangular shelters usually have long facades placed back to back. In this way, even if half of the shelters in the settlement area are likely to be oriented correctly according to the climate zone, the other half is likely to be oriented oppositely and, therefore, incorrectly. These solutions do not provide adequate thermal comfort for long-term sheltering, and they give rise to numerous serious problems, including health issues for users and extreme thermal discomfort in both summer and winter [4].

Thermal comfort studies in temporary shelters lack a reference standard. This situation requires further research to determine thermal comfort conditions for temporary buildings suitable for different climate zones, thereby better understanding potential problems related to indoor thermal comfort in these structures.

This study will base its analyses on the mild-dry climate zone conditions of Elazığ, considering the layout scheme in which temporary shelters are located. The analysis results will evaluate the suitability of the thermal comfort values provided in the neighborhood where the temporary shelter is located. For this purpose, analyses will be conducted according to the currently implemented layout scheme (detailed in the method section).

This study evaluated the thermal comfort of temporary shelters in Türkiye using the Predicted Mean Vote (PMV) parameter. A standard type of container model has been preferred for analysis. On July 21st, simulations were conducted at 10:00, 12:00, 14:00, and 16:00 hours. Ansys Fluent, a CFD-based program, was used for the simulations. Simulations were made for eight shelters located in different zones of a standard temporary shelter configuration. Two different assumptions are used as doors are open, and both doors and windows are open.

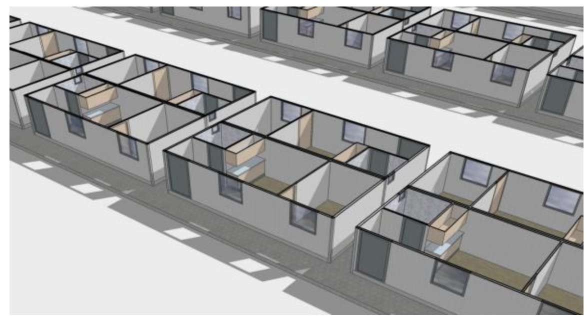
2. Materials and Methods

2.1. Properties of Temporary Shelters Used in Türkiye

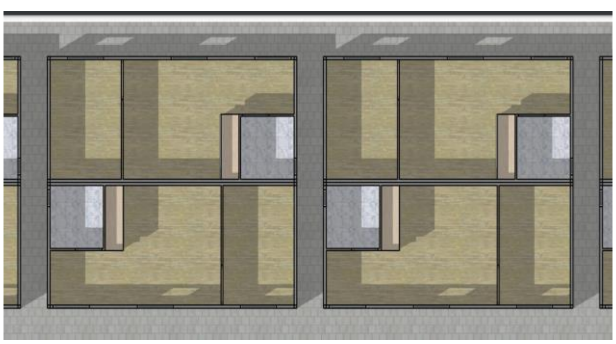
In Türkiye, for the settlement scheme of the temporary shelters used in the second stage after disasters, the Directive on the Establishment, Management and Operation of Temporary Shelters [15] put forward by AFAD

(Disaster and Emergency Management Authority) has determined some frameworks regarding the physical conditions of both the shelters and the settlement areas formed by their coming together. Accordingly, the width of the main roads in the temporary shelters should be at least 15 m, the width of the side roads should be at least 10 m, the temporary shelters should be made of materials suitable for climate conditions and fire standards, and the amount of indoor space per person should be between 3,5-4,5 m^2. An example of the settlement schemes currently applied in Türkiye is presented in Fig. (**1**). Accordingly, the long facades of the shelter units are placed back to back (Fig. **1a**). Although the road widths parallel to the long facade seem sufficient (Fig. **1b**), it is observed that the distances between the short facades are very narrow (Fig. **1c** and **1d**). According to this layout plan, it is anticipated that at least half of the accommodation units will not provide an adequate environment in terms of thermal comfort.

(a)



(b)



(c)

(d)

Figure 1: General properties of temporary shelters preferred by AFAD.

According to the guide published by the Chamber of Urban Planners of the Turkish Engineers and Architects [16], following the recent earthquakes, it was stated that temporary shelters should provide an area of 3,5 m² per person and at least 10,5 m² for a family of three. The guide suggested that each unit should be placed independently, with a distance of at least 2 m from other units. It emphasized that 16 units should come together to form a cluster, and a sanitation center with showers, toilets, laundry, and clean water units should be located at the center of the clusters. In the neighborhoods formed by the clusters, the distance between the clusters should be at least 6 m, and in the neighborhood unit formed by 16 clusters, the back roads should be at least 10 m wide (Fig. **2**).

This study used a settlement configuration by considering the currently applied and proposed schemes (Fig. **3**). On average, the temporary shelter unit was determined to be 21 (3x7) m² for four people (Fig. **4**). In the settlement plan, it was assumed that the long facades of the accommodation units were placed back-to-back. It was also assumed that a sanitation center existed between the clusters. Simulations were conducted for eight shelters (C1-C8) located in different zones of a standard temporary shelter configuration.

