UTM UNIVERSITI TEKNOLOGI MALAYSIA

IJBES

International Journal of Built Environment and Sustainability
Published by Penerbit UTM Press, Universiti Teknologi Malaysia
IJBES 13(1)/2026, 47-69

Evaluation and Improvement of Thermal Comfort and Indoor Air Quality in Post-Disaster Permanent Housing: A Case Study of Bingöl, Türkiye

Fatma Kürüm Varolgüneş,
Department of Architecture, Bingöl University, Selahaddin-i Eyyubi, Üniversite Caddesi No:1, 12000 Merkez/Bingöl, Türkiye.

Yahya Mutlu, Gonca Özer Yaman and İbrahim Halil Şeker,
Department of Architecture, Bingöl University, Selahaddin-i Eyyubi, Üniversite Caddesi No:1, 12000 Merkez/Bingöl, Türkiye

ABSTRACT

Post-disaster permanent housing plays a critical role in long-term recovery. In cold-climate regions like Bingöl, Türkiye, such housing must ensure adequate thermal comfort and indoor air quality (IAQ) to support occupant well-being. This study evaluates the environmental performance of a representative single-storey post-earthquake housing unit constructed after the 2003 Bingöl earthquake. Field measurements were conducted between December 2023 and February 2024 in five rooms, recording temperature, relative humidity, air velocity, CO^2 concentrations and PM (PM_{1-10}) levels. Results revealed that most rooms failed to meet ASHRAE 55 winter comfort thresholds, with temperature deviations exceeding 3.5°C in under-heated spaces. Stoves improved thermal comfort but elevated CO_2 and PM concentrations, indicating trade-offs between comfort and IAQ. Dynamic simulations using DesignBuilder tested envelope retrofit scenarios including insulation and glazing upgrades. Simulations showed a 7.1% reduction in discomfort hours, 60% lower heating energy demand, and a 12.3% drop in CO_2 emissions. These improvements were cost-effective and readily applicable in post-disaster contexts. This study contributes by combining field-based environmental data with simulation modelling to assess both thermal comfort and IAQ in cold-climate post-disaster housing. The findings inform resilient and sustainable housing strategies for future disaster recovery efforts.

Article History

Received: *25 November 2024*
Received in revised form 11 October *2025*
Accepted: 20 October *2025*
Published Online: 31 December 2025

Keywords:

Post-Disaster Permanent Housing, Thermal Comfort, Indoor Air Quality, Energy Efficiency, DesignBuilder, Field survey

Corresponding Author Contact:

gozer@bingol.edu.tr

DOI: 10.11113/ ijbes.v13.n1.1466

1. Introduction

Earthquakes are among the most devastating natural disasters, causing not only structural damage but also long-term disruptions in socio-economic and environmental systems. According to the United Nations Office for Disaster Risk Reduction, over 100 million people globally have been displaced due to natural disasters in the past decade (Varolgüneş,2025). The urgency of providing immediate shelter often leads to the rapid construction of permanent housing that disregards environmental performance, user needs, and long-term liveability, particularly in cold-climate regions such as Eastern Türkiye. Post-earthquake housing is often rapidly constructed with minimal attention to ventilation or material emissions, leading to degraded indoor air quality (IAQ) conditions that persist beyond emergency shelter needs.

Earthquakes, which occur unexpectedly, are not only natural disasters that cause significant physical destruction but also profoundly affect social and economic structures. They have a substantial impact on local housing markets and the habitability of affected regions (Boelhouwer and van der Heijden, 2018). Successful resettlement and reconstruction are critical to ensuring the rapid recovery of earthquake survivors and to minimising economic damage at the national level (Peacock et al., 2018). However, the urgency of providing housing often results in the development of residential areas that neglect cultural and local conditions, thereby overlooking user needs and satisfaction (Johnson, 2007). This lack of consideration can result in dissatisfaction among disaster survivors, prompting them to abandon these settlements (Dikmen and Elias-Ozkan, 2016). Several parameters influence user satisfaction, one of which is addressing occupants' thermal comfort requirements. In this context, the use of passive systems for ensuring thermal comfort and energy efficiency is of great importance (Yilmaz, 2006).

Buildings that achieve indoor comfort through passive methods consume approximately half the energy compared to those relying on mechanical systems. However, recent studies emphasize that passive strategies alone are insufficient unless combined with proper indoor air quality (IAQ) control (Mousavi et al., 2023).

Although studies such as Çulun et al. (2022) and Yaman et al. (2021) have addressed thermal comfort in different Turkish housing typologies, there remains a significant gap in evaluating both thermal and air quality conditions in post-earthquake housing using quantitative, field-based data and simulation methods. Therefore, permanent post-disaster housing should not only meet the basic need for shelter but also serve as sustainable physical environments that cater to all societal needs of users. Designs that disregard the local housing typologies and thermal comfort requirements of the region may lead to long-term dissatisfaction among occupants (Hamilton, 2012; Davidson et al., 2007). This study addresses a critical gap by combining in-situ environmental measurements and dynamic simulation (DesignBuilder) to assess and improve the thermal comfort and IAQ performance of post-disaster permanent housing in Bingöl, Türkiye. Unlike previous studies, it integrates field-collected environmental data with retrofit scenarios to propose cost-effective, climate-responsive design improvements. Thermal comfort evaluation is guided by internationally accepted standards such as ASHRAE 55 and ISO 7730, which define acceptable indoor temperature and humidity ranges based on adaptive and analytical models. ASHRAE 55, for instance, sets a winter comfort temperature range of 20–24°C under 30–60% relative humidity, while ISO 7730 uses PMV and PPD indices to evaluate thermal acceptability across different comfort categories (Fanger, 1970; Khovalyg et al., 2020). These standards are critical tools in the design and evaluation of healthy, sustainable indoor environments, especially in post-disaster contexts where design quality may be compromised by urgency.
This study aims to examine the impact of indoor air quality on residential satisfaction in post-disaster housing. To achieve this goal, thermal comfort was assessed using in-situ measurements of indoor air temperature (Ti), relative humidity (RH), air velocity, and calculated mean radiant temperature (Tr), interpreted in accordance with ASHRAE 55 and ISO 7730 standards. Indoor air quality was evaluated using CO_2 and particulate matter (PM_{1-10}) levels. Additionally, building envelope performance was modelled through DesignBuilder-based simulations, which incorporated climate data, construction parameters, and heating setpoints to simulate comfort levels and improvement scenarios. Specifically, the focus is on the single-storey post-disaster housing units constructed after the 2003 earthquake in Bingöl, Türkiye. Related research by Kürüm Varolgüneş (2021) has investigated user satisfaction in these housing units by considering physical, social, aesthetic, economic, and technological parameters. This work highlighted adverse outcomes such as frequent changes in occupants, physical modifications within the dwellings, and the replacement of these units with larger buildings. However, no specific evaluation of indoor air quality has been conducted, particularly in this region with harsh winter conditions. This study, employing experimental methods, aims to measure and evaluate parameters related to indoor air quality in the field. In addition, the study includes DesignBuilder-based dynamic simulations to assess current comfort levels and to propose envelope-level improvements. By situating Bingöl within the broader discourse of post-disaster reconstruction in cold climates, this study challenges the assumption that rapid permanent housing necessarily compromises long-term environmental quality. The contribution is twofold: first, it documents the environmental conditions of a widely used post-disaster housing typology in a cold region; second, it provides simulation-supported strategies that can guide policy and design decisions for similar contexts.
Building on this approach, the study contributes not only to academic literature but also provides practical recommendations for improving indoor environmental quality in similar cold-climate disaster regions. This aligns with recent calls in the literature for more integrated, evidence-based, and simulation-supported design strategies for post-disaster housing (Liu et al., 2023; Mousavi et al., 2023).

Research Objectives:

- To analyse indoor thermal environment variables using in-situ measurements during the winter season.
- To evaluate parameters such as temperature, relative humidity, air velocity, radiant and surface temperatures in single-storey post-disaster housing units.
- To assess CO_2 and PM levels in relation to space usage and perceived comfort.
- To simulate the current thermal performance and propose improvements using DesignBuilder, with focus on passive envelope enhancements.

Bingöl offers a uniquely challenging context where a cold continental climate, high seismic risk, and rapidly constructed post-earthquake housing converge. Its long, harsh winters (often below –10°C), widespread reliance on solid-fuel heating, and the absence of district heating systems intensify indoor air quality concerns. Additionally, behavioural patterns such as indoor smoking and multigenerational cohabitation compound these challenges. These overlapping factors make Bingöl a scientifically distinctive case for evaluating the environmental performance of permanent post-disaster housing under combined climatic, infrastructural, and socio-cultural stressors. This complex intersection necessitates a concurrent, field-based examination of thermal comfort and indoor air quality (CO_2/PM), uniquely shaped by both post-seismic reconstruction practices and occupant behaviours in cold-climate conditions.

The study's contributions are threefold, in the following order of priority:

- Contextual: thermal comfort and IAQ are addressed together, in situ, in post-disaster permanent housing in a cold climate.
- Methodological: on-site measurements are combined with DesignBuilder-based dynamic simulation in a mutually reinforcing manner.
- Applied: envelope upgrades are evaluated using straightforward reductions in heating load and discomfort hours, complemented by a preliminary cost–benefit/payback appraisal.

This explicit hierarchy underscores the study's primary contribution to contextual novelty, while methodological integration and applied retrofit guidance serve as its supporting pillars.

2. Literature Review

2.1 Global Literature Overview

Research on thermal comfort in post-disaster and low-income housing consistently highlights the significance of user behaviour in shaping indoor environmental conditions and energy performance. For instance, Malik et al. (2021) and Aguilar-Perez et al. (2023) employed mixed-method approaches—combining environmental measurements and user surveys—to demonstrate that adaptive behaviours such as night-time ventilation and passive solar utilization enhanced thermal comfort. However, these studies did not evaluate objective indoor air quality (IAQ) parameters, leaving a methodological gap in holistic assessment.

In a broader comparative study, Malik et al. (2020) emphasized that active behavioural adaptations can significantly reduce discomfort hours, but their findings were also limited to thermal metrics, omitting the interaction with air quality factors. Another group of studies focused on prototype housing design. Shrestha et al. (2023) used simulation tools to evaluate thermal comfort in rapidly built housing and found that poor insulation led to night-time heat loss. Similarly, D'Orazio and Maracchini (2019) examined temporary housing units and identified high humidity levels due to construction speed and material limitations. Although informative, these studies lacked real-world validation, which limits the generalizability of simulation-based results. This underscores the need for studies that integrate on-site measurements with simulation to verify indoor comfort levels.

Thermal comfort has also been linked to architectural design strategies. Albadra et al. (2018) and Nocera et al. (2020) advocated re-integrating passive design elements from vernacular architecture to improve indoor conditions. Yet, most of this research centres on hot or temperate climates, and neglects cold-climate, seismic-risk zones—highlighting a geographical gap in literature. Research into comfort parameters such as temperature, humidity, air velocity, and CO_2 is well-established (Calis and Kuru, 2017; Özbey and Turhan, 2022). Nevertheless, the tendency to analyse thermal comfort and air quality separately remains a limitation. As Wong et al. (2008) argue, indoor environmental quality (IEQ) is a multidimensional construct encompassing temperature, humidity, air quality, and acoustics. However, very few post-disaster housing studies operate IEQ holistically, especially in relation to user health and comfort in cold climates. A growing body of literature calls for holistic, data-driven studies that combine comfort and IAQ evaluations with simulation-based performance optimization an approach adopted in the present research. (Bernardi and Kowaltowski, 2006). While Table 1 summarizes prior work, it also exposes methodological and contextual contradictions that complicate cross-regional applicability. For example, Shrestha et al. (2023) modelled thermal comfort in cold-climate Nepal using simulations but provided no field validation—raising uncertainty about real-world accuracy. In contrast, Ahmed et al. (2023) combined on-site measurements and simulations in semi-arid Iraq, yet their findings are not transferable to Türkiye's cold, humid continental climate, where both heating demand and occupant practices differ markedly. Likewise, Zhai et al. (2024) addressed comfort at high altitudes but excluded direct CO_2 and PM monitoring, overlooking IAQ–comfort interactions. These contrasts reveal that even methodologically strong studies often remain climate- or culture-specific, limiting generalization. Hence, the literature highlights the need for context-sensitive frameworks that simultaneously address measurement, simulation, and behavioural dimensions—an agenda to which the present study contributes. In evaluating thermal comfort, international standards such as ASHRAE 55 and ISO 7730 rely on indices like Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), and operative temperature (To). These indices consider the combined effects of temperature, humidity, radiation, and air speed to assess human thermal perception (Fanger, 1970; ISO, 2005). Design decisions—such as envelope insulation, glazing, and ventilation strategy—are increasingly guided by such metrics to ensure energy-efficient and user-centred buildings (ASHRAE, 2020). Despite their importance, many field studies in post-disaster housing contexts fail to incorporate or report these indices directly, instead relying solely on temperature or humidity measurements. The present study partially responds to this gap by interpreting in-situ measurements in alignment with ASHRAE-defined comfort zones and proposing simulation-supported envelope improvements.

