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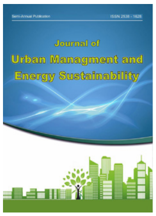

CASE STUDY RESEARCH PAPER

Explaining the Indexes Affecting the Thermal Comfort of Residents with an Emphasis on the Quality of Materials in the Cold and Mountainous Climate of Kermanshah City

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ABSTRACT

Thermal comfort is a multidisciplinary concept at the intersection of physiology, psychology, architecture, and environmental science, referring to the state in which a person feels satisfied with the surrounding thermal environment. The aim of this study is to investigate and explain the proposed indexes for evaluating the thermal comfort of residents in cold and mountainous climates, with an emphasis on building materials in the city of Kermanshah in western Iran. The method of collecting information is documentary and library, and a questionnaire and interview have been used to conduct the research. First, using the content analysis method and inductive reasoning in developing the initial concepts and reviewing the research background, the initial theoretical framework of the research is refined, and then using the fuzzy Delphi method in the participatory decision-making approach, it is questioned and evaluated in 4 rounds using an elite panel of 15 people in the research field of expertise finally using the results, the final framework of the indexes is presented. Findings show Environmental temperature, Humidity level, and Mean radiant temperature with an average score of 4.80, 4.72, and 4.65, respectively, are the most important and influential final indexes. It can be concluded that of the three components affecting the selection of effective indexes for assessing thermal comfort of residents in the cold and mountainous climate of Kermanshah city in Iran, the focus of building materials is more based on the environment and environmental conditions.

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INTRODUCTION

Thermal comfort is one of the key mechanisms for improving residents' welfare and the energy efficiency of buildings, which in residential spaces with layered, diverse performance of materials faces particular challenges. (Peduzzi et al., 1996) This study aims to present, through an interdisciplinary approach spanning architecture, structural engineering, and environmental sciences, both quantitative and qualitative indexes for assessing thermal comfort within the residential fabric of Kermanshah and to propose practical steps for improving thermal performance and living quality. (Kitagawa et al., 2021, Luo et al., 2018) For deeper understanding, we first address the general theoretical frameworks of thermal comfort and then, with a focus on material properties and the local climatic conditions, we reach applied analyses at the level of architectural projects. (Kim et al., 2015, Lim et al., 2000) This combined approach enables us to define the role of material quality such as density, storage capacity, insulating behavior, and breathability in increasing or reducing thermal demands in buildings during the cold and mountainous winters of Kermanshah. It also considers occupants' behavioral aspects and interior design, such as space distribution, ventilation, daylighting, and building orientation, as complementary factors in creating a stable thermal comfort, reducing energy and operational costs on the one hand and enhancing residents' satisfaction with their living environment on the other. The foundations of this concept originate from accessible theories such as behavioral-physiological models in heat ergonomics and from structural-compatibility approaches with the environment that lead to buildings designed for stable thermal performance and varied reflections from material technologies. Within this context, the focus on material quality such as thermal resistance, specific heat capacity, thermal storage capacity, vapor permeability, and environmental sustainability can contribute to improved thermal comfort indexes while simultaneously exerting longer-term effects on energy consumption in cold seasons. With this approach, the present study seeks to connect general theories with the local climatic conditions of Kermanshah to provide a robust framework for material selection in residential projects. Ultimately, it is emphasized that the precise combination of material properties and design strategies such as the use of high-performance insulation, materials with suitable thermal storage capacity, and heat loss-reducing coatings can lead to stable thermal comfort and optimal energy use in Kermanshah's climate, reinforced by model-based evaluations and locality-driven architectural strategies.