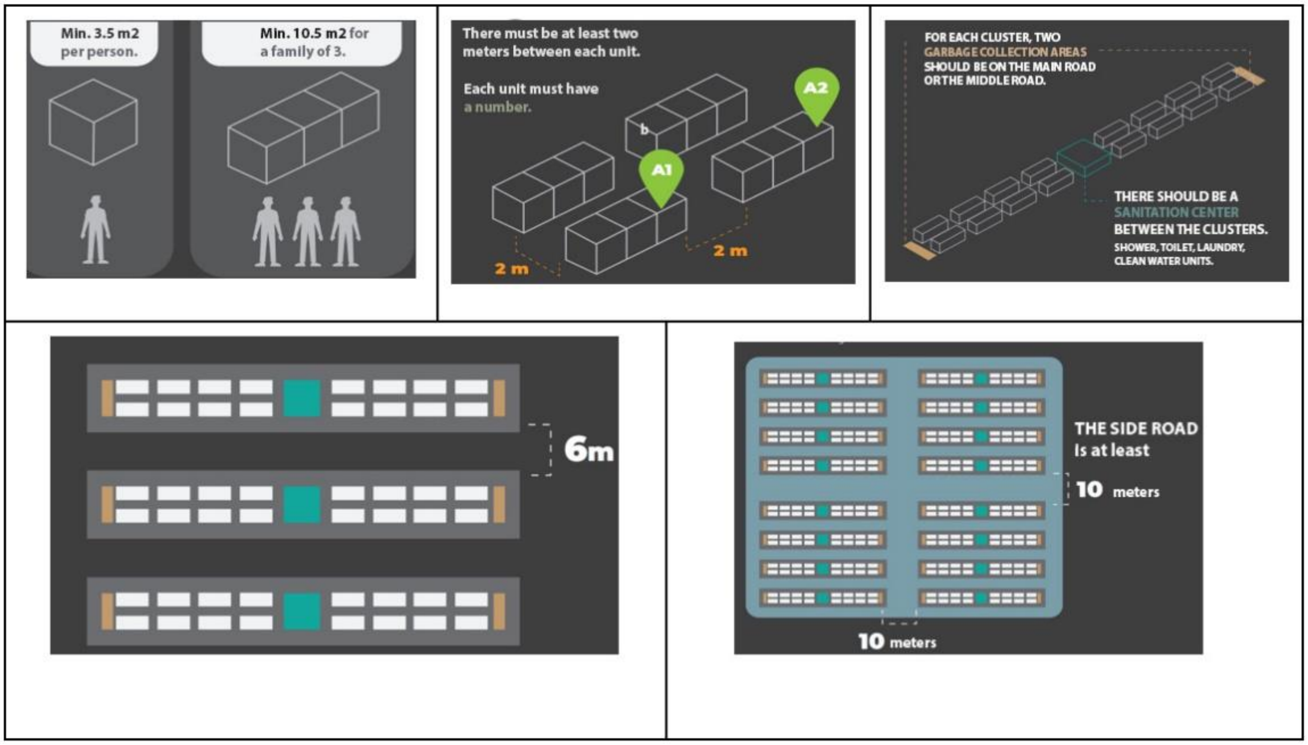


Figure 2: Advised schemes for temporary shelter configurations by the Chamber of Urban Planners of the Turkish Engineers and Architects.

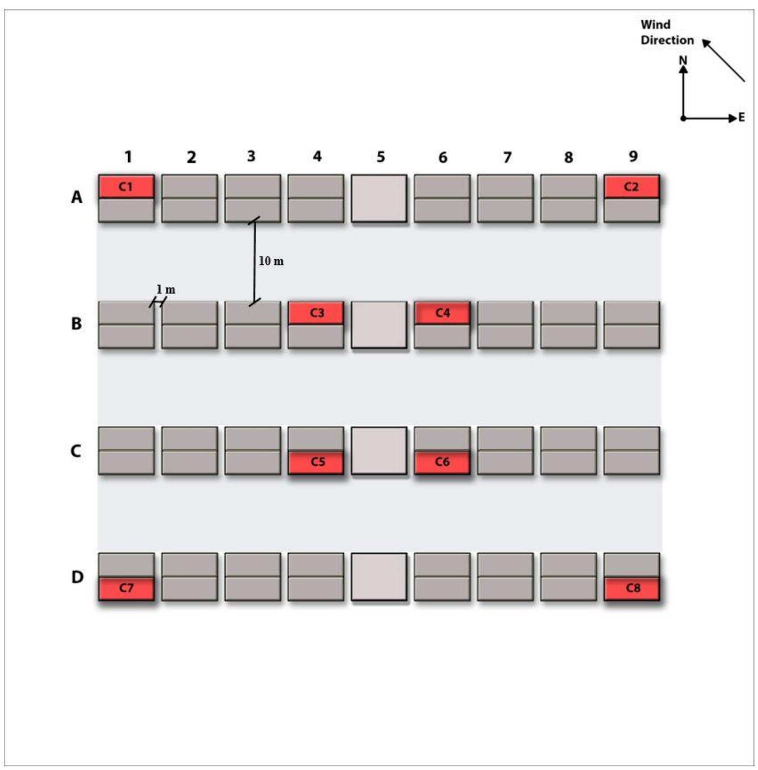


Figure 3: General layout of the study area with eight containers.