2.2 Literature Review from Turkey

In Türkiye, recent studies have addressed thermal comfort across various building types. Çulun et al. (2022) and Yaman et al. (2021) conducted environmental measurements in residential and academic buildings in Bingöl and compared results with ASHRAE and ISO standards. Their short-term data collection in winter provided insight into seasonal comfort issues but did not examine IAQ or adaptive behaviours. This limits their applicability to long-term, user-focused post-disaster housing analysis. Several earlier studies, including Emir (2016), Esiyok (2006), and Gür & Sezer

(2019), investigated indoor comfort in schools and mid-income residential units across different Turkish climate zones. However, their findings are not directly transferable to post-disaster housing in cold, seismic-prone areas such as Bingöl. Moreover, their focus was largely on comfort perception, without linking it to measured IAQ or energy behaviour. Kuru and Calis (2017), as well as Turhan and Gokcen-Akkurt (2018), employed robust mixed methods combining user surveys and on-site environmental data in university buildings. While methodologically comprehensive, these works did not apply simulation techniques or address housing developed under emergency conditions. The present study builds on this foundation by introducing DesignBuilder-based simulation scenarios informed by empirical field data, offering actionable retrofit solutions tailored to post-disaster housing.

In summary, although previous Turkish studies have generated valuable insights, none have comprehensively examined both IAQ and thermal comfort in permanent post-disaster housing under cold-climate conditions. To clarify the positioning of this study within the broader research context, Table 1 synthesizes key methodological differences and research gaps in existing literature. The present research responds to this gap by integrating measurement, simulation, and retrofit analysis within a real-world setting, thereby making a novel contribution to both national and international discourse. The overall research framework (spanning from the identification of the problem to methodological execution and analytical outputs) is summarized in Figure 1.

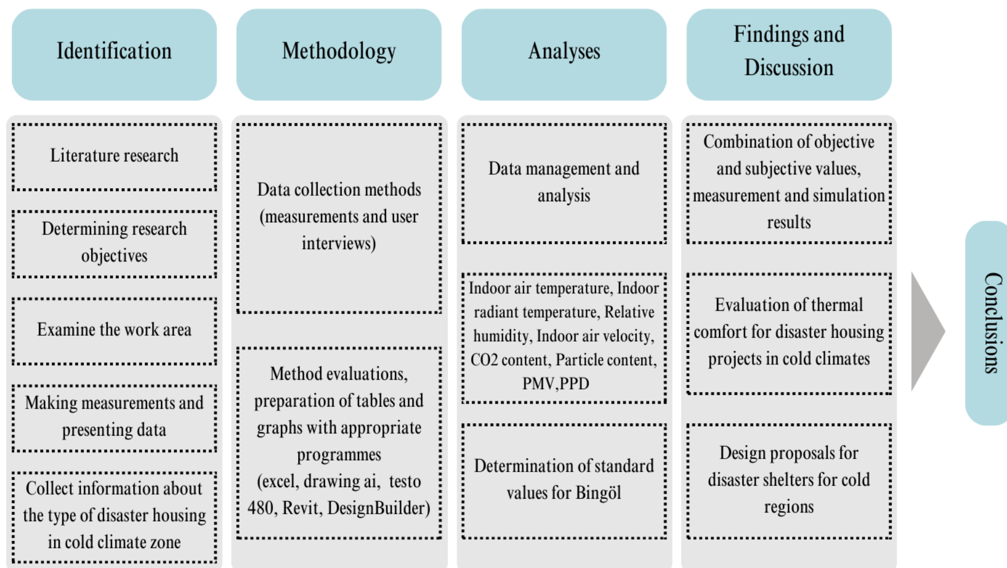


Figure 1 Flowchart of the paper

Table 1 Summary of methodological and thematic gaps in related literature

Study	Focus	Methodology	Climate Region	IAQ Included?	Simulation Used?	Identified Gap
Malik et al. (2021)	Adaptive behaviour in low-income housing	Surveys & interviews	Hot, humid (Mumbai)	✕	✕	Behaviour-focused, no IAQ
Aguilar-Perez et al. (2023)	Thermal dissatisfaction in post-disaster housing	Surveys	Hot-arid (Mexico)	✕	✕	Seasonal discomfort, no measurement
Shrestha et al. (2023)	Prototype vs. traditional housing	Simulation	Cold (Nepal)	✕	✓	No field validation
D'Orazio & Maracchini (2019)	Moisture and comfort in emergency housing	Measurement & simulation	Mediterranean	✕	✓	Focused on temporary housing
Albadra et al. (2018)	Refugee housing IEQ	On-site measurement	Hot-arid	✓	✕	Surface temp focus only
Mihara et al. (2025)	Location/climate effects on thermal comfort; home vs office; Bayesian estimation of comfort ranges	Longitudinal field study; daily watch-based surveys + indoor env. monitoring	Singapore (hot-humid); Tokyo, Japan (temperate)	✕	✕	Not post-disaster housing; no IAQ/health linkage; no simulation/retrofit
Ahmed et al. (2025)	Field–simulation validation of indoor air temperature; dataset generation for a modern residence	In-situ measurements (Ashty House) + DesignBuilder	Erbil, Iraq (hot-dry/semi-arid)	✕	✓	No PMV/PPD or adaptive comfort; no IAQ/health linkage; single-case, not post-

		modelling				disaster/cold-seismic context
Zhai et al. (2024)	Thermal comfort in passive solar houses; active solar heating vs. coal stove; PMV-PPD & LPD; energy/payback	Field experiment; PMV-PPD & LPD evaluation; energy metering; CO_2 reduction	Tibetan Plateau (arid–cold, high-altitude; Gan-nan	✕ (no direct CO_2/PM measurements; pollution discussed contextually)	✕	Not post-disaster/cold-seismic housing; no IAQ/health metrics; no building-energy simulation/retrofit exploration
Kaihoul et.al. (2024)	Sensitivity of PMV-PPD vs. adaptive models in hotel design	In-situ measurements for model validation+ EnergyPlus dynamic simulations; sensitivity analysis	Algeria (8 climate zones; Ghardaïa reference)	✕	✓	Hotel typology only; no IAQ/health outcomes; not post-disaster/cold-seismic context; limited retrofit/cost linkage
Çulun et al. (2022)	Thermal comfort in residential units	Measurement vs. ASHRAE	Cold (Bingöl)	✕	✕	No IAQ or retrofitting
Kuru & Calis (2017)	Gender and age in comfort	Statistical survey + measurement	Moderate (Turkey)	✕	✕	No dynamic analysis
This study	Post-disaster thermal & IAQ performance	Field measurement + simulation	Cold (Bingöl)	✓	✓	First integrated study in this context

3. Methodology

3.1 *Study Area and Examined Post-Disaster Housing*

Bingöl, located in eastern Türkiye, is situated in a first-degree seismic zone. Positioned at the intersection of the East Anatolian Fault Line and the North Anatolian Fault Line, Bingöl is a region of high seismic activity. Over the past five years, the area has experienced significant seismic events, including a 6.4 magnitude earthquake in the city centre in 2003, a 5.0 magnitude earthquake in 2004, two earthquakes with magnitudes of 5.6 and 5.9 in Karlıova in 2005, a 5.2 magnitude earthquake in Yedisu in 2005, and a 5.5 magnitude earthquake in Karlıova in 2007, all of which caused substantial damage (AFAD, 2018). The 2003 earthquake caused extensive destruction, with a recorded peak ground acceleration significantly higher compared to other recent earthquakes in Türkiye (Doğangün, 2004). In the aftermath of the 2003 earthquake, 308 buildings were destroyed, 2,566 buildings were heavily or moderately damaged, and 2,546 buildings sustained minor damage. Official reports indicated 174 fatalities and 520 injuries (Kaplan et al., 2004). Bingöl, which suffered considerable economic losses following the earthquake, struggled to adequately allocate resources to meet housing needs. Post-earthquake organizational shortcomings hindered the development of effective, long-term solutions. Emergency shelters built shortly after the earthquake were eventually replaced by permanent housing. However, authorities hastily built the permanent housing units without sufficient planning, so earthquake survivors did not welcome them. This lack of acceptance led to spatial modifications that compromised the structural integrity of these units. The housing constructed in urban areas for earthquake survivors from rural regions underwent significant physical and demographic changes within 10 to 13 years. Identifying the underlying causes of these transformations is critical for the success of future permanent housing projects. Consequently, the permanent housing units constructed in the Selâhattin Eyyubi neighbourhood of Bingöl after the 2003 earthquake were selected as the study area (Figure 2).

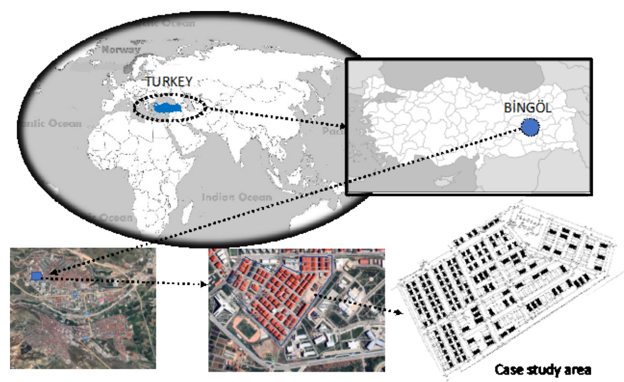


Figure 2 Case study area

These housing units are categorized into two types: Single-storey (Type 1) and Two-Story Disaster Housing (Type 2). Twenty years after the earthquake, it has been observed that the demographic structure of the region where these housing units were initially designed has changed significantly. It has also been noted that the location of the permanent housing built post-disaster did not adequately consider climatic and topographical factors. Some units were oriented along the east-west axis, while others were positioned on the north-south axis (Figure 3.a, b). As the measurements in this study were conducted on single-storey housing, the two-story housing type will not be discussed in detail. The permanent single-storey housing (Type 1) features a net usable area of 110 m², constructed using a reinforced concrete shear wall frame system. These units include a living room, a guest room, two bedrooms, a kitchen, and a separate bathroom and toilet (Figures 4 and 5). The rooms serve multiple purposes, such as living, sleeping, dining, and hosting guests. The outdoor area (garden) is utilized for various activities, including storing firewood and animal feed, composting manure, raising poultry, cooking, and laundry. The kitchen and Bedroom 1 are located on the southern side, while the guest room, Bedroom 2, and living room are oriented to the north. The individual rooms range between approximately 20–25 m². The kitchen floors and walls are finished with ceramic tiles, while the remaining rooms and hallways are covered with laminated wood flooring. Interior walls are coated with gypsum plaster (Table 2). The typical household size is between four and seven individuals. Smoking is prevalent in most of the units. The site plan, architectural layout, and front elevation of the selected housing type are presented in Figures 3.a, b, c, and d.

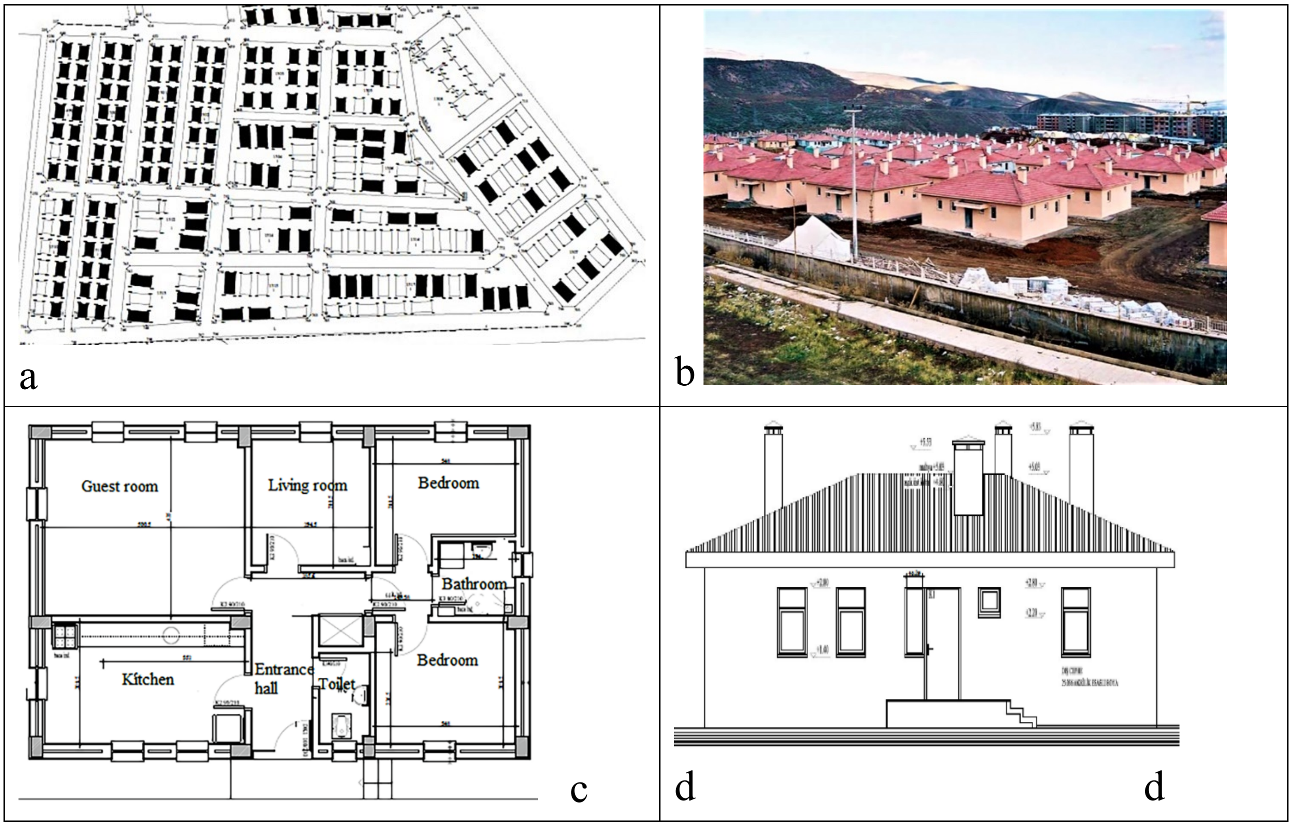


Figure 3 a. Bingöl post-disaster permanent housing area layout plan) b. General view of single-storey disaster Housing c. Single-storey disaster housing Type 1 plan example d. Front view of single-storey disaster housing (Kürüm Varolgüneş, 2021)