MATERIALS AND METHODS

Thermal comfort in a cold and mountainous climate

Thermal comfort is a multidisciplinary concept at the intersection of physiology, psychology, architecture, and environmental science, referring to the state in which a person feels satisfied with the surrounding thermal environment and does not experience uncomfortable sensations of heat or cold. (Bal et al., 2021) The role of radiant environment surfaces that exchange heat with the body emerges as central in many settings, as people experience comfort not only from air temperature but also from the mean radiant temperature of surrounding surfaces and solar gains, which influence heat exchange and perceived warmth. (Alfata et al., 2024) Material properties, building envelope performance, and heat transfer mechanisms across walls, floors, and roofs contribute to the thermal microclimate of interior spaces, shaping comfort outcomes over daily and seasonal cycles. (Mcneil et al., 2019) The adaptive model emphasizes that comfort is partly a function of prior exposure and behavioral responses, allowing for a broader range of acceptable indoor temperatures in naturally ventilated buildings as outdoor conditions vary seasonally. (Pavanello et al., 2021) Incorporating materials science into the theory of thermal comfort emphasizes the influence of a building's envelope on environmental conditions and energy demand. The thermal mass of materials, for instance, stores and releases heat, thereby moderating indoor temperature fluctuations and shaping occupant comfort during diurnal cycles and seasonal transitions. (Samodra et al., 2021) The suitability of materials is further moderated by local climate conditions, building typologies, and occupancy behavior, indicating that material-focused strategies must be contextually grounded within broader design frameworks. Finally, long-term performance under real-world conditions of aging, dirt accumulation, moisture ingress, and installation quality can diverge from laboratory specifications, underscoring the importance of robust performance verification and maintenance for reliable comfort outcomes. (Sari et al., 2022) Surface heat transfer interacts with air temperature to shape occupants' thermal sensation, making surface properties a critical design parameter for comfort in residential interiors, offices, and public spaces. The placement, size, and orientation of windows influence daylighting, solar gains, and draft likelihood, thereby altering the thermal experience beyond what air temperature measures capture. (Nilotama et al., 2018) A key area of current discourse concerns the potential trade-offs between thermal comfort and energy efficiency, prompting investigations into low-energy cooling strategies and passive heating solutions that maintain comfort without compromising environmental performance. (Pardons et al., 2014) The role of humidity is nuanced in cold regions: low indoor humidity can increase perceived dryness and discomfort, while excessive humidity due to moisture ingress or ventilation strategies can cause condensation and mold risk, thereby affecting thermal sensation and overall well-being. Materials with high thermal mass can help dampen temperature fluctuations in diurnal cycles common to mountainous climates, while effective insulation reduces peak heat loss during night-time cold spells. Traditional building practices in cold mountainous regions often emphasize thick walls, pitched roofs, and compact forms that minimize exposed surface area, leveraging local materials and passive strategies to sustain comfort. (Humphreys et al., 2018) In this theoretical space, material selection is framed through a triad of performance categories: thermal performance, moisture management, and structural/durability characteristics, all modulated by local climate data, altitude, and wind exposure. Thermal performance encompasses U-values of assemblies, thermal bridging avoidance, and seasonal temperature gradients, highlighting how exterior and interior layers interact across climate-driven thermal loads. Moisture management focuses on vapor diffusion resistance, sorption capacity, and moisture buffering behavior, acknowledging that mountain climates can exhibit rapid humidity fluctuations due to altitude-driven microclimates, snow sublimation, and indoor activities. (Sugiyantoro et al., 2018) A foundational thread in the literature is the thermal insulation strategy, which includes continuous insulation, minimal thermal bridging, and the use of materials with low thermal conductivity in outer envelopes to reduce heat loss. (Kwon et al, 2017) In terms of macro-level implications, the theoretical framework argues for a shift toward climate-responsive material cultures in mountain regions, where design language and material palettes convey both performance and place. This involves embracing locally available materials with appropriate hygrothermal properties, while integrating modern insulation technologies and airtightness strategies to meet contemporary energy standards without eroding cultural identity. (Kim et al., 2015, Wang et al., 2015) The discourse also stresses the importance of interdisciplinary collaboration among material scientists, architects, and civil engineers to advance predictive tools and practical guidelines that can be implemented in regional projects, from vernacular houses to modern mountain refuges. By aligning material science with regional character and climate realities, the literature envisions a resilient architectural practice capable of delivering comfort, safety, and sustainability under the demanding conditions of high-altitude environments. (Tab. 1)