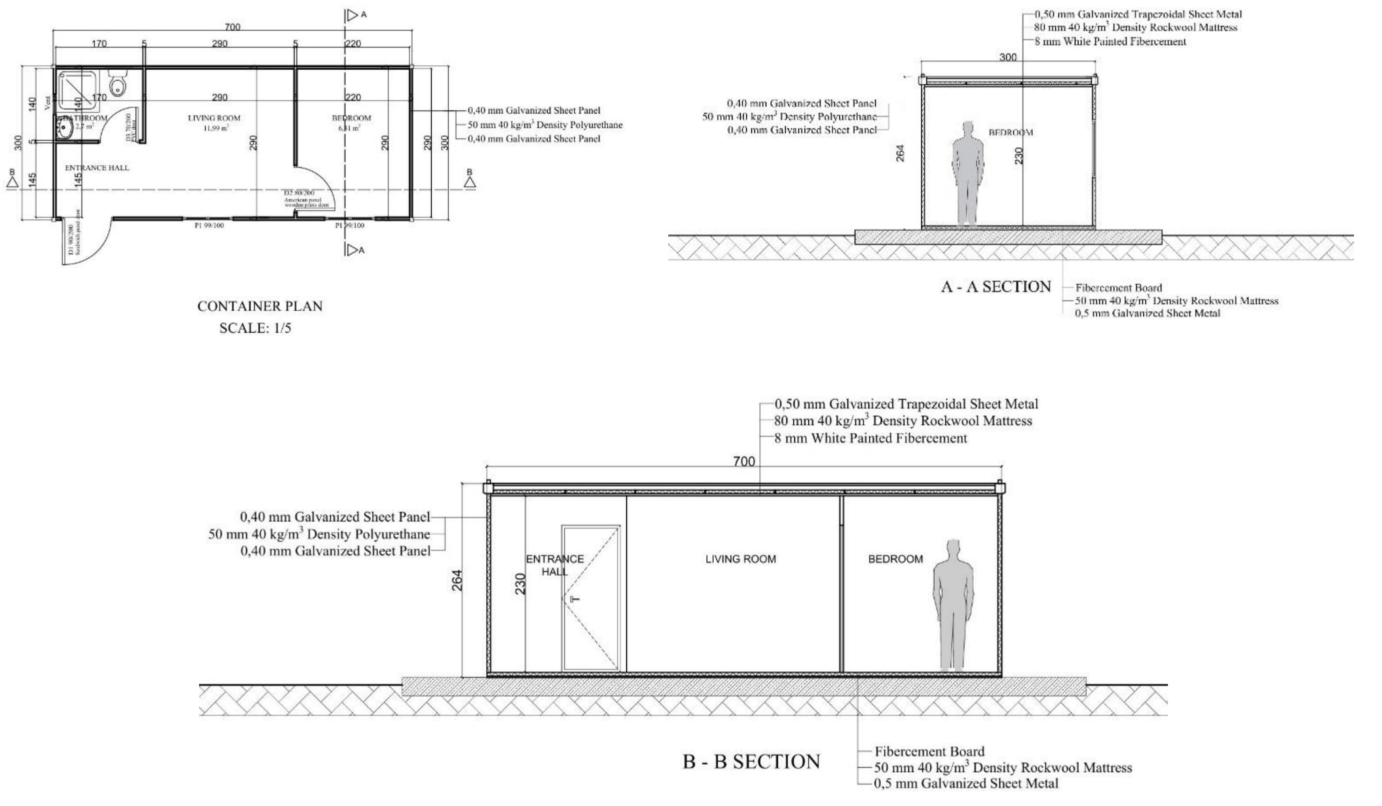


Figure 4: General dimensions of containers modeled in the study [15].

2.2. Thermal Comfort and Predicted Mean Vote

Thermal comfort encompasses the user's satisfaction with the values, such as temperature, humidity, air speed, and solar radiation, of the space they experience [17]. The integrated cooperation of these elements that determine the air quality in the living space determines the comfort level experienced by the user. The human body is constantly interacting with its thermal environment. Excess heat generated from metabolic activities is dissipated to the external environment or transferred from the external environment when body temperature is insufficient [18]. This mutual interaction continues until thermal balance is achieved [19]. These balancing systems in human physiology create the person's thermal sensation sensitivity and protect physical and psychological health. The control of this balancing system forms the person's satisfaction level with the space they experience. Many factors influence a person's thermal comfort experience.

This study used PMV to measure thermal comfort in temporary shelters. The Predicted Mean Vote (PMV) index is derived from Fanger's heat balance model, which quantifies thermal comfort based on the heat exchange mechanisms of the human body under steady-state conditions [20]. The model treats the human body as a unified thermodynamic system and is primarily applicable to stable, air-conditioned environments; it lacks the capability to account for transient thermal responses. The PMV calculation integrates six key variables: four environmental parameters—air temperature, air velocity, relative humidity, and mean radiant temperature—and two personal factors—metabolic rate and clothing insulation level. The Predicted Percentage of Dissatisfied (PPD) is mathematically derived from the Predicted Mean Vote (PMV) and describes the expected percentage of thermally dissatisfied people in a given environment. While PMV quantifies the average thermal sensation on a scale from -3 (cold) to +3 (hot), PPD estimates how many people are likely to feel uncomfortable at a particular PMV value. The PPD (Predicted Percentage of Dissatisfied) value should not exceed 10% to ensure thermal comfort for the user [17]. Table **1** presents the PMV index and the thermal sensation categories. According to ISO7730 standards, an acceptable thermal environment is achieved when the Predicted Mean Rating (PMV) falls in the range of -0.5 to +0.5. Also, to ensure thermal comfort for most occupants, the Predicted Percentage Dissatisfaction (PPD) should not exceed 10% [21]. PMV is calculated by Equations given below and detailed information on the PMV calculation method can be found in the study presented by Enescu [20].