Table 2 Post-Disaster housing features (Type 1)

Criteria		**Post-Disaster housing features**				
		Kitchen	**Guest room**	**Bedroom 1**	**Bedroom 2**	**Living room**
Orientation		SW	NW	NE	SE	N
Location Floor		Ground floor	Ground floor	Ground floor	Ground floor	Ground floor
Field (m²)	**Wall (m²)**	40 m²	50.94 m²	39.50 m²	38.92 m²	36.5 m²
	Flooring (m²)	16.00	21.75 m²	10.85 m²	11 m²	10.00 m²
	Ceiling (m²)	16.00 m²	21.75 m²	10.85 m²	11 m²	10.00 m²
Cladding/Finishing	**Interior Plaster+Pain**	-	+	+	+	+

Material	**Wall**	**Interior Plaster+ Tile**	-	+	+	+	+
	Flooring	**Laminate**	-	+	+	+	+
		Ceramic	+	-	-	-	-
	Ceiling	**Glass wool (8 m)**	+	+	+	+	+
		Wooden Roof+Water	+				
Volume (m^3)	**Floor Height**		2.8 m	2.8 m	2.8 m	2.8 m	2.8 m
	Floor Area		16 m²	21.75 m²	10.85 m²	11 m²	10.00 m²
	Total Volume		44.8 m³	60.90 m³	30,38 m³	30,80 m³	28 m³
Window Features	**Dimensions**		3*0.8*1.40	3*0.8*1.40	1*0.8*1.40	1*0.8*1.40	1*0.8*1.40
	Area/Volume		% 8	% 6	% 4	% 4	% 4
Door Features	**Laminate**		90/210	90/210	90/210		90/210
	Steel		-	-	-	-	-
Heating System			None	Wood/coal stove	Electric stove	Wood/coal stove	Electric stove (part-time)
Lighting System Features	**Type**		+	+	+	+	+
	Ampoule						
Smoking Status			+	+	-	-	-

The reference building selected for this study is located in Bingöl, a city situated in Türkiye's climatic region characterized by cold winters and hot summers. Bingöl is positioned in the Upper Euphrates subregion of Türkiye's Eastern Anatolia Region, between 41°20' and 39°56' east longitudes and 39°31' and 36°28' north latitudes (URL-1). Due to exposure to humid-cold air masses from the north and the influence of elevation, the summers in Bingöl are hot, and winters are cold. According to data from the Turkish State Meteorological Service, the annual average temperature in Bingöl is 12.1°C. The city receives up to 873.7 mm of annual precipitation, with an average of 24.5 snow days and approximately 94.1 frost days per year (URL-1). For the purposes of the study, the climate data for this city were obtained in the form of an epw (EnergyPlus Weather) file, which was used for simulations conducted with the DesignBuilder software.

3.2. Measurements and Method of Analysis

The importance of parameters affecting thermal comfort varies according to the climatic conditions of different countries. In many cases, air temperature is considered the most critical factor influencing thermal comfort, and most indices developed focus primarily on determining comfort temperature (ASHRAE-Standart-55, 2013; ASHRAE-Handbook, 1989). International standards such as ASHRAE Standard 55 and ISO 7730 (De Dear and Brager, 1998) are frequently utilized by architects and professionals to assess thermal comfort conditions within buildings. These conditions are often analysed through field measurement studies. The objective parameters of thermal comfort measured and examined in this context are as follows (Chen et al., 2016; Yilmaz, 2006; Wang, 2006):

- Indoor air temperature : T_i (°C)
- Indoor radiation temperature : TR (°C)
- Relative humidity : RH (%)
- Indoor air velocity : V_a (m/s)

Since radiation between surrounding surfaces and occupants can affect perceived comfort, the mean radiant temperature (TR) was calculated using the empirical method developed by Nagano and Mochida (2004). This method estimates TR based on instantaneous indoor air temperature (Ti) and is particularly suitable for field conditions where advanced equipment is unavailable. The formula used in this study is shown in Equation (1), where $R^2 = 0.99$ indicates a strong correlation between TR and Ti (Nagano & Mochida, 2004; Kuru & Calis, 2017).

$$TR = 0.99 \times T_i - 0.01,\ R^2 = 0.99 \quad (1)$$

The measurements were conducted during December, January, and February of 2023–2024, which are the coldest months in Bingöl, Türkiye. A Testo 480 multifunctional measuring device was used to assess thermal comfort and indoor air quality. This device, equipped with digital probes, can record parameters such as airflow, temperature, humidity, pressure, radiant temperature, and CO_2 levels (Yaman et al., 2021; Çulun et al., 2022).

In the selected post-disaster housing units, measurements were carried out in five distinct spaces—kitchen, guest room, bedrooms, and living room (K, GR, B1, B2, LR). These rooms were selected to represent diverse indoor functional conditions, including both high- and low-occupancy zones, thereby enhancing the contextual relevance of the data. Although the study sample was limited to a single housing unit, the depth of data collected—15 repeated measurements per space on five different days per month—provided 225 high-frequency data points per room. This high temporal resolution compensates for the limited spatial coverage and enhances internal validity. The sample selection was also influenced by logistical and ethical considerations, including homeowner consent and measurement feasibility during cold-weather conditions in an occupied post-disaster structure.

For each space, five measurement days per month were designated, and 15 measurements were taken per day. Each measurement lasted 40 minutes, with 20-minute breaks in between. The daily average of measurements was calculated for each measurement day. Outdoor measurements were taken in 5-minute intervals both before starting the indoor measurements and after completing all measurements for the day. Particulate matter (PM) measurements were conducted using a PCE Air Quality Detector (PCE-RCM 05) device. PM and CO_2 concentrations were recorded during the 40-minute measurement periods in each room. While this device provides real-time readings with a range of 0.001–150 mg/m³ and ±5% accuracy, it does not provide information on particle source or composition, which limits interpretability.

Outdoor CO_2 levels range between 300–400 ppm, while the World Health Organization (WHO) recommends a maximum indoor CO_2 concentration of 1000 ppm. The CO_2 levels vary depending on personal factors, the number of occupants, and their activities. In crowded spaces, increased oxygen consumption raises CO_2 levels, thereby reducing indoor air quality. Elevated CO_2 levels can affect thermal comfort conditions, making breathing more difficult. Insufficient oxygen supply for bodily functions can lead to health complications (Özdamar and Umaroğulları, 2017). To minimize measurement bias, devices were placed 1.1 meters above the ground, in accordance with ISO 7726, and all measurements were conducted with doors and windows closed to ensure consistent indoor conditions. The sensors were calibrated before each measurement day.

For particulate measurements, particle sizes 1 μm, 2,5 μm, 4 μm, 10 μm were recorded. The device's measurement interval was set to 1–2 minutes based on its specifications, with a range of 0.001 to 150 mg/m³ and an accuracy of ±5%. The analysis of indoor air quality parameters (CO_2 and PM) in this study was conducted in compliance with the ASHRAE Standard 62.1-2019. PMV and PPD calculations were not performed in this study. Measurements were set at 5-minute intervals, with the device positioned at a central point in each room, 1.1 meters above the floor. During the measurements, doors and windows remained closed. Thermal comfort parameters were evaluated in accordance with ISO EN 7730 and ASHRAE Standard 55. According to ISO 7730, the winter comfort temperature is considered to be between 20°C and 24°C for 50% relative humidity (Özdamar and Umaroğulları, 2017). Khovalyg et al. (2020) reported that the winter temperature range is 19–25°C according to ISO 7730 and 20.5–24.5°C according to ASHRAE 55 (Khovalyg et al., 2020). ISO 7730 provides broader comfort temperature ranges and offers various categories, whereas ASHRAE 55 does not categorize thermal environments but instead specifies acceptable values. In this context, ASHRAE 55 defines winter comfort temperatures within the range of 20–24°C and relative humidity between 30–60% for both summer and winter seasons. In the absence of direct globe thermometer measurements, operative temperature was approximated by averaging the measured indoor air temperature (Ti) and the calculated mean radiant temperature (Tr), in accordance with the simplified model recommended by ASHRAE 55 and applied in similar studies (Nagano & Mochida, 2004). This approach ensures consistency with international thermal comfort evaluation practices in low-energy housing.

3.3. Simulation Methodology for Current Conditions and Improvement Scenarios

To evaluate current thermal comfort levels and test retrofit scenarios in the post-disaster housing unit, DesignBuilder, a dynamic simulation software based on the EnergyPlus engine, was employed. This tool enables the assessment of indoor thermal performance, energy demand, and climate-adaptive envelope strategies in a detailed and repeatable manner (Mousavi et al., 2023; Garg et al., 2020). Compared to other BES tools, DesignBuilder offers several advantages that align well with the aims of this study. Unlike EnergyPlus, which requires manual scripting and has a steep learning curve, DesignBuilder provides a user-friendly visual interface with built-in templates for residential buildings. TRNSYS, another widely used software, excels in component-level energy system simulation but lacks robust geometry modelling capabilities, limiting its usefulness for envelope-based retrofit analysis. Similarly, while IDA ICE is effective in dynamic simulation of indoor environments, its availability and regional climate adaptability are more limited compared to DesignBuilder. DesignBuilder is a comprehensive user-friendly graphical interface simulation software developed for EnergyPlus (a building energy dynamic simulation program) for building heating, cooling, lighting, ventilation, daylighting, and other popular total energy simulations and economic analyses (Hou et. al. 2024). Thus, DesignBuilder was chosen for its balance of interface usability, simulation depth, and regional climate support, making it especially suitable for post-disaster housing performance analysis in cold climates. DesignBuilder's output accuracy has been validated in previous research using the BIM-DB methodology (Liu et al., 2023), showing strong consistency between simulated PMV, energy consumption, and real-world data. The building was modelled using original architectural plans, with field-verified inputs for occupancy, schedules, internal gains, and materials. Weather data from the IWEC database was used to simulate seasonal dynamics for Bingöl's cold climate. The permanent disaster housing under consideration was modelled in DesignBuilder to determine its comfort levels through simulations and to measure the impact of proposed improvements. The visual representation of the modelled building is shown in Figure 4.

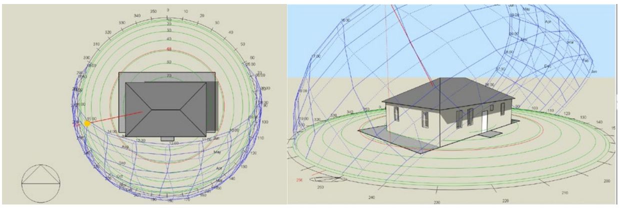
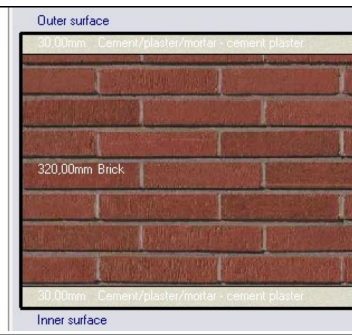
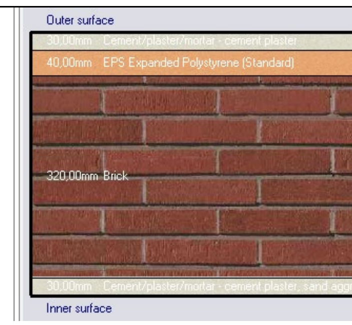


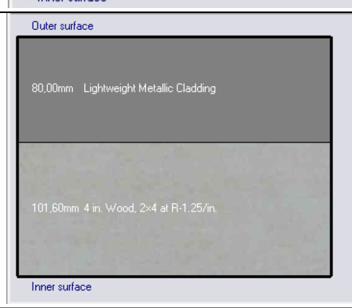
Figure 4 *DesignBuilder model of post-disaster housing*

To address the building's poor envelope performance, retrofit scenarios were modelled using low-cost, locally available insulation strategies, targeting roof, walls, windows, and slab insulation—without altering the building's structural form. All retrofit scenarios aimed to reduce transmission heat loss by improving U-values of envelope components (walls, roof, glazing, floor slab) as detailed in Table 3 (Yaman, 2023). The simulation also incorporated seasonal clothing insulation values and heating setpoint temperatures (from 20.5°C to 24.5°C, based on ASHRAE 55 winter comfort range), which were used to calculate discomfort hours and heating energy demand. Table 4 provides space activity types and corresponding clothing insulation values used in simulations to ensure scenario alignment with seasonal behaviours.