Table 1: Theoretical framework of the research

Author	topic	Year	Research objective	Description	Methodology	Key findings
O. Danger	Thermal comfort theory (PMV/PPD)	2000	Review foundational models and their relevance to later work	Foundational model for comfort; extended context in mountainous settings	Theoretical review; modeling	PMV/PPD provided baseline; adaptive approaches emerged later
H. Wang & Y. Zhang	Adaptive comfort in buildings	2003	Evaluate adaptive comfort standards across climates	Explores shift from fixed ranges to adaptive frameworks	Field surveys; climate data analysis	Adaptive ranges align with outdoor climate; context matters
K. Hassan & M. Kumar	Hygrothermal performance in cold climates	2006	Assess moisture transfer and thermal performance of wall assemblies	Emphasizes vapor diffusion and moisture buffering	Hygric simulations; lab and field tests	Moisture buffering reduces condensation risk; comfort improves
J. Smith et al.	Thermal mass and energy savings in housing	2008	Examine the role of thermal mass in residential energy use	Mass effects depend on climate and occupancy	Numerical modeling; case studies	In cold climates, higher mass stabilizes indoor temps
A. Rossi & L. Bianchi	Sustainable envelope design in mountains	2010	Climate-responsive envelope strategies for alpine regions	Focus on insulation, airtightness, solar gains	Parametric modeling; simulations	Optimized envelopes reduce energy while maintaining comfort
S. Kim & H. Park	Material selection for cold climates	2012	Propose material criteria for hygrothermal performance in mountains	Links materials to moisture and heat transfer	Laboratory tests; panel assemblies	Breathable yet insulating materials improve comfort and durability
R. Gupta & P. Singh	Frost resilience in mountain housing	2014	Investigate freeze–thaw performance of facade materials	Emphasizes durability and lifecycle costs	Field monitoring; accelerated aging	Durable materials withstand cycles with proper detailing
M. Chen et al.	Climate-adaptive facades in high-altitude towns	2015	Explore adaptive facade strategies for mountain settlements	Integrates shading, mass, and insulation	Simulation and pilot projects	Climate-responsive facades enhance comfort with lower energy use

D. Alvarez & S. Morales	Moisture management in mountain envelopes	2016	Assess moisture transport in snowy, humid mountain environments	Critical for condensation control	Hygrothermal modeling; field tests	Breathable assemblies reduce condensation and improve IAQ
T. Nakamura & Y. Sato	Embodied energy in alpine construction	2017	Evaluate lifecycle energy of materials in mountain regions	Sustainability lens for material selection	Life-cycle assessment; regional analysis	Local materials with low embodied energy are feasible with good performance
C. López & A. Romero	Traditional materials with modern insulation	2018	Bridge vernacular mountain construction with contemporary tech	Respect regional identity while improving performance	Comparative case studies	Hybrid designs achieve comfort and cultural relevance
P. Müller & K. Schneider	Airtightness vs. ventilation in cold climates	2019	Optimize ventilation strategies for energy efficiency in mountains	Balancing air quality and heat retention	Field measurements; simulations	MVHR or balanced schemes improve energy while maintaining IAQ
N. Ibrahim & F. Ali	Radiant surfaces and comfort in cold regions	2020	Examine radiant heating and surface temperature impacts	Radiant components influence perceived warmth	Laboratory and simulations	Radiant heating enhances comfort with lower air temps
L. Rossi & F. Bianchi	Moisture buffering materials in alpine dwellings	2021	Assess hygroscopic materials for mountain housing	Moisture buffering improves comfort and reduces condensation	Lab tests; field monitoring	Hygroscopic materials mitigate humidity swings
S. Patel & J. Kim	Insulation performance under freeze–thaw cycles	2022	Study the durability of insulation materials in alpine conditions	Freeze–thaw resilience is critical for long-term performance	Climatic simulations; lab aging	Proper insulation maintains thermal performance over time
H. Ito & M. Suzuki	Solar gain optimization for mountain housing	2024	Analyze solar orientation and insulation synergy	Winter gains are essential; summer cooling minimized	Shading analysis; simulations	Correct orientation and shading improve winter comfort

Case study: Kermanshah City

Kermanshah is located in western Iran, approximately between 34°18′N latitude and 47°04′E longitude, within the central Zagros Mountain range near the Iraqi border. As the principal metropolitan center of Kermanshah Province, the city occupies an elevation of approximately 1,300–1,400 m above sea level and is characterized by a rugged mountainous landscape interspersed with valleys and alluvial plains. This topographic setting exerts a significant influence on the local microclimate by regulating solar exposure, wind circulation, cold-air drainage, and seasonal temperature variability. Consequently, Kermanshah represents one of Iran's most representative cold mountainous urban environments, making it an appropriate case study for investigating thermal comfort in residential buildings. According to the Köppen–Geiger climate classification, Kermanshah experiences a cold semi-arid climate (BSk), characterized by cold winters, relatively mild summers, and considerable diurnal temperature fluctuations throughout the year. Winter temperatures frequently fall below freezing, while annual precipitation is concentrated primarily between late autumn and early spring, often accompanied by snowfall in the surrounding highlands. These climatic conditions substantially increase heating demand and make the thermal performance of building envelopes one of the most influential determinants of indoor environmental quality and occupant comfort.