$$PMV = (0.303e^{-0.036M} + 0.028)\{(M - W) \quad (1)$$

$$-3.05 \times 10^{-3} \times [5733 - 6.99\,(M - W) - P_a\,] \quad (2)$$

$$-0.42 \times [\,(M - W) - 58.15\,] - 1.7 \times 10^{-5} M(5867 - P_a) \quad (3)$$

$$-0.0014\mathrm{M}(34 - \mathrm{T}_a\,) \quad (4)$$

$$-3.96 \times 10^{-8} f_{cl} \;\times [\,(T_{cl} + 273)^4 - \;(T_{cl} - 273)^4] - f_{cl} h_{cl}(T_{cl} - T_a\,)\} \quad (5)$$

Here; M (W/m^2) represents the metabolic heat production rate of humans, while Pa (kPa) represents the partial vapor pressure. Ta (°C), Fcl, and Tcl represent the air temperature, (dimensionless) represents the clothing area factor, and represents the clothing surface temperature, respectively. Tr (°C) represents the radiant temperature, and hcl (W/m^2) represents the clothing surface heat transfer coefficient [22].

The following formula is used to calculate the PPD index:

$$PPD = 100 - 95e^{-0.03353PMV^4} - 0.2179PMV^2. \quad (6)$$

Table 1: Predicted Mean Vote (PMV) index and thermal sensation categories.

PMV Value	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**
Thermal Sensation	Hot	Warm	Slightly Warm	Neutral	Slightly Cool	Cool	Cold

2.3. Simulation Set-up and Boundary Conditions

Container width and length dimensions are presented in Fig. (**4**). The height of the computational domain is set to 5H, while the container height is equal to H. In contrast, the inlet boundary is set to 5H, and the outlet boundary is set to 10H away from containers (Fig. **5a**). The general domain size is based on guidelines established by Franke *et al*. [23]. The analyses were conducted for July 21, which is considered the hottest day for Elazığ according to the average values of the last 10 years, based on data from the Turkish Meteorological Service (Turkish State Met. Office). Table **2** presents the data for inlet values, including convective heat transfer coefficient (h_c (W/m^{2}K)) for vertical and horizontal surfaces, wind direction, and wind velocity. The domain's inlet and outlet boundary conditions were changed for the N and NW directions.

Table 2: Inlet boundary conditions for four hours on 21st July [24].

Time	**Hour**	**Ambient Air Temperature (°C)**	**Wind Speed (m/sn)**	**Wind Direction**	**h_c Horizontal (W/m^{2}K)**	**h_c East (W/m^{2}K)**	**h_c West (W/m^{2}K)**	**h_c North (W/m^{2}K)**	**h_c South (W/m^{2}K)**
21st July	**10.00**	35,3	3,1	NW	27,03	20,09	11,41	20,09	11,41
	12.00	36,7	3,4	NW	28,18	21,21	11,92	21,21	11,92
	14.00	36,4	3,95	NW	30,16	23,08	12,80	23,08	12,80
	16.00	33,7	3,35	W	28,00	11,84	11,84	21,03	11,84

In this study, numerical simulations were conducted using the commercial CFD software Ansys Fluent 2024 [25]. Validation study was performed due to simulations performed by Gulten and Oztop [26]. The accuracy of the simulation results was highly dependent on the appropriate mesh resolution within the computational domain. Both geometry modeling and mesh generation were carried out in ANSYS Workbench, ensuring compatibility with the Fluent solver Hu and Yoshie [27]. The mesh structure was generated using Ansys Fluent Meshing. To ensure the accuracy of the solution without unnecessarily increasing computation time, mesh structures with varying densities were tested to achieve an adequate quality level. Accordingly, finer mesh elements with a size of 0,07 m were applied around and within the container units. In comparison, coarser elements with a size of 0,4 m were used farther away from the containers. The resulting mesh structure has a minimum orthogonal quality of 0,17 and a maximum cell skewness of 0,77 (Fig. **5b**). In previous studies, researchers compared the RNG k-ε turbulence model with the Standard k-ε turbulence model. The comparison revealed that numerical simulations performed using the RNG k-ε model produced results that were more consistent with experimental data, whereas the Standard k-ε turbulence model was found to be less accurate in this regard [28]. In this study the ventilation efficiency of container arrays was analyzed by steady-state three-dimensional simulations with RNG k-ε turbulence model. All governing equations were discretized using the second-order upwind scheme. The minimum convergence criteria obtained from the repeated simulations were as follows: 10^{-3} for continuity, 10^{-4} for the u–v–w velocity components, 10^{-3} for k and ε, and 10^{-6} for energy and radiation.