Table 3 Current State and Improvement Proposals for Building Exterior Surfaces

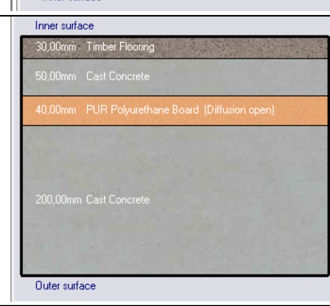
<table>
<tr><td></td><td colspan="2">Current situation</td><td colspan="2">Improvement Proposals</td></tr>
<tr><td>External wall</td><td>
</td><td>Number of layers: 3

U-Value: 1.433 (W/m2-K)</td><td>
</td><td>Number of layers: 4

U-Value: 0,589 (W/m2-K)</td></tr>
<tr><td>Roof</td><td>
</td><td>Number of layers: 2

U-Value: 1.933 (W/m2-K)</td><td>
</td><td>Number of layers: 4

U-Value: 0,397 (W/m2-K)</td></tr>
<tr><td>Ground floor</td><td>
</td><td>Number of layers: 2

U-Value: 1,549 (W/m2-K)</td><td>
</td><td>Number of layers: 4

U- Value: 0.482 (W/m2-K)</td></tr>
</table>

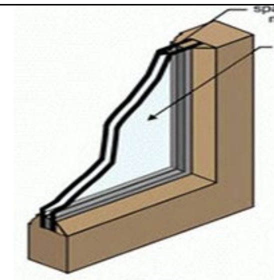
Window		Number of layers: 1 Generic Clear 4mm glass SHGC: 0,819 U- Value: 5.778		Number of layers: 1 Generic Clear 4mm glass+ 12mm air+ 4mm glass SHGC: 0,741 U- Value: 2,726

Table 4 The clothing data

Occupancy density (people/m2) = 0,0215, Factor (Men=1.00, Women= 0,85, Children=0,75)= 1						
Clothing schedule definition	Winter clothing (clo)	Summer clothing (clo)	Heating setpoint temperature		Cooling setpoint temperature	
			Heating (°C)	Heating set back (°C)	Cooling (°C)	Cooling set back (°C)
Generic summer and winter clothing	1.00	0.50	20	13	26	32

4.0 Findings

4.1. Findings of Thermal Environment Measurements

Indoor air temperature is the most direct indicator of thermal comfort. In cold-climate post-disaster housing, maintaining temperatures within acceptable comfort ranges is a challenge due to inconsistent heating systems and user-dependent practices. This study was conducted during the winter season, and the measurements were evaluated considering winter conditions. To facilitate comparison, the lower and upper limits of the ASHRAE 55 standard for winter months (20–24°C) were included in the same graphs. The heating system of the house relies on wood and coal stoves. In the analysed residence, the guest room and Bedroom-2 are heated with wood/coal stoves, while other rooms are occasionally heated using electric heaters. The kitchen typically lacks any heating device. When analysing the spaces individually, the kitchen stands out due to the absence of heating equipment. Measurements taken in December revealed that the indoor temperature values in the kitchen remained below the lower threshold of 20°C defined by the ASHRAE 55 standard on almost all days. However, despite the absence of a heating system, the average of eight measurements taken at different times of the day showed indoor temperatures higher than the outdoor temperatures. While the kitchen did not meet thermal comfort conditions in terms of temperature, the frequent use of the stove and water heating appliances, along with its south-facing orientation that receives direct sunlight during the day, contributed positively to temperature increases. Quantitative comparison with ASHRAE 55 thresholds revealed that the kitchen recorded indoor temperatures below 20°C for approximately 85% of the measured winter days. Similarly, Bedroom-1 fell below the acceptable thermal range for 62% of the period, largely due to sporadic electric heater usage. In contrast, the guest room where the stove operated continuously maintained comfort-compliant temperatures (20–24°C) for over 90% of the measurement duration. The analysis of measurement results indicated that the guest room and Bedroom-2, both heated with wood/coal stoves, maintained temperatures within the comfortable range of 20–24°C specified by ASHRAE 55. These rooms were thus considered more comfortable compared to other spaces. The guest room, in particular, serves as the largest space in the house and is used by the entire family during the day, for hosting guests, and as a sleeping area for family members other than the parents at night. Consequently, the wood/coal stove in this room was observed to burn continuously. In the living room, where the older adults in the family spent most of their time, an electric heater was consistently in use. Although the measured indoor temperature of this room hovered around the lower threshold of the standard, it remained stable throughout the day. Temperature measurements in Bedroom-1 conducted in December revealed that the temperature was at the lower threshold of the standard and exhibited greater variability compared to other rooms. In this room, the electric heater was used only when necessary (Figure 5). These findings suggest that heating is prioritised in communal or multifunctional spaces (guest room, living room), while private spaces (kitchen, Bedroom-1) remain underheated. This uneven temperature distribution may affect user satisfaction, particularly in bedrooms where low nighttime temperatures can impair sleep quality.

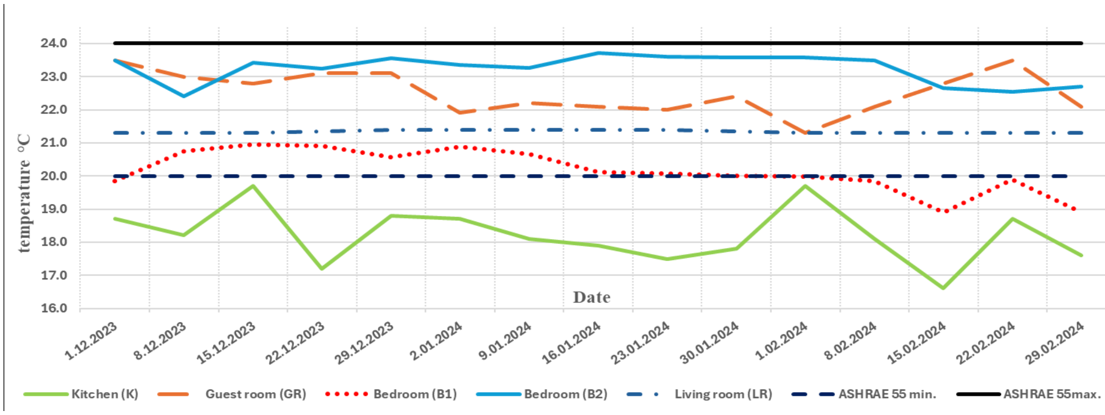


Figure 5 Indoor air temperature (Ti) measurement results for winter period (December-January-February)

Unlike air temperature, radiant temperature reflects the thermal radiation exchanged between occupants and surrounding surfaces (walls, windows, ceilings). In under-insulated, cold-climate housing, radiant discomfort often persists even when air temperatures are within acceptable limits—making this metric critical in understanding perceived comfort. Radiation temperatures within indoor spaces play a crucial role in ensuring appropriate comfort conditions and maintaining effective insulation in buildings. Proper insulation helps stabilize wall temperatures, preventing excessive drops during winter and extreme increases during summer, thereby contributing to the maintenance of optimal radiation temperatures. For instance, during winter, outdoor temperatures can be significantly low, causing wall temperatures to fall slightly below indoor air temperatures. However, to maintain comfort, the difference between wall and indoor air temperatures should not exceed 3°C. If the temperature difference surpasses 3°C, radiant heat transfer between the human body and the colder wall can cause discomfort, even if the room is adequately heated. To address this, TS 825 (the standard for thermal insulation in Türkiye) specifies that wall temperatures should not fall below 17°C. Radiation temperatures of the dwellings, calculated using Equation 1, are illustrated in Figure 6. In general, these radiation temperatures followed a pattern similar to that of indoor air temperatures. For rooms equipped with heating devices such as stoves during the winter, radiation temperatures remained within the comfort boundaries, albeit closer to the lower limit. However, in spaces like kitchens, which are not continuously heated, the radiation temperatures fell below the threshold defined in TS 825. This condition promoted condensation and the eventual development of mold on the walls, particularly in kitchens and comparable areas. These results confirm that air temperature alone is not sufficient for evaluating comfort, as radiation heat loss from occupants toward cold wall surfaces remains significant. Particularly in intermittently heated zones such as kitchens, radiant temperatures drop below 18°C, posing a risk of condensation, structural degradation, and thermal discomfort despite moderate air temperatures. This highlights the urgent need for envelope-level thermal improvements, especially in spaces used for cooking, storage, or passive daytime occupation.

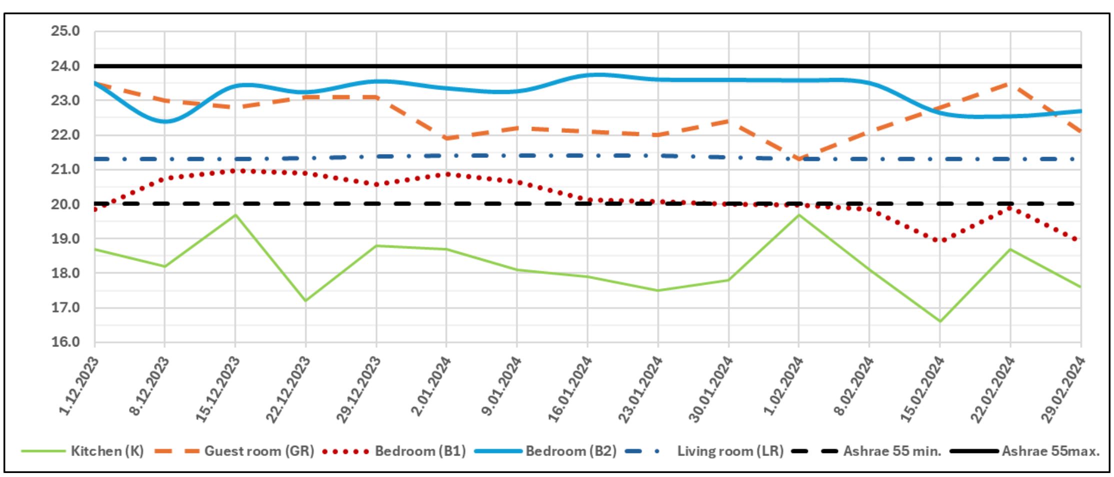


Figure 6 Radiant Temperature (TR) Measurement Results for Winter Period (December–February)

The relative humidity levels for December, January, and February are presented in Figure 7. According to this figure, the humidity levels in the guest room and the living room, both heated with a stove, fall below the standard thresholds during the winter months. In the living room, kitchen, and Bedroom 1, relative humidity levels generally remain near the lower limit of the ASHRAE 55 standard's acceptable range of 30%–65%. When relative humidity drops below the lower limit (30%–40%), it can lead to health issues such as dryness and itching of the skin and lips. On the other hand, humidity levels above 65% can result in discomfort, including difficulty breathing, excessive sweating, and a sensation of suffocation. The World Health Organization has reported that viruses can spread not only through human-to-human contact but also via airborne transmission. Numerous studies have confirmed that airborne contamination and viral transmission are closely associated with the level of humidity in the air. When relative humidity falls below 40%, the spread of influenza (flu) viruses is significantly higher. Therefore, low relative humidity is a critical factor contributing to seasonal flu outbreaks, particularly during the winter months (Shaman et al., 2010). These measurements indicate that most rooms operate at the lower edge of the comfort range, suggesting excessive drying of indoor air caused by solid-fuel heating and insufficient ventilation. Such dryness not only reduces perceived comfort but also increases respiratory vulnerability, especially for children and elderly occupants. The coexistence of low humidity and elevated particulate levels (as shown in Figure 10) further intensifies indoor health risks in these homes.

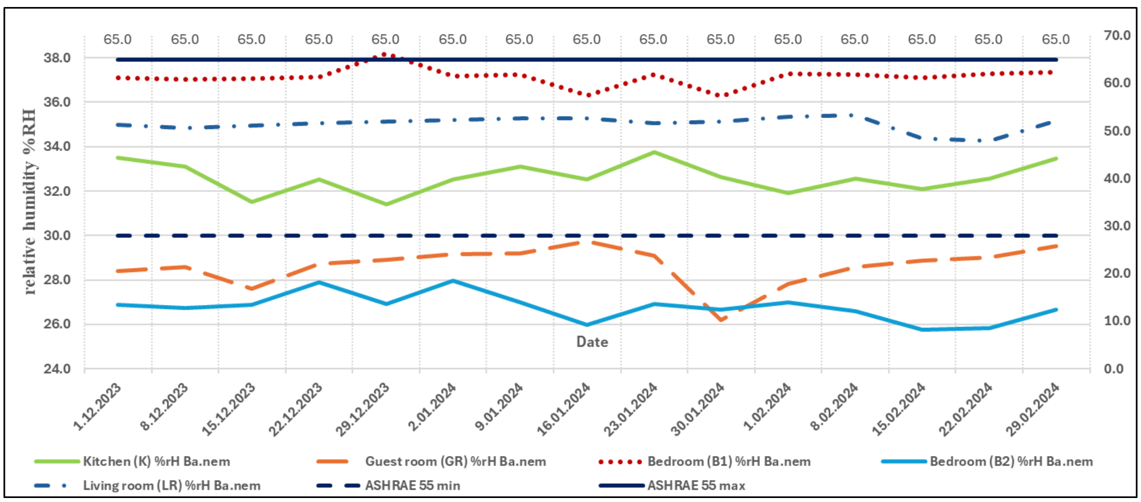


Figure 7 Winter period (December-January-February) relative humidity (RH) measurement results

Air velocity is a key parameter for indoor comfort, particularly in naturally ventilated, cold-climate housing. As shown in Figure 8, most rooms remained within acceptable velocity ranges during winter. However, the kitchen and Bedroom-1 consistently showed low air speeds (<0.15 m/s), indicating poor ventilation, while Bedroom-2 and the living room occasionally exceeded 0.22 m/s, possibly due to localized heating or draft (Halıcı, 2019). These findings suggest ventilation imbalances between rooms, which may contribute to uneven IAQ performance. In under-ventilated spaces, low air movement can amplify CO_2 and PM accumulation, underscoring the need for more uniform airflow strategies.