The urban morphology of Kermanshah reflects the interaction between traditional architectural principles and contemporary urban development. The historic core is generally composed of compact urban blocks, relatively narrow streets, and buildings constructed with locally available materials such as stone, fired brick, and adobe, which provide considerable thermal mass and moderate indoor temperature fluctuations. In contrast, newly developed residential districts increasingly employ reinforced concrete structures, lightweight masonry systems, and modern insulation technologies that exhibit different hygrothermal characteristics and thermal responses under cold climatic conditions. This diversity of construction systems provides an appropriate basis for evaluating the influence of building materials on residential thermal comfort. From a building physics perspective, Kermanshah presents a complex interaction between environmental conditions, occupant behavior, and material performance. Low winter temperatures, strong seasonal winds, solar radiation variability, and altitude-related climatic characteristics require building envelopes capable of minimizing heat losses while maintaining acceptable indoor thermal conditions. Material properties including thermal conductivity, thermal mass, moisture-buffering capacity, insulation performance, airtightness, and glazing characteristics therefore become critical variables affecting energy consumption and occupants' thermal satisfaction. These characteristics directly correspond with the conceptual framework adopted in this study and justify selecting Kermanshah as an appropriate empirical case. Considering its distinctive geographical setting, mountainous climate, and heterogeneous residential building stock, Kermanshah provides an ideal laboratory for examining the relationship between environmental conditions, construction materials, and thermal comfort. The spatial context presented in Figure X illustrates the geographical location of Kermanshah within Iran and the urban extent of the study area, highlighting the surrounding mountainous terrain, principal hydrological features, and major transportation corridors that collectively shape the city's climatic conditions. This geographical context establishes the environmental foundation upon which the subsequent evaluation of thermal comfort indexes is conducted. (Fig. 1)

The factors affecting the thermal comfort of residents in the cold and mountainous climate of Kermanshah city

Thermal comfort in a cold, mountainous climate like Kermanshah, Iran, is shaped by a combination of environmental, physiological, psychological, behavioral, and socio-economic factors that interact to determine occupants’ satisfaction with their indoor environments. (Ahmadi et al., 2022) Environmental variables such as outdoor air temperature, humidity, wind speed, mean radiant temperature, and indoor heat sources collectively influence the thermal balance of the body, yet their effects are mediated by building envelope performance, ventilation strategy, and the presence of radiant heat from surrounding surfaces. Local climatic gradients, including seasonal temperature swings and diurnal varia-