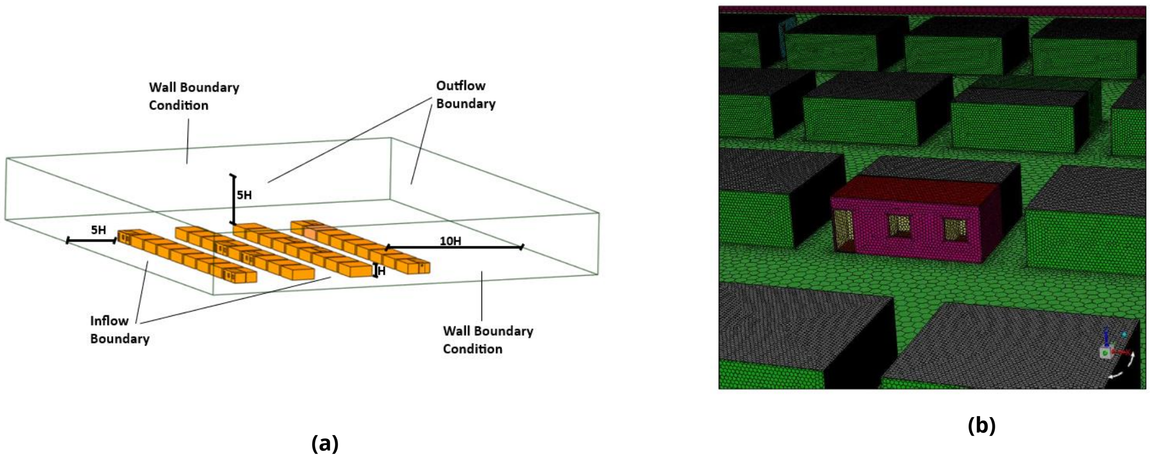


Figure 5: (**a**) Domain of the study area (**b**) Surface mesh image of the working volume.

3. Results and Discussion

This study conducted simulations for a defined layout of temporary shelter configurations and evaluated the PMV and PPD indices for eight temporary shelters located at different nodes. The simulations were run on July 21st at 10:00, 12:00, 14:00, and 16:00, considering two scenarios: when only the window is open (Scenario 1) and when both the door and window are open (Scenario 2). PMV measurements were conducted at the center of each space in the container, including the bedroom, living room, and bath. The simulation outcome of 10:00 is presented in Fig. (**6**). On the vertical axis, measurements were taken at the sitting level of occupants at 1,10 m. In the configuration layout, C1-C4 containers are oriented to the North, while the C5-C8 containers are oriented to the South (Fig. **6**). For 10:00, 12:00, and 14:00 hours, the wind direction is NW, and the wind velocities are close to each other. The first and second rows experience better natural ventilation with a diagonal wind direction influencing the configuration.

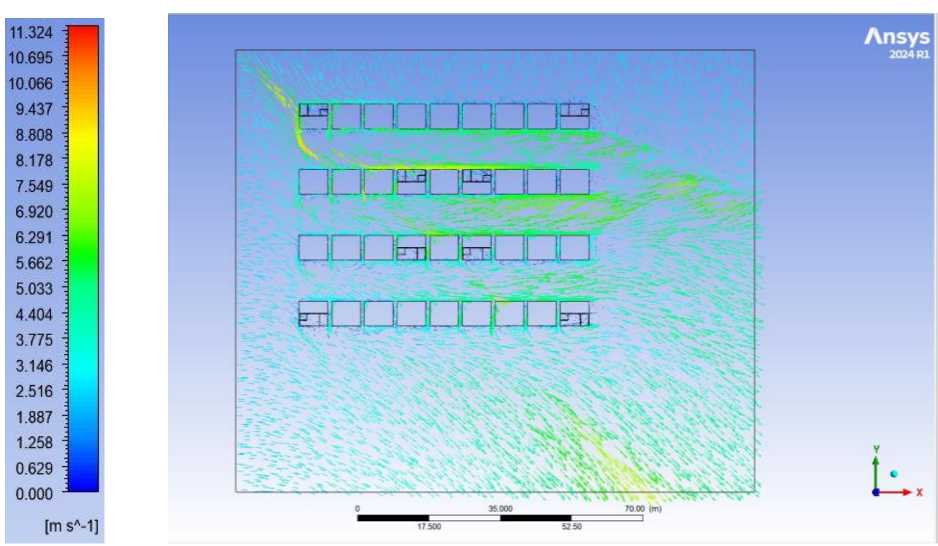


Figure 6: Velocity vectors at 10:00 on 21st July.

Table **3** presents the PMV and PPD values of eight containers for Scenario 1. For summer conditions, at 10:00, an early hour of the day, PMV values are generally high and exceed the acceptable levels to provide thermal comfort. The diagonal wind direction and ventilation performance effect provide lower PMV values for the living rooms of C3 and C4 containers since they face the incoming wind directly. C5, C6, C7, and C8 containers with leeward surfaces generally have higher PMV values and a significant thermal discomfort than North-oriented C1, C2, C3, and C4 containers (Fig. **7**). North-oriented C3 and C4 containers present better natural ventilation and lower PMV values for living rooms, while C5 and C6 containers present higher PMV values for living rooms because of the weak ventilation effect provided in the space for Scenario 1 (Fig. **8**).

Table 3: PMV and PPD values for eight containers in Scenario 1.