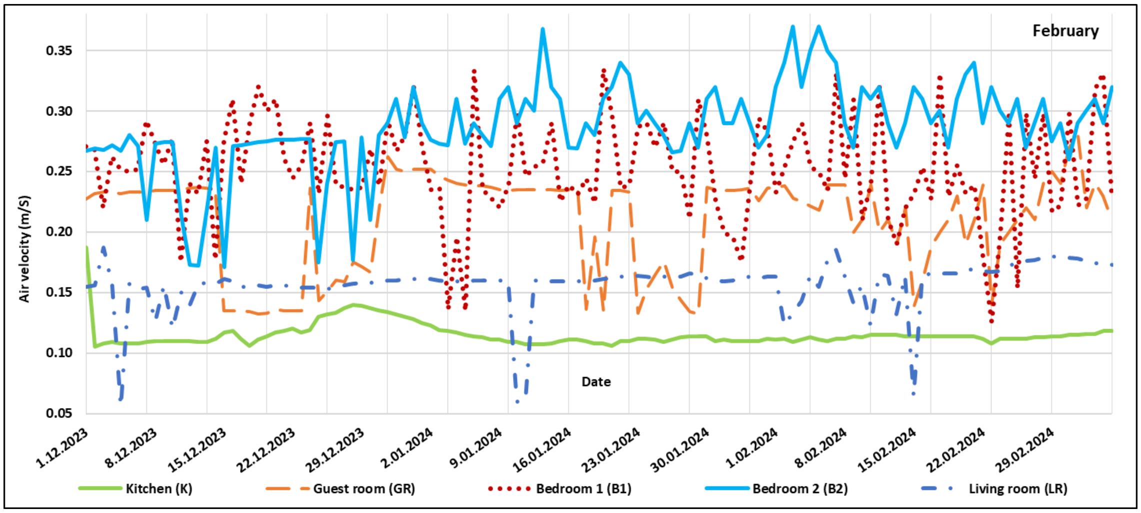


Figure 8 Winter period (December-January-February) air velocity (m/s) measurement results

CO_2 concentration is a key proxy for indoor air quality and ventilation efficiency. In the studied dwelling, measured CO_2 levels ranged from 550 to 950 ppm, remaining under the ASHRAE 62.1 (1000 ppm) and WHO thresholds (Figure 9). However, rooms heated with coal-burning stoves (especially the guest room and kitchen) frequently approached the upper limits—especially during periods of high occupancy and closed windows. This trend signals inadequate air exchange, particularly in rooms where heating is prioritized over ventilation—a common trade-off in cold-climate housing. Sustained CO_2 near 900 ppm may reduce cognitive performance, impair concentration, and signal broader IAQ deficiencies. Özdamar and Umaroğulları (2017) emphasized that solid fuel combustion indoors substantially increases CO_2 and pollutant loads. Cigarette smoking further exacerbates this by introducing VOC and PM pollutants, creating compound health risks—especially for vulnerable groups such as children and the elderly. Long-term exposure is associated with respiratory and cardiovascular diseases, underscoring the need for integrated thermal-ventilation design in post-disaster homes.

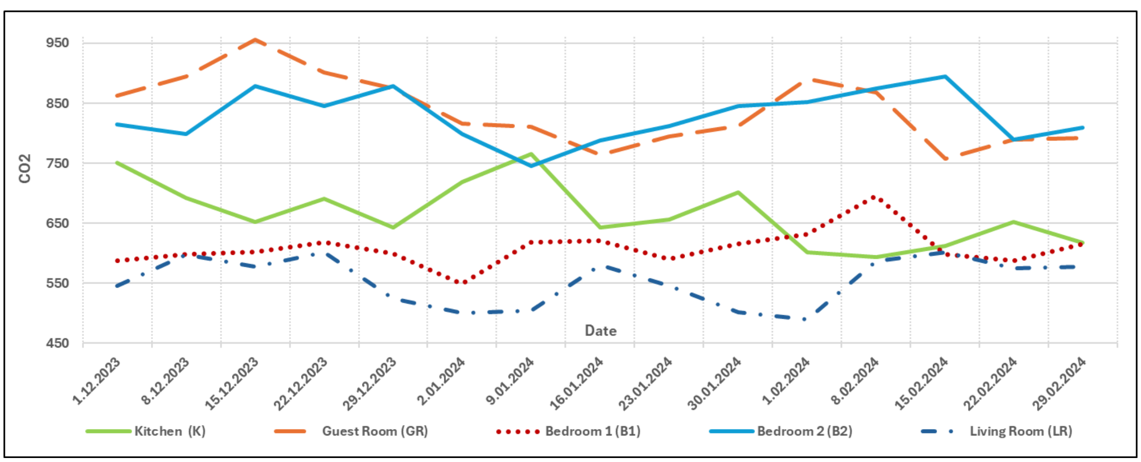


Figure 9 Winter period (December-January-February) CO_2 measurement results

Fine particulate matter (PM_1, $PM_{2.5}$, PM_4, and PM_{10}) was measured to assess pollutant load in indoor air. As shown in Figure 10, PM_1 particles exhibited the highest concentration peaks, followed by $PM_{2.5}$ and PM_4. These ultrafine particles can penetrate deep into the respiratory system, posing serious health risks.

Elevated PM_1 and $PM_{2.5}$ values were recorded particularly in rooms where coal stoves were used continuously and indoor smoking occurred, supporting previous findings (Shaman et al., 2010; WHO). Additionally, dense furnishings and limited air movement contributed to the re-suspension of dust, further amplifying PM concentrations.

These results align with previous studies linking high indoor PM exposure to increased rates of respiratory infections, asthma exacerbation, and cardiovascular disease. Moreover, when low relative humidity coincides with elevated PM levels, the risk of airborne viral transmission significantly increases—a critical concern in overcrowded, post-disaster housing settings. Several contributing factors were identified:

- The use of coal stoves in poorly ventilated rooms increases the emission of fine particles.
- Indoor smoking further elevates PM_1 and $PM_{2.5}$ levels, releasing toxic compounds such as carbon monoxide, formaldehyde, and benzene.
- Dense furniture layouts and insufficient air circulation promote the accumulation of dust and re-suspended particulates.

According to recent WHO guidelines and studies by Shaman et al. (2010), $PM_{2.5}$ and smaller particles are strongly associated with respiratory infections, increased asthma symptoms, and cardiovascular mortality. Furthermore, viral transmission (e.g., influenza) has been shown to increase in indoor environments where low humidity and high PM concentrations coexist.

Given these findings, urgent interventions are needed to improve indoor air quality in post-disaster housing. Suggested strategies include:

- Transitioning to cleaner heating technologies,
- Enforcing indoor smoking bans, and
- Enhancing natural and mechanical ventilation systems.

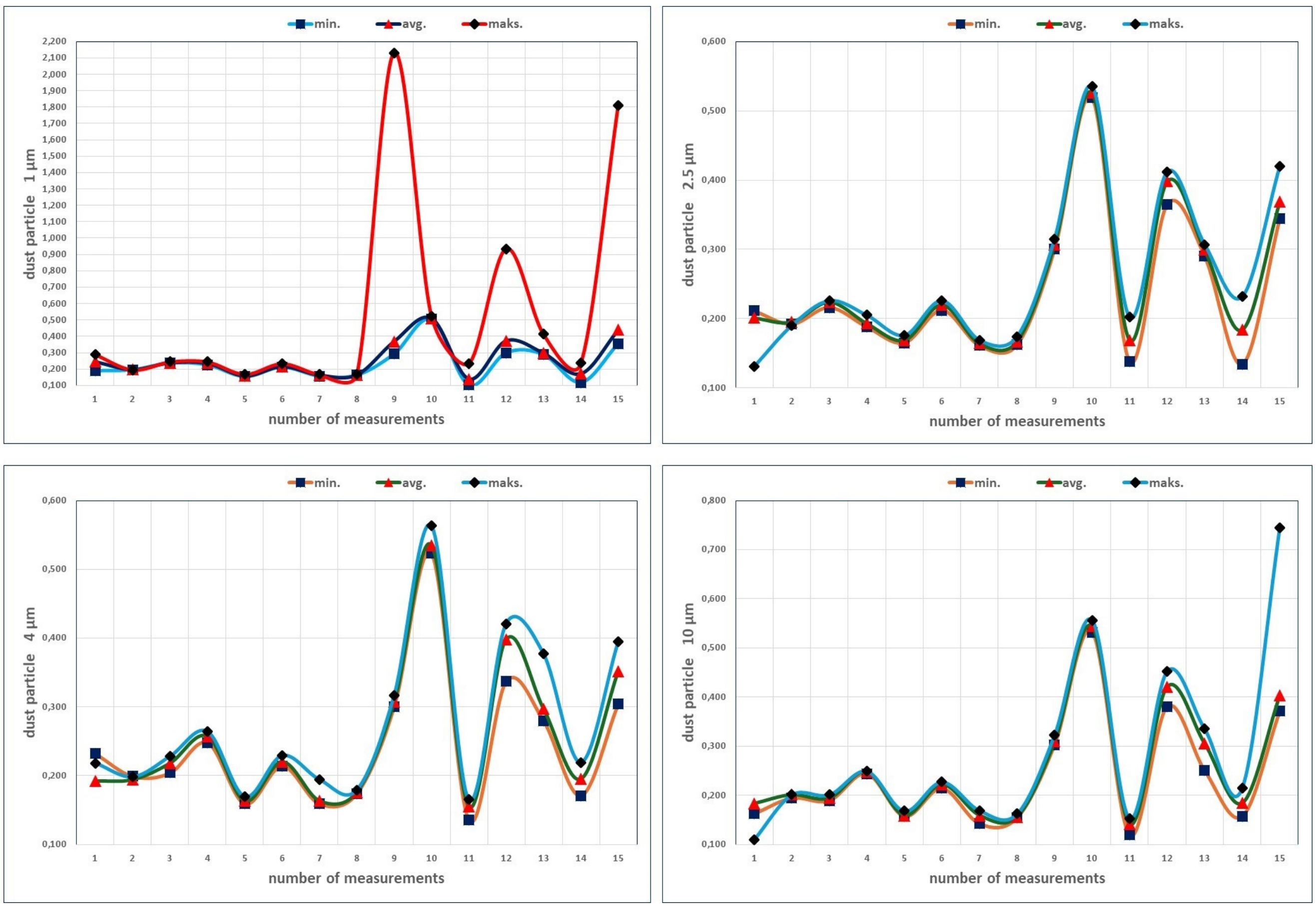


Figure 10 Winter period (December-January-February) PM measurement results

4.2. Findings from DesignBuilder Dynamic Simulations on Thermal Comfort Conditions

In this study, the thermal comfort and indoor air quality of post-disaster housing in Bingöl province were investigated. In the first phase of the study, measurements were conducted during the heating periods, and the findings revealed that the comfort conditions were not achieved in the interior spaces of the reference building. In this phase, the residential unit was modelled using dynamic simulation software to evaluate comfort conditions and energy performance simulations across all seasons. Based on the simulation results, improvement proposals were presented to address the identified deficiencies, and the changes implemented in the building were compared with the existing structure to demonstrate the resulting enhancements.

4.2.1. Current Situation Thermal Comfort and Thermal Load Analysis in Post-Disaster Permanent Housing

In this phase of the study, simulations of the building model were performed using the DesignBuilder software to analyse comfort levels as well as the building's annual energy consumption and thermal loads. Initially, a graph illustrating the comfort analysis of the building is presented below in Figure 11. The graph includes five key parameters: temperatures, relative humidity, discomfort hours, PPD (Predicted Percentage of Dissatisfied), and PMV (Predicted Mean Vote) values. These parameters were monitored daily throughout the year. This comprehensive simulation provides insight into seasonal variations in thermal performance and reveals critical deficiencies in user comfort. In particular, discomfort peaks align with both extreme outdoor temperatures and limited passive design interventions. The comfort simulation results also allow triangulation with field data: previously observed low indoor temperatures and insufficient humidity levels during winter are now confirmed via dynamic thermal modelling. This dual validation strengthens the reliability of the findings. Moreover, discomfort hours exceeding four per day across multiple seasons underscore persistent inadequacies in envelope insulation and heating strategy. These issues are especially concerning in the post-disaster context, where construction was expedited, and thermal quality may have been deprioritized. Such analyses can serve as a guide for optimizing the building's HVAC and insulation systems to enhance energy efficiency and ensure occupant comfort.