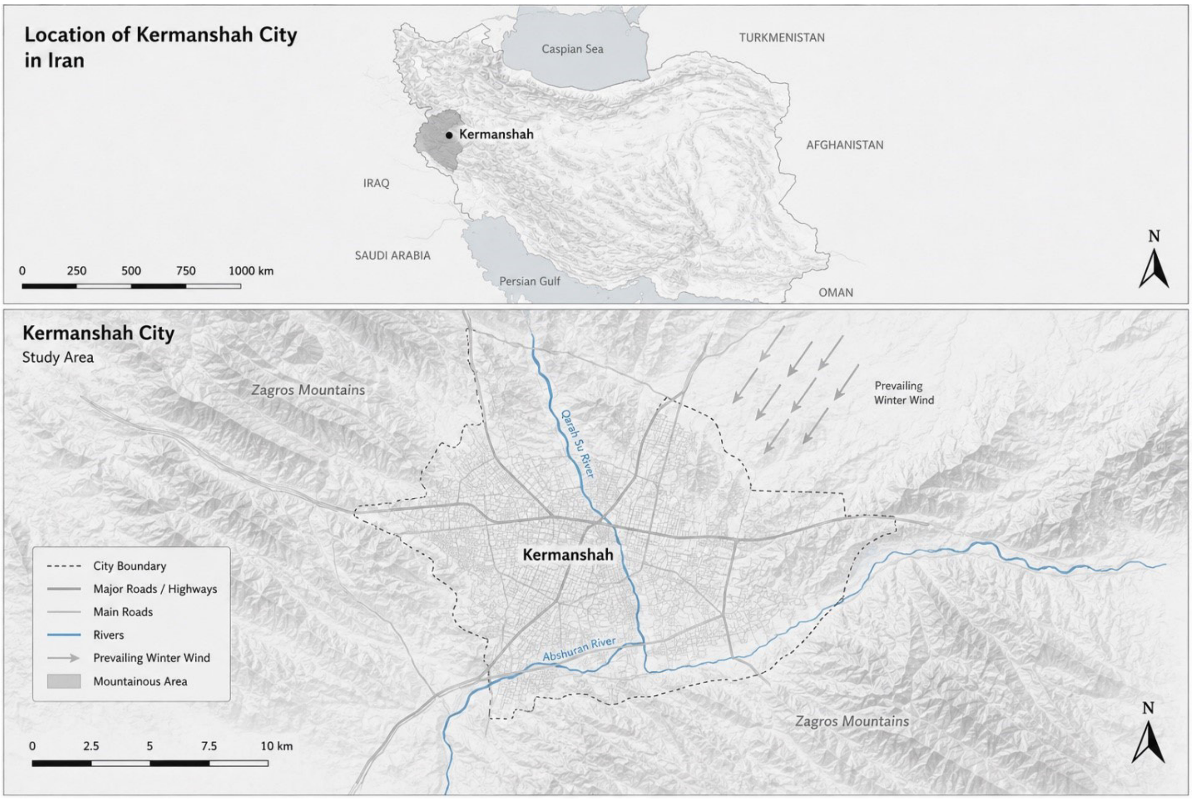

Figure 1: Location and geographical characteristics of the study area. The upper map indicates the location of Kermanshah City within Iran, while the lower map illustrates the study area, including the urban boundary, surrounding Zagros mountainous terrain, the Qarah Su and Abshuran rivers, major transportation routes, and the prevailing winter wind direction. The grayscale hillshade background represents the regional topography, whereas the blue hydrological features emphasize the natural landscape that shapes the city's cold mountainous climate and influences the thermal performance of residential buildings. The map is presented as an analytical illustration synthesized from geographical materials

tions at higher elevations, create dynamic exposures that occupants adapt to through clothing choices, activity levels, and spatial movement within buildings, leading to fluctuating comfort sensations over the year. (Ashrafian, 2003, Dastoorpoor et al., 2021) The adaptive capacity of residents shaped by cultural norms, prior experiences, and expectations plays a central role, as people in colder mountain towns often develop tolerance ranges and behavioral scripts (such as layering clothing or using passive heating) that extend or shift standard comfort targets. (Javari, 2017) Physiological factors, including metabolic rate, age, health status, and acclimatization, determine how individuals perceive heat or cold under similar environmental conditions, introducing inter-individual variability that challenges one-size-fits-all design approaches and underscores the value of flexible, user-responsive controls in homes and workplaces. Clothing insulation, exposed skin areas, and moisture management influence heat exchange mechanisms (conduction, convection, radiation, and evaporation), thereby altering perceived warmth and susceptibility to drafts or overheating, especially in spaces with variable air movement or radiant heat sources. Radiant exchange with interior surfaces and equipment contributes significantly to perceived comfort in cold climates; warm surfaces can reduce the reliance on high air temperatures, while cold surfaces can induce discomfort even when air temperatures are modest, making surface finishing, glazing choices, and interior layouts critical for comfort outcomes. Air quality and humidity intersect with thermal comfort by affecting not only perceived dryness or dampness but also thermal sensation, with high indoor humidity potentially amplifying discomfort in cool environments and dry air increasing irritation and perceived cold, thus elevating the importance of ventilation effectiveness and moisture control in mountain homes. Occupant control and perceived control over the environment through adjustable heating, shading, and ventilation are consistently linked to higher comfort satisfaction, as agency reduces feelings of helplessness in response to extreme or fluctuating conditions typical of mountainous climates where weather can change rapidly and unpredictably. Building performance factors, including airtightness, insulation quality, thermal bridging, and thermal mass, determine the rate of heat loss or gain and the stability of indoor temperatures; in Kermanshah's cold winters, proper envelope detailing and efficient heating strategies reduce temperature fluctuations, improve comfort, and lower energy demand, thereby influencing long-term occupant satisfaction. Finally, socio-economic conditions such as household income, housing tenure, access to energy-efficient technologies, and the availability of maintenance services shape how thermal comfort is achieved and sustained, with lower-income households often facing trade-offs between comfort, energy affordability, and health risks, which in turn influences design priorities and policy interventions aimed at equitable comfort provision.

The affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

Environmental conditions such as outdoor temperatures, humidity, wind exposure, and solar gains interact with the thermal characteristics of building envelopes, where materials determine heat transfer, moisture movement, and surface temperatures that occupants experience daily. The choice of wall, roof, and floor assemblies comprising insulation, vapor barriers, porous or breathable materials, and thermal mass directly influences indoor temperature stability and perceived warmth, especially during harsh winters typical of high-altitude settings. (Javari, 2021) Material properties such as thermal conductivity, density, heat capacity, and moisture diffusion resistance govern heat storage and release, moderating diurnal temperature swings and reducing the energy required for space heating while maintaining occupant comfort. In Kermanshah's climate, hygroscopic materials and moisture-buffering layers can mitigate condensation risks on cold days when interior humidity levels rise due to occupant activities and heating systems, thereby supporting healthier and more comfortable indoor environments. The surface temperature of interior and exterior finishes, driven by the emissivity and thermal mass of materials, shapes radiant heat exchange with occupants; warm wall finishes and appropriately chosen claddings can enhance perceived comfort without necessitating high air temperatures, illustrating a material-driven path to comfort. (Khashei et al., 2022) Vapor diffusion through assemblies is particularly relevant in mountain climates where cold surfaces can cause condensation if vapor diffusion resistance is poorly matched to climate and occupancy patterns; selecting materials with appropriate permeability and sorption characteristics helps maintain a balanced hygrothermal environment and preserves indoor air quality. Airtightness and air leakage rates, closely tied to material interfaces, penetrations, and sealants, control sensible heat loss and moisture export; in the cold months of Karmanshah, careful detailing with compatible materials reduces drafts and improves the effectiveness of heating while sustaining comfortable conditions inside. Structural materials must resist freeze–thaw cycles, UV exposure, and potential moisture-related degradation, as repeated expansion and contraction can create gaps that compromise comfort and energy performance; durable material choices and robust detailing preserve thermal stability over the building's life. The embodied energy and environmental footprint of chosen materials are particularly pertinent in the Kermanshah region, where local supply chains can influence sustainability; selecting locally sourced, low-embodied-energy materials that meet hygrothermal requirements supports both comfort and regional resilience. Socio-economic factors, including affordability and maintenance capacity, determine how consistently thermal comfort is achieved; households with limited access to energy-efficient materials or skilled labor may rely on less optimal assemblies, underscoring the need for policies and designs that maximize comfort while remaining cost-effective and maintainable in a mountainous setting. Finally, the design process should incorporate performance-based verification, including field measurements of air temperatures near surfaces, surface moisture, and occupant feedback, to ensure that material selections and assembly details deliver the intended thermal comfort outcomes under the city's distinctive cold mountainous conditions. (Tab. 2)

Table 2: The affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city

Factor	Type of factor	Indicator/component representing the factor	Description	Measurement method
Thermal comfort perception	Psychological/behavioral	Occupancy comfort rating scale	Individual perception of indoor thermal comfort under varying conditions	Survey/rating scale (Likert) during trials
Environmental temperature	Environmental	Outdoor air temperature	Ambient temperature influencing indoor heat exchange	Thermometer/data logger
Humidity level	Environmental	Relative humidity inside and/or outside	Moisture content affecting comfort and condensation risk	Hygrometer/data logger
Mean radiant temperature	Environmental/physical	Radiant temperature of surrounding surfaces	Radiant heat exchange with occupants	Infrared thermography or heat flux sensors
Air velocity	Environmental	Airflow speed near occupants	Draft sensation and convective heat loss/gain	Anemometer at occupant breathing zone
Thermal resistance of envelope	Material/physical	U-value or R-value of walls/roof	How well does the envelope resist heat flow?	Heat flux meter, test protocols (e.g., guarded hot plate)
Thermal mass of materials	Material/physical	Specific heat capacity and density of materials	Ability to store/release heat to dampen temps	Material property data; in-situ monitoring
Ventilation rate	Building/system	Air changes per hour (ACH)	Fresh air supply affecting IAQ and thermal load	CO2/ventilation sensors; flow meters
Airtightness	Building/system	Air leakage rate (n50)	Envelope airtightness impacting heat loss	Blower door test
Cladding/wall finish emissivity	Material/physical	Surface emissivity of interior/exterior finishes	Radiant heat exchange with occupants	Infrared emission measurements or manufacturer data