Scenario 1		10:00 (3,1 m/s-NW)		12:00 (3,4 m/s- NW)		14:00 (3,95m/s- NW)		16:00 (3,35m/s- W)	
		PMV	PPD	PMV	PPD	PMV	PPD	PMV	PPD
C1	Bedroom	4,68	%100	3,94	%100	4,05	%100	4,54	%100
	Living Room	3,84	%100	3,36	%100	3,36	%100	4,67	%100
	Bath	2,29	%88	3,11	%100	3,60	%100	4,31	%100
C2	Bedroom	3,79	%100	5,08	%100	4,84	%100	3,96	%100
	Living Room	3,91	%100	4,45	%100	4,44	%100	3,87	%100
	Bath	3,38	%100	3,57	%100	4,11	%100	4,02	%100
C3	Bedroom	4,09	%100	4,15	%100	3,90	%100	3,71	%100
	Living Room	2,75	%97	3,44	%100	3,57	%100	4,00	%100
	Bath	3,32	%100	4,53	%100	3,37	%100	3,87	%100
C4	Bedroom	3,97	%100	3,37	%100	3,36	%100	3,66	%100
	Living Room	3,12	%100	3,33	%100	3,70	%100	4,02	%100
	Bath	3,05	%99	4,00	%100	3,69	%100	3,96	%100
C5	Bedroom	4,05	%100	5,36	%100	3,95	%100	3,83	%100
	Living Room	5,06	%100	5,40	%100	4,68	%100	3,87	%100
	Bath	4,79	%100	4,75	%100	5,16	%100	3,82	%100
C6	Bedroom	2,21	%85	3,75	%100	3,60	%100	4,22	%100
	Living Room	3,68	%100	4,20	%100	4,22	%100	3,83	%100
	Bath	4,94	%100	5,22	%100	5,32	%100	3,79	%100
C7	Bedroom	4,95	%100	5,18	%100	5,29	%100	3,71	%100
	Living Room	4,62	%100	4,16	%100	4,56	%100	3,69	%100
	Bath	1,97	%76	3,30	%100	3,32	%100	3,18	%100
C8	Bedroom	3,01	%99	4,53	%100	3,64	%100	4,27	%100
	Living Room	3,79	%100	4,63	%100	4,47	%100	4,09	%100
	Bath	4,85	%100	4,96	%100	4,91	%100	3,87	%100

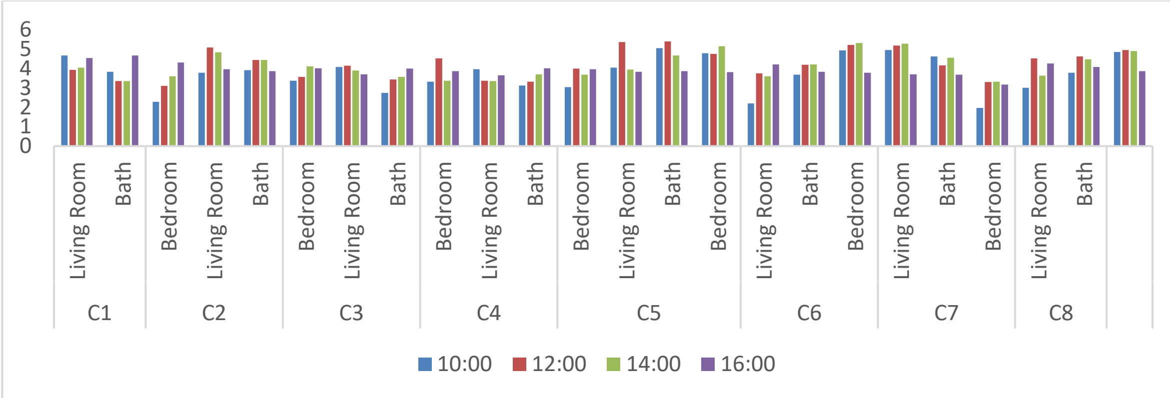


Figure 7: PMV values of containers in Scenario 1 for different hours.

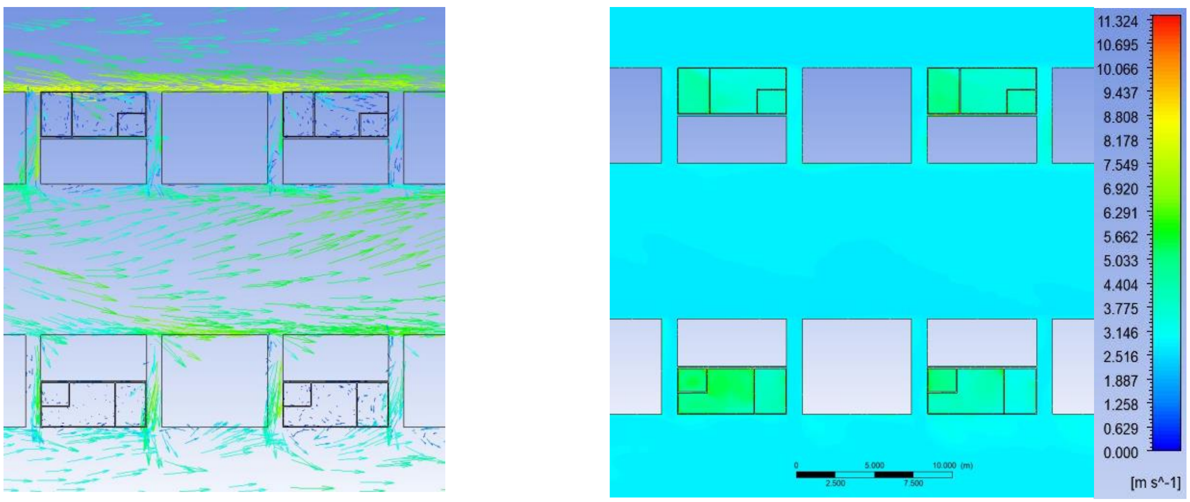


Figure 8: Velocity vectors and temperature contours of C3, C4, C5 and C6 containers at 10:00.