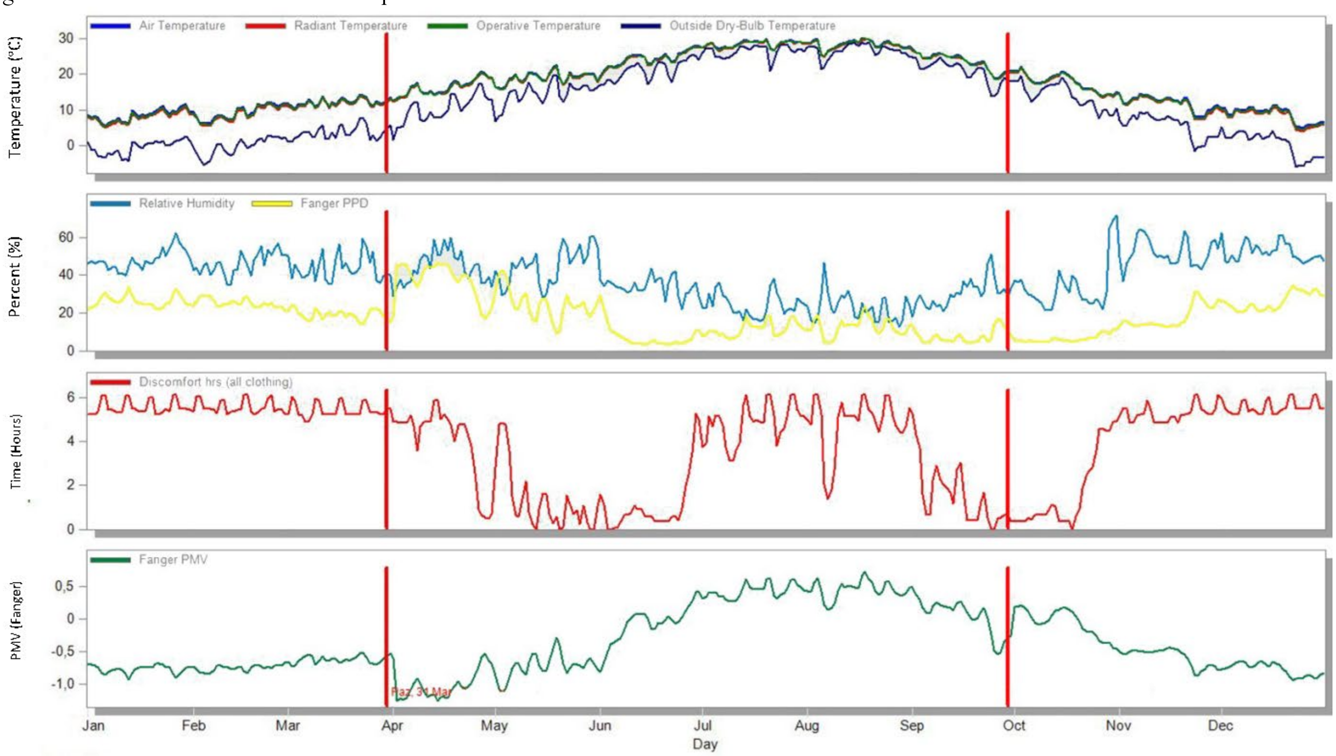


Figure 11 Permanent Disaster Housing current situation comfort analyses

This graph presents the comfort analysis results obtained from the EnergyPlus simulation, which is employed by the DesignBuilder software. The graph displays various temperature and comfort parameters on a daily basis throughout the year (January to December). Using data derived from the EnergyPlus simulation, the indoor comfort levels of a building were analysed over an annual cycle.

The first graph illustrates temperature parameters, including Air Temperature, Radiant Temperature, Operative Temperature, and Outside Dry-Bulb Temperature, over the course of the year. The Outside Dry-Bulb Temperature increases during the summer and decreases during the winter, dropping to approximately -2°C in the colder months and rising to around 30°C during the summer. This variation demonstrates the direct influence of outdoor air temperature on indoor thermal conditions. The Radiant Temperature closely corresponds to the Air Temperature, indicating a balanced thermal environment indoors. Differences between the Outside Dry-Bulb Temperature and the Radiant Temperature are more pronounced in winter and summer, reflecting factors that influence indoor comfort.

The second graph presents Relative Humidity (RH) and the Predicted Percentage of Dissatisfied (PPD). Relative humidity fluctuates between 40% and 50% throughout the year, influenced by outdoor air temperature. It tends to be slightly lower in the winter and relatively higher in the summer. The Fanger PPD (Fanger, 1970), representing the percentage of individuals dissatisfied with thermal comfort, remains generally low throughout the year. This indicates that the thermal environment is mostly acceptable. The PPD values obtained from the building simulation range between 10% and 30%.

The third graph depicts Discomfort Hours, which represent the daily duration during which thermal conditions deviate from the comfort range. Discomfort hours vary between 4 to 6 hours daily. An increase in discomfort hours is observed during summer, likely due to elevated indoor temperatures. Conversely, discomfort hours are comparatively lower in winter. Daily discomfort hours reaching up to six can cause significant dissatisfaction among occupants. This highlights the need for potential improvements in cooling or ventilation systems, particularly during the summer months.

The fourth graph shows the Predicted Mean Vote (PMV), a thermal comfort index. PMV values indicate cooler conditions during winter, ranging from -0.5 to -1, and warmer conditions during summer, approaching +0.5. This pattern reflects indoor thermal conditions perceived as cooler in winter and warmer in summer.

The monthly averages of key parameters are as follows:

- Air Temperature: From an average of 8.35°C in January to approximately 29°C in July and August.
- PPD: Reaches 26% in winter and decreases to 10–15% in summer, suggesting better comfort during the warmer months.
- Discomfort Hours: Approximately 6 hours per day in winter, reducing to 4–5 hours in summer.
- These graphs provide valuable insights into the variations in indoor temperature, humidity, and comfort conditions throughout the year. The influence of outdoor air temperature on indoor comfort is evident, with summer requiring increased cooling interventions and winter demanding additional heating.

For the summer months, discomfort hours can be reduced by optimizing ventilation or cooling systems. During the winter, controlling indoor humidity can enhance thermal comfort. Additionally, improvements in building envelope elements, such as insulation and window systems, can help improve indoor conditions during colder months. This analysis provides essential guidance for optimizing building systems, reducing energy consumption, and improving overall indoor comfort. The energy consumption and thermal loads derived from the simulation of the reference building are presented in Figure 12.

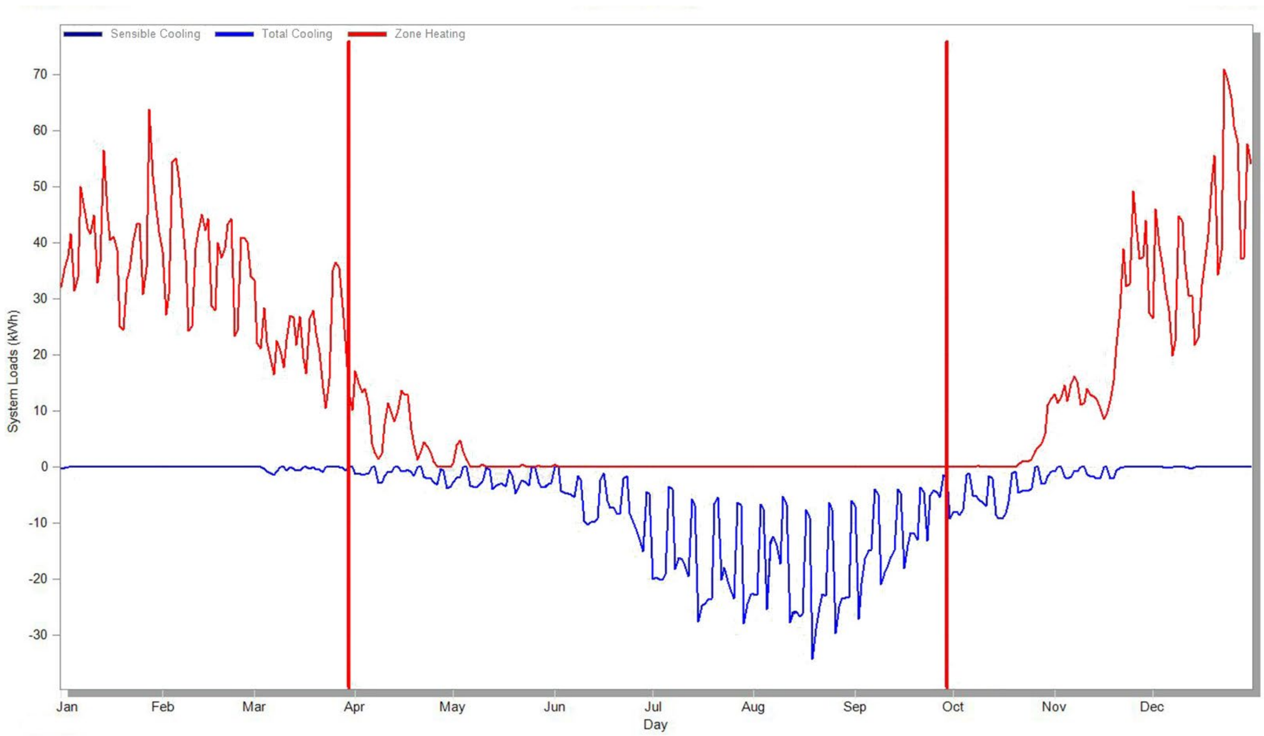


Figure 12 Analysis graph of energy use and thermal loads of the housing

This graph analyses the annual energy use and thermal loads of a building. It categorizes system loads into three main components: Sensible Cooling, Total Cooling, and Zone Heating.

Sensible cooling loads increase during the summer months (June–September), indicating a higher cooling demand due to rising outdoor air temperatures. During summer, sensible cooling loads drop to as low as -30 kWh (negative values may represent energy gains rather than consumption). This suggests that part of the cooling demand is met through natural cooling from external conditions. In the winter months (January–March and October–December), cooling loads are generally negligible as the indoor temperature remains low, eliminating the need for cooling.

Total Cooling: Total cooling loads also increase significantly in the summer months, following a similar trend to sensible cooling. These values encompass both sensible (temperature-related) and latent (humidity-related) cooling loads. The rise in temperature and humidity levels during summer contributes to the increase in total cooling loads.

Heating loads are notably high during the winter months (January–March and November–December), reaching up to 60 kWh in December. This highlights the substantial energy required to heat the building under cold weather conditions. During the summer months (June–September), heating loads are close to zero, as outdoor air temperatures are sufficient to maintain indoor comfort. Seasonal Transitions (March 31 and September 30): Red lines in the graph mark the start and end of daylight-saving time. Following the start of daylight-saving time (March 31), cooling loads increase, while after its conclusion (September 30), heating loads begin to rise. This highlights the impact of seasonal transitions on the building's energy consumption.

- Winter Heating Requirements: Heating loads are significantly high during the winter months, indicating that the majority of the building's energy consumption occurs during this period. Improving wall, window, and roof insulation can help reduce heating loads.
- Summer Cooling Requirements: The increase in cooling loads during summer months can be managed through solar shading strategies (e.g., shading devices or low-transmittance glazing) and enhanced ventilation techniques.
- Seasonal Energy Balance: The graph clearly illustrates the increase in cooling loads during summer and heating loads during winter. Enhancing the building envelope and employing passive design strategies are critical for achieving seasonal energy balance.

This analysis serves as an important guide for evaluating the building's energy performance and optimizing its heating and cooling systems. Appropriate insulation, ventilation, and energy-efficient solutions can help reduce thermal loads during both summer and winter. Additionally, the DesignBuilder dynamic simulation program provides the results of Building Simulations and Thermal Comfort Assessments based on Discomfort ASHRAE 55 (ASHRAE-Standart-55, 2013) 80% and 90% Acceptability (hours). EnergyPlus and similar building performance simulation tools are frequently used for thermal comfort analysis in compliance with ASHRAE 55 (Crawley et al., 2001). From optimization simulations conducted using DesignBuilder, discomfort hours under ASHRAE 55 80% and 90% acceptability criteria were found to be 940 hours and 1271 hours, respectively. Discomfort ASHRAE 55 90% Acceptability (hours): This metric represents the number of hours during which the indoor thermal environment does not meet the 90% acceptability criteria outlined in ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy). This standard aims to ensure that at least 80% of occupants are comfortable in a given indoor environment, while the 90% acceptability criterion represents a stricter evaluation.

- Discomfort Hours: Discomfort hours are periods when indoor conditions fall outside the thermal comfort range specified by ASHRAE 55. This is often assessed using thermal comfort indicators such as the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD).
- PMV: Should range between -0.5 and +0.5.
- PPD: The percentage of dissatisfied occupants should be below 10%.

The simulation results indicate that 1271 hours, equivalent to approximately 15% of the year, fail to meet the ASHRAE 55 90% acceptability criteria. During this time, more than 10% of occupants likely feel too hot, too cold, or otherwise uncomfortable indoors. Potential causes include inadequate insulation in walls, roofs, or windows, leading to indoor temperatures being highly sensitive to seasonal variations. Poor window insulation or external air infiltration could exacerbate these issues. Enhancing wall, roof, and window insulation can improve the balance of indoor temperatures. Tools like EnergyPlus can evaluate the impact of building system and design changes on comfort conditions before implementation. In conclusion, the discomfort hours (1271 and 940) highlight a significant issue in the building's design or operation. Reducing this duration is essential to improving occupant thermal comfort and optimizing energy consumption. Analyses like these are critical for understanding and enhancing building performance.