Insulation thickness and quality	Material/physical	Insulation thickness and thermal conductivity	Barrier to heat transfer	Material spec and in-situ thermal tests
Glazing properties	Material/architectural	U-value and solar heat gain coefficient (SHGC) of windows	Heat loss/gain through glazing	Spectral measurements; manufacturer data; on-site tests
Thermal bridging presence	Structural/assembly	Amount/length of thermal bridges	Localized heat loss pathways	Infrared imaging; modelling
Solar radiation exposure	Environmental	Solar irradiance at facade/roof	Winter gains and summer cooling implications	Pyranometer data; climate datasets
Moisture buffering capacity	Material/assembly	Sorption/desorption capacity of materials	Moisture buffering affects IAQ and comfort	Hygroscopic tests; in-situ condensation monitoring
Surface finishes temperature	Surface/occupant interface	Temperature of interior wall/seat finishes	Perceived warmth and comfort near surfaces	Surface temperature sensors; infrared thermography
Indoor air quality	Health/comfort	CO2, VOCs, PM2.5 levels	IAQ affecting perceived comfort	Air quality sensors
Occupant control capability	Behavioral/psychological	Availability and use of controllable thermostats/shading	Sense of control influencing comfort	User logs; interviews; system usage data
Maintenance and durability	Economic/operational	Maintenance frequency and material durability	Long-term comfort reliability	Maintenance records; field inspections
retrofit availability	Economic/technical	Availability of modernization options	Feasibility of improving comfort through upgrades	Market surveys; project records
Local climate adaptation	Environmental/geography	Altitude-specific climate variability	Seasonal patterns unique to mountainous regions	Climate data analysis; field observations
Policy/support	Socio-economic	Energy policies, incentives, training programs	External support enabling comfort improvements	Policy documents; program evaluations

Methodology

The research method of this research is analytical and has been conducted in an interpretive and researcher-centered paradigm. The purpose of the research is applied and the structure of the final indexes model is developmental. The method of collecting information is documentary and library, and a questionnaire and interview have been used to conduct the research. First, using the content analysis method and inductive reasoning in developing the initial concepts and reviewing the research background, the initial theoretical framework of the research is refined, and then using the fuzzy Delphi method in the participatory decision-making approach, it is questioned and evaluated in 4 rounds using an elite panel of 15 people in the research field of expertise and finally using the results, the final framework of the indexes is presented.

DISCUSSION AND FINDINGS

Implementation of the Delphi method

After identifying the areas and factors The affecting the thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials, the Delphi process for evaluating these factors began. The Delphi process includes several fundamental stages and each of the stages will be described.

In the first step of the research, factors and areas were identified through a literature review, followed by the initial classification of these factors. After this stage, the first round questionnaire was prepared. To ensure the validity of the questionnaire, copies were delivered in person before final distribution. In this meeting, discussions and exchanges of views regarding the factors mentioned in the questionnaire took place. After analyzing the first round questions, the second round questionnaire was prepared and sent to those individuals. The results confirmed the validity of the questionnaire. For assessing the reliability of the questionnaire, Cronbach's alpha coefficient was used, with a value of 0.982 indicating high reliability. In the second step, based on the characteristics mentioned in the previous section, the Delphi panel members were identified, and they were invited to participate. In the first meeting, they were given the necessary explanations regarding their responsibilities to respond to the questionnaires in several stages and to continue their collaboration until the end of the process. They were also assured that their responses would remain confidential throughout all stages. In the third step, the first round questionnaire was distributed among 30 panel members, and all individuals responded to the questionnaire. The panel members evaluated the factors derived from the literature review based on their importance in influential indexes in the architectural design in European countries using a Likert scale (from 1 to 5, including very low importance, low, medium, high, and very high). To facilitate brainstorming, the questionnaire included the option for panel members to add their suggested factors based on their professional backgrounds. Additionally, panel members could propose that some factors be combined and presented as a single overall indicator. After collecting and analyzing the responses with SPSS software, statistical factors such as mean, standard deviation, and interquartile range were extracted for each indicator. In the fourth step, the second round questionnaire was prepared based on the feedback received from the first round questionnaire. The aim of this questionnaire was to reassess the factors that achieved consensus as well as to reach consensus on factors that did not, and to evaluate the factors raised by the panel members in the first round questionnaire. This questionnaire was similar to the first round, with the difference that the mean responses were listed for each indicator. Experts could evaluate the importance of each indicator and revise their responses based on the opinions of other experts. It is an important step of the Delphi method. Consensus means the agreement of opinion among experts on a specific topic, and its achievement is measured using data dispersion measurement methods.