Table **4** presents PMV values measured for Scenario 2. In this scenario, opening the window and door together enhances the effect of natural ventilation and improves thermal comfort. North-oriented containers C1, C2, C3, and C4 provide superior PMV values, particularly at 10:00 for living rooms. The PMV values from south-oriented containers C5, C6, C7, and C8 also show better results than in Scenario 1. However, at 12:00, with the increasing effect of natural ventilation from both openings and the rising amount of radiation, PMV values and thermal discomfort increase. The improvement in PMV values at 10:00 is more significant due to the lower radiation effect. For both scenarios, thermal discomfort generally increases due to PPD values, as presented in Tables **3** and **4**. In Scenario 1, the general scale of PMV is hot or exceeds the hot scale, while the number of situations classified as warm and slightly warm in Scenario 2 increases (Fig. **9**). However, in general, for hot summer conditions, containers' PMV values exceed the extreme hot level of thermal comfort for human beings.

Table 4: PMV and PPD values for eight containers in Scenario 2.

Hours		10:00 (3,1 m/s-NW)		12:00 (3,4 m/s- NW)		14:00 (3,95m/s- NW)		16:00 (3,35m/s- W)	
		PMV	PPD	PMV	PPD	PMV	PPD	PMV	PPD
C1	Bedroom	2,91	%97	4,17	%100	4,12	%100	4,26	%100
	Living Room	1,40	%46	3,26	%100	3,08	%99	4,10	%100
	Bath	1,96	%75	3,11	%100	2,70	%97	4,33	%100

Table 4 (contd)

Hours		10:00 (3,1 m/s-NW)		12:00 (3,4 m/s- NW)		14:00 (3,95m/s- NW)		16:00 (3,35m/s- W)	
		PMV	PPD	PMV	PPD	PMV	PPD	PMV	PPD
C2	Bedroom	2,43	%100	4,03	%100	3,53	%100	3,30	%100
	Living Room	2,83	%97	3,86	%100	3,84	%100	3,40	%100
	Bath	2,31	%89	3,25	%100	3,99	%100	3,56	%100
C3	Bedroom	3,00	%100	5,01	%100	4,44	%100	3,83	%100
	Living Room	2,30	%88	3,99	%100	4,03	%100	3,56	%100
	Bath	2,15	%83	3,64	%100	3,55	%100	3,42	%100
C4	Bedroom	3,67	%100	5,52	%100	4,58	%100	3,72	%100
	Living Room	3,29	%100	4,11	%100	3,91	%100	3,68	%100
	Bath	3,69	%100	5,20	%100	4,10	%100	3,46	%100
C5	Bedroom	1,66	%60	4,67	%100	2,98	%99	3,46	%100
	Living Room	3,26	%100	4,78	%100	3,88	%100	3,25	%100
	Bath	4,26	%100	5,51	%100	5,46	%100	3,46	%100
C6	Bedroom	1,87	%71	3,34	%100	3,02	%99	3,64	%100
	Living Room	3,30	%100	4,69	%100	4,95	%100	3,35	%100
	Bath	4,67	%100	6,00	%100	5,75	%100	3,51	%100
C7	Bedroom	3,12	%100	4,51	%100	3,74	%100	3,79	%100
	Living Room	3,25	%100	4,12	%100	4,72	%100	3,45	%100
	Bath	2,29	%88	3,48	%100	3,47	%100	2,84	%98
C8	Bedroom	2,20	%80	3,77	%100	3,49	%100	3,71	%100
	Living Room	2,28	%88	3,44	%100	3,60	%100	3,40	%100
	Bath	4,63	%100	5,70	%100	5,47	%100	3,57	%100

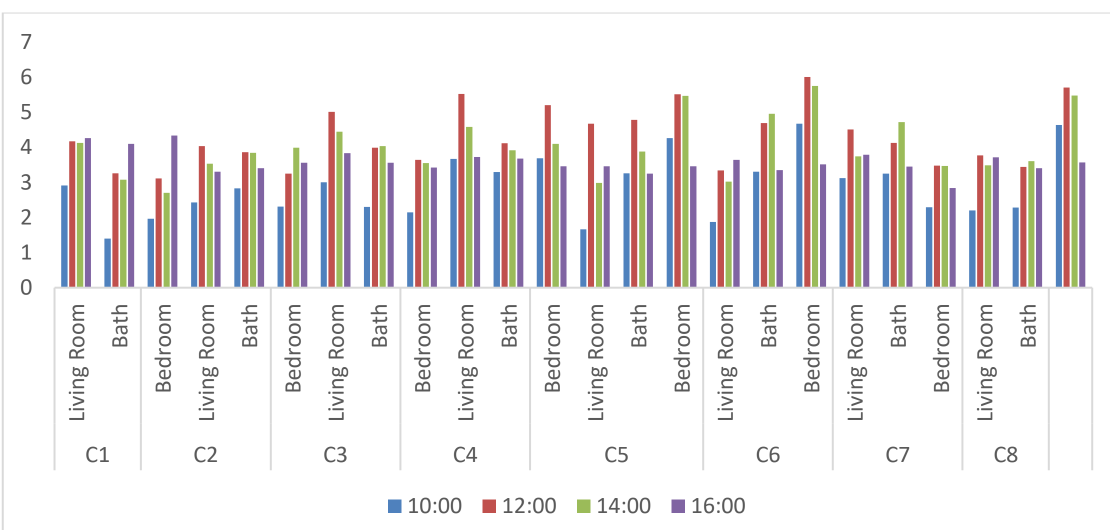


Figure 9: PMV values of containers in Scenario 2 for different hours.