4.2.2 Comparison of Baseline Condition and Improved Condition

In light of the issues and proposed solutions presented in the previous section, simulations were conducted with improvements made to the envelope materials of the permanent disaster housing, as outlined in Table 2. This section compares the data obtained from these improvements with the existing conditions to reveal the rates of improvement.

The first graph (in Figure 13) above compares discomfort hours. In the Baseline Condition, discomfort hours for General (All), Winter, and Summer clothing is quite high (All: ~1900 hours, Winter: ~1700 hours, Summer: ~1800 hours). This indicates that the current system is not providing adequate thermal comfort for the occupants. In the Improved Condition, a significant reduction in discomfort hours is observed (All: ~1400 hours, Winter: ~1500 hours, Summer: ~1600 hours). The improvements have increased comfort levels throughout the year, although they may still not reach an entirely ideal level. As a result of the improvements, discomfort hours for all clothing have decreased by approximately 7.1%. This decrease can be attributed to improvements in the building insulation and window design. The second graph (in Figure 13) compares the Heating Load (kWh) results for the Baseline Condition and the improved building. In the Baseline Condition, the heating load is quite high (~5500 kWh), indicating that the current system requires high energy consumption to offset heat losses. In the Improved Condition, the heating load is significantly reduced

(~2000 kWh), demonstrating the effectiveness of energy efficiency measures. A reduction of approximately 60% in heating load has been achieved. This improvement can be linked to strengthening the insulation of the building envelope (walls, roofs, and windows). The third graph (in Figure 13) compares the CO_2 Emissions (Kg) rates. In the Baseline Condition, CO_2 emissions are quite high, reflecting a significant contribution from fossil fuel-based energy consumption. In the Improved Condition, CO_2 emissions have been reduced by approximately 15% (~10,500 kg). This reduction in CO_2 emissions demonstrates the positive environmental impact of the energy efficiency measures. However, the emissions are still not at the lowest levels, which may indicate that renewable energy sources are not yet sufficiently utilized. These graphs clearly demonstrate the positive effects of the improvement measures on both building performance and environmental impact (Figure 13 and Table 5).

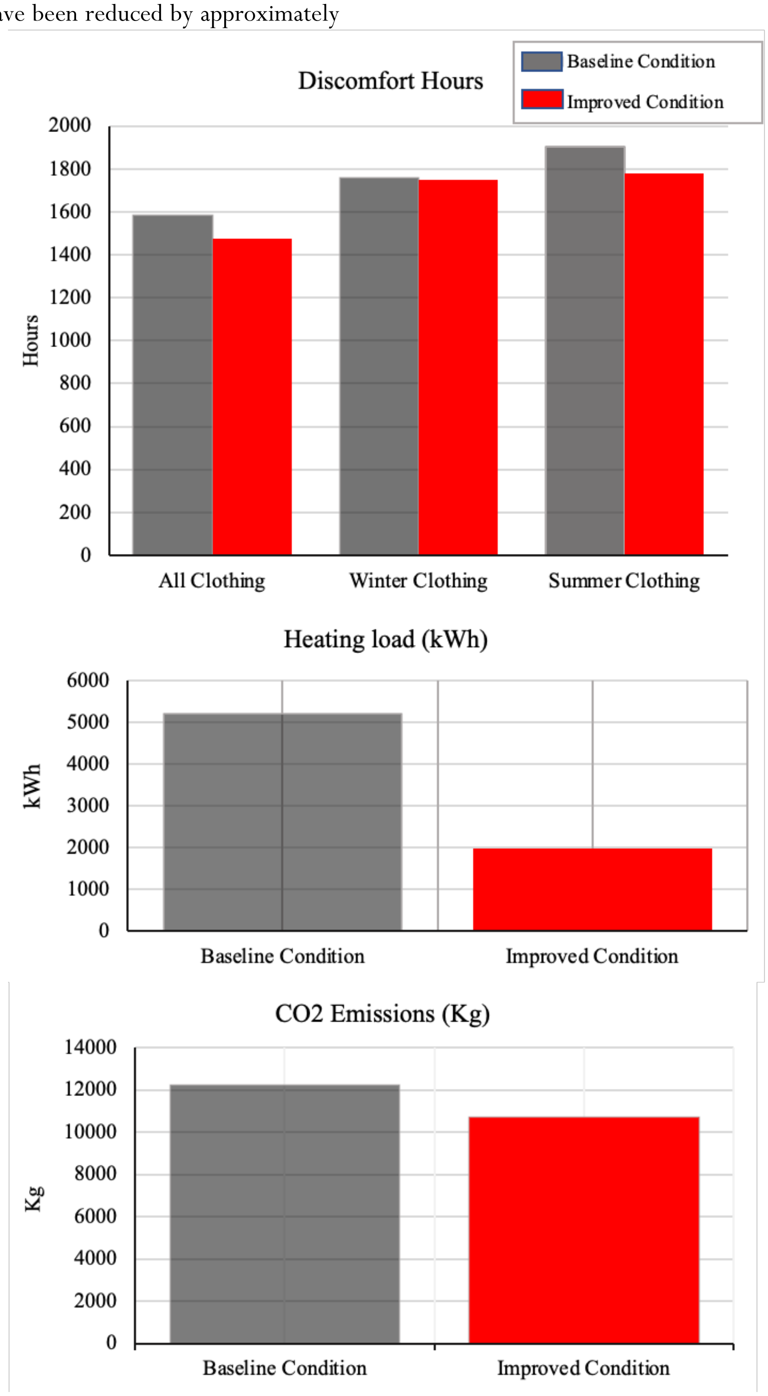


Figure 13. Comparison of discomfort hours, heating load, and CO_2 emissions between baseline and improved envelope conditions based on DesignBuilder simulation results.

Table 5 Baseline vs. Improved Scenario: Discomfort Hours, Heating Load, and CO_2 Emissions

Metric (unit)	Baseline	Improved	Reduction (absolute)	Reduction (%)
Discomfort hours – All clothing (h)	1584.9	1472.7	112.2	7.1%
Discomfort hours – Winter clothing (h)	1759.0	1748.0	10.9	0.6%
Discomfort hours – Summer clothing (h)	1902.2	1776.5	125.7	6.6%
Heating load (kWh)	5206.6	1988.2	3218.4	61.8%
CO_2 emissions (kg)	12249.5	10737.9	1511.6	12.3%

4.2.3 Preliminary Cost–Benefit Analysis

This subsection presents a preliminary cost–benefit appraisal based on the simulated annual reduction in heating energy of 3,218.431 kWh. We adopt a simple-payback method (NIST Handbook 135):

Payback (years) = CAPEX / (Annual saving × unit energy price).

The unit costs used below assume EPS for external walls, glass wool for the roof, PUR for the floor, and replacement with 4–12–4 double glazing. Surface areas are taken from the study geometry and envelope specifications. The CAPEX values derived from unit costs are presented in Table 6

Table 6. CAPEX derived from unit costs (source of unit costs: 2025 National Unit-Price Schedule-EMRA, 2025)

Measure	Unit cost	Area (m²)	CAPEX (TRY)
External wall insulation +4 cm EPS (TR100)	1,325 TL/m³ (converted to m² using 0.04 m thickness)	100.2684	5,314.23
Roof insulation +8 cm glass wool	237.13 TL/m²	99.63	23,625.26
Floor insulation +4 cm PUR	277.50 TL/m²	99.63	27,647.32
Double glazing 4–12–4 (replacement)	1,337.85 TL/m²	11.556	15,460.19
Total			72,047.00

Note: Since the unit price for EPS is given per m³, it was converted to a per-m² basis using a 4 cm thickness to compute CAPEX. All items are approximate values representing material plus typical installation rates.

Based on the reduction calculated in the simulation, the approach adopted below uses the residential tariff to estimate the annual monetary savings and the simple payback. Energy price sensitivity and payback (MEUCC,2025): Annual monetary saving = 3,218.431 × (energy unit price). For the residential tariff, the most appropriate row is: Low Voltage - Residential (above 8 kWh/day) - Single-term - Total tariff excluding capacity charge = 345.1626 kr/kWh ≈ 3.451626 TL/kWh.("Above 8 kWh/day" is selected because 3,218 kWh/year ≈ 8.8 kWh/ day.) Energy price sensitivity and simple payback results are given in Table 7.

Table 7 Energy Price Sensitivity and Simple Payback (Retrofit Package)

Energy unit price (TRY/kWh)	Annual saving (kWh)	Annual saving (TRY)	Total CAPEX (TRY)	Simple payback (years)
3.00	3,218.431	9,655.29	72,047	7.46
3.4516 (residential tariff)	3,218.431	11,108.60	72,047	6.49
4.00	3,218.431	12,873.72	72,047	5.60

Based on these results, the illustrative retrofit package yields a simple payback of ≈6.5 years at the residential single-rate tariff. In addition, the simulation output indicates a reduction of approximately 1.51 tCO_2/yr, demonstrating a clear environmental benefit alongside the economic gain. This analysis is preliminary; a full life-cycle cost (LCC) assessment is recommended, including labor/site costs, maintenance, occupant behavior, and service-life effects.

5. Discussion

The results of this study indicate that post-disaster permanent housing in cold-climate regions, such as Bingöl, Türkiye, fails to consistently meet internationally accepted thermal comfort thresholds. While certain spaces (such as the guest room and Bedroom-2) were able to achieve acceptable indoor temperatures due to the presence of continuously operating stoves, other spaces like the kitchen and Bedroom-1 remained below comfort thresholds throughout the winter. Despite these limitations, residents did not abandon the housing units, nor did they express extreme dissatisfaction, contrasting with several studies in hot-climate post-disaster contexts where thermal discomfort led to increased rates of home abandonment or low occupancy (e.g., Aguilar-Perez et al., 2023). This divergence may be partially explained by cultural adaptation, resource constraints, and behavioural flexibility in colder climates, where

prolonged exposure to seasonal discomfort is more normalized and where residents apply coping strategies to manage it.
Occupant behaviour played a critical role in moderating indoor environmental conditions. As revealed by the field measurements and usage patterns, residents employed targeted heating—focusing their limited resources on key rooms such as the guest room or spaces occupied by older adults—and relied on passive gains in the kitchen through cooking activities and solar exposure. Additionally, demographic shifts such as increased household size and multigenerational living, commonly observed in post-disaster regions like Bingöl, may further complicate thermal comfort needs and indoor air quality expectations. Such adaptive strategies are consistent with findings from Malik et al. (2021) and Shrestha et al. (2023), who emphasize the impact of behavioural patterns on energy use and perceived comfort in low-resource housing environments. While this study did not employ in-depth behavioural surveys, observational insights on room usage and heating practices have been discussed. Future studies should include user-centric analyses to capture behavioural adaptation patterns more comprehensively. Importantly, while many existing studies investigate thermal comfort or indoor air quality in isolation, this research underscores their interdependency, particularly in the context of fuel-based heating. For instance, rooms with wood/coal stoves exhibited not only better thermal conditions but also elevated CO_2 and PM levels, raising long-term health concerns. This duality highlights the trade-offs inherent in current occupant-driven solutions and reinforces the need for integrated approaches that consider both comfort and air quality together.

Although the study is based on a single housing typology and limited seasonal data, the simulation scenarios provide a forward-looking perspective. The proposed envelope retrofit strategies—such as enhanced roof and wall insulation, window upgrades, and floor slab treatment—demonstrated significant reductions in heating demand and discomfort hours. These interventions were selected based on their practicality in post-disaster contexts: they require minimal structural alteration, rely on locally available materials, and offer measurable energy benefits. While a full life-cycle cost analysis was beyond the scope of this study, the simplicity and scalability of the improvements suggest a strong cost-benefit potential, particularly when considered against the long-term economic and health costs associated with continued energy inefficiency and poor indoor conditions. In previous work by Mousavi et al. (2023), similar passive retrofit strategies applied to cold-climate housing resulted in a 55–65% reduction in heating demand, which aligns closely with the 60% reduction observed in our simulations. Moreover, Liu et al. (2023) reported a 5–8% reduction in discomfort hours using BIM-DB simulation techniques, comparable to the 7.1% improvement documented in our scenario analysis. These findings reinforce the consistency and reliability of our DesignBuilder simulation outputs and demonstrate that even modest, locally sourced interventions can achieve measurable thermal performance gains in post-disaster housing contexts. Future studies may build on this framework to quantify financial payback periods and assess large-scale applicability across different climate zones and housing types.

Ultimately, the contribution of this study lies in bridging empirical indoor measurements with simulation-based retrofit modelling, while also accounting for real-world user behaviour. By combining these dimensions in the underexplored context of cold-climate post-disaster housing, the research offers a multi-layered understanding that can inform both design standards and policy frameworks aimed at increasing housing resilience and user well-being.

This study is based on a single-case, single-season (winter) analysis of post-disaster housing in Bingöl, a cold-climate region in Türkiye. While this may limit the generalizability of findings across all geographic or climatic contexts, the chosen case offers a high degree of representativeness for similar post-disaster housing typologies in Eastern Türkiye and other cold continental regions with limited infrastructure and rapid reconstruction practices. The housing units analyzed share common construction features (e.g., insulation level, heating method, ventilation constraints) with standard government-supplied post-earthquake dwellings. Furthermore, behavioral and indoor air quality (IAQ) patterns observed here (such as the use of solid-fuel heating, indoor smoking, and multi-generational occupancy) are prevalent across multiple cold-climate, low-income settings globally. While generalization to warm or temperate climates may not be feasible, the study offers a transferable methodological framework that can be replicated in other contexts. The integration of field measurements with simulation-supported retrofit evaluation provides a scalable approach to diagnosing and improving environmental performance in post-disaster housing worldwide. Future research should extend this framework across multiple seasons and regions to further validate its applicability.

6. Conclusions and Recommendations

This study evaluated thermal comfort and indoor air quality (IAQ) in permanent post-disaster housing in Bingöl, Türkiye, revealing critical deficiencies in energy efficiency and indoor environmental quality during winter. Field measurements showed that indoor temperatures in several rooms did not meet ASHRAE 55 standards, with insufficient humidity and elevated CO_2 and PM levels linked to fossil fuel heating and poor ventilation. Simulation-based retrofit scenarios demonstrated that modest envelope improvements can reduce heating demand by 60%, discomfort hours by 7.1%, and CO_2 emissions by 12.3%.

While the findings are promising, the study has limitations: it was limited to one season and a single housing type and did not include detailed behavioural tracking or cost analysis. Future research should include multi-seasonal monitoring, diverse housing types, and occupant behaviour models to assess long-term effectiveness and real-world feasibility of retrofits.
Based on the results, it is recommended that post-disaster housing design prioritize passive thermal strategies and enhanced ventilation systems. Although ventilation performance was not simulated, enhancements are proposed based on observed IAQ deficiencies and current best practices. Low-cost insulation

improvements and natural ventilation solutions should be integrated early in the design phase. Additionally, occupant awareness regarding indoor air quality and heating behaviour can significantly impact outcomes. Addressing these aspects together may improve comfort, health, and sustainability in disaster-affected communities. Furthermore, this study offers a replicable framework for assessing indoor environmental quality in post-disaster housing by combining empirical measurements with dynamic simulation. This dual-method approach not only addresses a significant research gap in cold-climate contexts but also provides a transferable methodology for similar housing typologies globally. The findings are particularly relevant for architects, engineers, and policymakers aiming to implement cost-effective, energy-efficient retrofits in resource-constrained, post-disaster settings. By integrating user behaviour insights, building performance data, and simulation-driven scenario testing, the research contributes to the growing interdisciplinary discourse on resilient and sustainable housing solutions.

Acknowledgement

This research utilized field measurements conducted under the project number 1919B012304281, supported by the "TUBITAK 2209-A University Students Research Projects Support Program."

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

Reference

AFAD. (2018) All Earthquakes in Turkey, Disaster and Emergency Management Authority, https://www.afad.gov.tr/, Accessed date: 17 September 2018.

Ahmed JA, Yusoff WFM and Mohamed MF. (2025) Validation Field-Measured Data Through Design-Builder Simulation Software of Indoor Air Temperature in a Modern Residential Building in Erbil, Iraq. *Instrumentation Mesure Métrologie* 24(2): 131–141.

Aguilar-Perez Y, Rodrigues L, Beccarelli P, et al. (2023) Post-Occupancy Evaluation in Post-Disaster Social Housing in a Hot-Humid Climate Zone in Mexico. *Sustainability* 15: 13443.

Albadra D, Coley D and Hart J. (2018) Toward healthy housing for the displaced. The Journal of Architecture 23: 115-136.

ASHRAE-Handbook. (1989) Physiological Principles: Comfort and Health.

ASHRAE-Standart-55. (2013) ASHRAE Standard 55 - Thermal Environmental Conditions for Human Occupancy(ANSI Approved), Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

ASHRAE (2020) *ANSI/ASHRAE Standard 55-2020: Thermal Environmental Conditions for Human Occupancy*. Atlanta, GA: ASHRAE.

Boelhouwer, P., & van der Heijden, H. (2018). The effect of earthquakes on the housing market and the quality of life in the province of Groningen, the Netherlands. *Journal of Housing and the Built Environment*, 1-10.

Bernardi N and Kowaltowski DC. (2006) Environmental comfort in school buildings: A case study of awareness and participation of users. *Environment and behavior* 38: 155-172.

Calis G and Kuru M. (2017) Statistical significance of gender and age on thermal comfort: a case study in Turkey. Proceedings of the Institution of Civil Engineers-Engineering Sustainability. 40-51. Thomas Telford Ltd

Chen X, Yang H and Sun K. (2016) A holistic passive design approach to optimize indoor environmental quality of a typical residential building in Hong Kong. *Energy* 113: 267-281.

Crawley DB, Lawrie LK, Winkelmann FC, et al. (2001) EnergyPlus: creating a new-generation building energy simulation program. E*nergy and Buildings* 33: 319-331.

Çulun P, Varolgüneş FK, Özer G, et al. (2022) Thermal Comfort Comparison of Different Dwelling Typologies. *İdealkent* 13: 2677-2701.

Davidson, C. H., Johnson, C., Lizarralde, G., Dikmen, N., & Sliwinski, A. (2007). Truths and myths about community participation in post-disaster housing projects. *Habitat international,* 31(1): 100-115.

Dikmen, N., & Elias-Ozkan, S. T. (2016). Housing after disaster: a post occupancy evaluation of a reconstruction project. *International Journal of Disaster Risk Reduction,* 19, 167-178.

D'Orazio M and Maracchini G. (2019) An experimental investigation on the indoor hygrothermal environment of a reinforced-EPS based temporary housing solution. *Energy and Buildings* 204: 109500.

De Dear R and Brager GS. (1998) Developing an adaptive model of thermal comfort and preference.

Doğangün A. (2004) Performance of reinforced concrete buildings during the May 1, 2003 Bingöl Earthquake in Turkey. *Engineering Structures* 26: 841-856.

Emir S. (2016) The evaluation of thermal comfort on primary schools in hot-humid climates: a case study for Antalya. *European Journal of Sustainable Development* 5: 53-53.

Energy Market Regulatory Authority (EMRA). (2025). Activity-Based Consumer Tariffs. Ankara, Türkiye. Retrieved on October 7, 2025 from https://www.epdk.gov.tr/Detay/Icerik/3-1327/elektrik-faturalarina-esas-tarife-tablolari

Esiyok U. (2006) Energy consumption and thermal performance of typical residential buildings in Turkey. Dortmund, Techn. Univ., Diss., 2007.

Fanger PO. (1970) Thermal comfort. Analysis and applications in environmental engineering. Thermal comfort. Analysis and applications in environmental engineering.

Garg V, Mathur J and Bhatia A. (2020) *Building energy simulation: A workbook using designbuilder*™: CRC Press.

Gür M and Sezer FŞ.(2018) Indoor Comfort Condıtıons in Terms of User Satısfactıon For Mıddle-Income Groups: The Case of Ataevler, Bursa, Turkey.

Halıcı F. (2019) Kalorifer ve Havalandırma Tesisatı (Isı Yalıtımı ve Örnek Proje). Birsen Yayınevi.

Hamilton, N. (2012). Post-disaster shelter: A studio-based response to emergency shelter in natural disaster zones. Sustainable futures: Architecture and urbanism in the global south, Kampala, Uganda, 2730.

Hou C, Hu W, Jiang Y and Gao W. (2024) Optimization and renovation design of indoor thermal environment in traditional houses in Northeast Sichuan (China)—A case study of a three-section courtyard house. *Sustainability* 16(7): 2921.

ISO-7730. (2005). *Ergonomics of the thermal environment–assessment of the influence of the thermal environment using subjective judgement scales.* ISO: Geneva, Switzerland.

Johnson, C. (2007). Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey. *Habitat international,* 31(1): 36-52.

Kaihoul A, Pitzalis E, Sriti L, Di Turi S, Amraoui K. (2024) Enhancing thermal comfort assessment: A sensitivity study of PMV-PPD and adaptive models in an Algerian reference hotel across different climate zones. *Indoor and Built Environment.* 33(9): 1680-1704. DOI:10.1177/1420326X241266762

Kaplan H, Yilmaz S, Binici H, et al. (2004) May 1, 2003 Turkey—Bingöl earthquake: damage in reinforced concrete structures. *Engineering Failure Analysis* 11: 279-291.

Khovalyg D, Kazanci OB, Halvorsen H, et al. (2020) Critical review of standards for indoor thermal environment and air quality. *Energy and Buildings* 213: 109819.

Kuru M and Calis G. (2017) Understanding the relationship between indoor environmental parameters and thermal sensation of users via statistical analysis. *Procedia Engineering* 196: 808-815.

Kürüm Varolgüneş, F. (2021). Post-disaster permanent housing: the case of the 2003 Bingöl earthquake in Turkey. *Disaster Prevention and Management,* 30(2): 77-93.

Liu Y, Li T, Xu W, et al. (2023) Building information modelling-enabled multi-objective optimization for energy consumption parametric analysis in green buildings design using hybrid machine learning algorithms. *Energy and Buildings* 300: 113665.

Malik J, Bardhan R and Banerji P. (2021) Understanding the Effect of Occupant Behaviour on Thermal Comfort and Energy Use in Slum Rehabilitation Housing. *Urban Science and Engineering: Proceedings of ICUSE 2020.* Springer, 287-295.

Malik J, Bardhan R, Hong T, et al. (2020) Contextualising adaptive comfort behaviour within low-income housing of Mumbai, India. *Building and Environment* 177: 106877.

Mihara K, Cheung T, Ono E, Arisaka S and Hasama T. (2025) Longitudinal analysis of thermal responses: A comparative study of home and office environments in Singapore and Japan. *Building and Environment* 280: 113108.

Ministry of Environment, Urbanization and Climate Change (MEUCC), (2025). Unit prices (EPS, glass wool, PUR, and window replacement rates). Ankara, Türkiye.

Mousavi S, Gheibi M, Wacławek S, et al. (2023) Low-energy residential building optimisation for energy and comfort enhancement in semi-arid climate conditions. *Energy Conversion and Management* 291: 117264.

Nagano K and Mochida T. (2004) Experiments on thermal environmental design of ceiling radiant cooling for supine human subjects. *Building and Environment* 39: 267-275.

Nocera F, Castagneto F and Gagliano A. (2020) Passive house as temporary housing after disasters. *Renewable Energy and Power Quality Journal (RE&PQJ)* 18: 42-47.

NIST (2022). Handbook 135: Life-Cycle Costing Manual for the Federal Energy Management Program.

Özbey MF and Turhan C. (2022) A comprehensive comparison and accuracy of different methods to obtain mean radiant temperature in indoor environment. *Thermal Science and Engineering Progress* 31: 101295.

Özdamar M and Umaroğulları F. (2017) Bir Ofis Yapısı Örneğinde Isıl Konfor ve İç Hava Kalitesinin İncelenmesi. *Megaron* 12.

Peacock, W. G., Dash, N., Zhang, Y., & Van Zandt, S. (2017). Post-disaster sheltering, temporary housing and permanent housing recovery. In Handbook of Disaster Research. 569-594. Springer.

Shaman J, Pitzer VE, Viboud C, et al. (2010) Absolute humidity and the seasonal onset of influenza in the continental United States. P*los Biology* 8: e1000316.

Shrestha B, Uprety S, Pokharel JR, et al. (2023) Study on the Winter Thermal Environment and Thermal Satisfaction of the Post-Disaster Prototype and Vernacular Houses in Nepal. *Buildings* 13: 2430.

Turhan C and Gokcen-Akkurt G. (2018) Assessment of thermal comfort preferences in Mediterranean climate: A university office building case. *Thermal Science* 22: 2177-2187.

Wang Z. (2006) A field study of the thermal comfort in residential buildings in Harbin. *Building and Environment* 41: 1034-1039.

Wong LT, Mui KW and Hui P. (2008) A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices. *Building and Environment* 43: 1-6.

Varolgüneş, S. (2025). A bibliometric analysis of the 2023 Kahramanmaraş Earthquakes: trends, gaps, and policy implications. *Natural Hazards*, 1-25.

Yaman GÖ. (2023) The effect of building facades window/wall ratio and window properties on energy performance. *Journal of the Faculty of Engineering and Architecture of Gazi University* 38: 851-863.

Yaman GÖ, Varolgüneş FK and Çulun P. (2021) Investigation of thermal comfort in university offices: The case of the Bingöl University. *Civil Engineering and Architecture,* 9 (7): 2441-2451.

Yilmaz Z. (2006) Akilli binalar ve yenilenebilir enerji. Tesisat Muhendisligi Dergisi,(91): 7-15.

Zhai P, Li J, Lei T, Zhu J and Novakovic V. (2025) Indoor thermal comfort comparison between passive solar house with active solar heating and without active solar heating in Tibetan. *Energy and Built Environment* 6(2): 285–296.

Republic of Türkiye Ministry of Environment, Urbanization and Climate Change. (2024).Geographical Situation of Bingöl Province. Retrieved on18 April 2024 from https://bingol.csb.gov.tr/cografi-durumu-i-1393