4. Conclusion

In this study, the thermal comfort performance of temporary shelter units in Türkiye was quantitatively analyzed using the Predicted Mean Vote (PMV) index as the primary metric. A standardized container-type shelter was adopted as the reference model for computational analysis. Steady- State simulations were performed for four specific time intervals (10:00, 12:00, 14:00, and 16:00) on July 21st to capture diurnal variations in thermal conditions. Computational Fluid Dynamics (CFD) simulations were conducted using Ansys Fluent to evaluate airflow and thermal distribution within the shelter units. Eight container modules, each located in distinct positions within a prototypical shelter layout, were assessed under two boundary condition scenarios: (1) only doors open, and (2) both doors and windows open, representing varying degrees of natural ventilation. Main findings of the study can be concluded as;

For Scneraio1

- PMV values were generally high and surpassed the thermal comfort threshold, especially during the morning and midday hours.
- Containers C3 and C4 benefited from diagonal (NW) wind flow, resulting in lower PMV values in living rooms due to improved natural ventilation.
- Containers C5–C8, situated on the leeward side, had restricted airflow and showed higher PMV values, indicating considerable thermal discomfort.
- Most spaces fell into the "hot" or "very hot" PMV categories, indicating inadequate thermal comfort in summer conditions.

For Scneraio 2

- Natural ventilation improved significantly, leading to lower PMV values that changes between 2 ℃ to 4 ℃ and enhanced thermal comfort.
- North-oriented containers (C1–C4), particularly at 10:00, showed improved PMV values with a reduction of about 30% in living rooms.
- South-oriented containers (C5–C8) also showed improved PMV results with a reduction of 1-2 ℃ compared to Scenario 1.
- At 12:00, the combined effect of increased solar radiation and ventilation resulted in higher PMV values and greater thermal discomfort.
- A noticeable shift occurred from "hot" to "warm" and "slightly warm" PMV categories under Scenario 2.

In conclusion, in both scenarios, PMV values often exceeded the acceptable thermal comfort limits for occupants under extreme summer conditions. Scenario 2 demonstrated improved thermal performance due to enhanced cross-ventilation, but it may still be insufficient during peak radiation hours. PPD values were generally high in both scenarios, indicating a significant percentage of occupants would experience thermal discomfort.

Based on the simulation results, it is evident that existing passive ventilation strategies—particularly in Scenario 1—are inadequate for maintaining thermal comfort under extreme summer conditions. Therefore, it is recommended that the thermal performance of temporary shelters be improved by implementing integrated passive design measures. These include:

- Optimizing cross-ventilation through strategically placing operable openings (e.g., ventilation louvers or high–low vent combinations) on opposing facades ensures consistent airflow, even in partially enclosed conditions.
- Solar control measures such as external shading devices (e.g., awnings, overhangs) and reflective coatings should be applied to reduce direct solar radiation and associated heat gain.

- It is advisable to consider site-specific orientation, prioritizing layouts that maximize exposure to prevailing wind directions, particularly for living and sleeping areas, while also minimizing the exposure of heavily occupied zones to intense solar radiation.
- Incorporating low-energy ventilation aids, such as solar-powered exhaust fans or passive evaporative cooling systems, further supports air exchange during hours of high ambient temperatures.

Implementing these strategies would reduce PMV and PPD indices and improve occupant thermal comfort throughout the diurnal cycle, thereby enhancing the overall habitability of temporary shelters in hot climates.

Nomenclature

%	=	Percent
°C	=	Centigrade
CO_2	=	Carbon Dioxide
m^2	=	Square Meter
m	=	Meter
cm	=	Centimeter
m/sn	=	Meter/Second
W/m^2K	=	Watt Per Square Metre Kelvin
M	=	Metabolic Heat Production Rate
P_a	=	Partial Vapor Pressure
H	=	Height
f_{cl}	=	Clothing Area Factor
T_{cl}	=	Clothing Surface Temperature
T_a	=	Air Temperature
T_r	=	Radiant temperature
h_{cl}	=	Clothing Surface Heat Transfer Coefficient
h_c	=	Heat Transfer Coefficient
W	=	West
N	=	North
NW	=	Northwest
PMV	=	Predicted Mean Vote
PPD	=	Predicted Percentage of Dissatisfied
CFD	=	Computational Fluid Dynamics
BES	=	Building Energy Simulation
BIM	=	Building Information Modeling
TSU	=	Temporary Shelter Unit
AFAD	=	Disaster and Emergency Management Authority

Conflict of Interest

The authors declare that there is no conflict of interest to disclose.

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Authors' Contributions

AG: Conceptualization, Methodology, Writing- Original draft preparation. AG-SY: Supervision, Writing- Reviewing and Editing, Funding acquisition. SY: Visualization, Data curation, Software, Validation.

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