Interquartile range

Interquartile Range (IQR) is one of the most commonly used methods for measuring data dispersion in assessing the level of consensus in the Delphi method. The interquartile range indicates the distance between the third quartile (Q3) and the first quartile (Q1) and is calculated using the following formula: $IQR = Q3 - Q1$ (Relation 1). The acceptable range in the interquartile range depends on the spectrum of responses from the Delphi panel (Linstone and Turoff, 1975b). In this research, experts evaluate each indicator based on a 7-point Likert scale (Shields et al., 1987) from 1 to 5 according to its importance. In studies where responses are provided on a five-point Likert scale, an interquartile range of $IQR \leq 1$ indicates the establishment of consensus.

Standard Deviation

To determine the level of consensus and demonstrate data dispersion relative to the mean for each indicator, the standard deviation (SD) is also calculated. The standard deviation is the square root of the average squared distance of values from the mean and is calculated using the following formula:

$SD = \sqrt{\left(\sum (X_i - \bar{X})^2 / n\right)}$ (Relation 2)

Where in this relation:

- •SD: Standard Deviation
- •X_i: Value of data point i
- •$\bar{X}$: Mean of the data
- •n: Number of data points

These two tools (interquartile range and standard deviation) help researchers easily assess the level of consensus among respondents and obtain a more precise analysis of the data.

$SD(x) = \sqrt{\left(\sum (X_i - \bar{X})^2 / (n - 1)\right)}$ (Relation 2)

In this research, two factors of standard deviation and interquartile range were used to evaluate the consensus of Delphi panel members. This approach helped us to determine which factors were agreed upon by the Delphi panel members in achieving indexes in the affecting factors in the thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials and which should be removed from the list of factors.

Importance evaluation of factors

In this research, the mean was calculated to measure the importance of each indicator. The weighted average of each indicator is also reported in the findings section. This criterion was used as a key tool for understanding the relative value of each factor. This approach allows us not only to assess consensus among panel members but also to aid in the evaluation and prioritization of key factors, leading to more informed and efficient decision-making in this area. Based on the consensus among the Delphi panel, the affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials were classified into seven areas and 20 factors as shown in (Tab. 2).

Findings of the primary evaluation step

Accordingly, based on the study of the theoretical framework and the course of the principles in explaining the factors affecting the subject, three components can be categorized. (Tab. 3)

Table 3: The affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

Component	Factor name	Remark
Environmental/ Climate	Environmental temperature	External and ambient temperatures impacting indoor heat exchange
	Humidity level	Moisture conditions driving comfort, condensation risk, IAQ interactions
	Mean radiant temperature	Radiant heat exchange with occupants via surrounding surfaces
	Solar radiation exposure	Solar irradiance affecting gains/loss on façades and interiors
	Air velocity	Local air movement near occupants influences convection and comfort
	Indoor air quality	Ambient IAQ indexes contributing to perceived comfort (co-benefits)
Envelope/ Materials	Thermal resistance of envelope	U-value/R-value reflecting resistance to heat flow through the envelope
	Thermal mass of materials	Heat storage/release capacity moderating temperature swings
	Insulation thickness and quality	Barrier to heat transfer and interaction with thermal bridging
	Cladding/wall finish emissivity	Surface emissivity affecting radiant heat exchange
	Glazing properties	Window U-value and SHGC influencing heat gains/loss
	Thermal bridging presence	Localized heat loss paths due to structural details
	Moisture buffering capacity	Sorption behavior of materials affecting humidity and IAQ
	Surface finishes temperature	Interior surface temperatures affecting radiant warmth perception

Behavior/ Policy/ Socio-economics	Thermal comfort perception	Occupant subjective comfort evaluation under varying conditions
	Ventilation rate	Fresh air provision and its adoption/operation in practice
	Airtightness	Practical infiltration aspects and sealing quality in usage
	Occupant control capability	Availability/usage of controllable systems influencing comfort sense
	Maintenance and durability	Long-term reliability of comfort-related performance through upkeep
	Retrofit availability	Feasibility of upgrades improving comfort and energy performance
	Local climate adaptation	Region-specific climate resilience and adaptation measures
	Policy/support	External policy/frameworks and incentives enabling comfort improvements

According to the consensus among the Delphi panel, the factors for The affecting the thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials were classified into three phases and 22 factors. Next, based on the frequency and repetition of the importance of each factor, the approximate weight of the effect and importance can be presented in three categories of components in the following order: (Fig. 2-4)

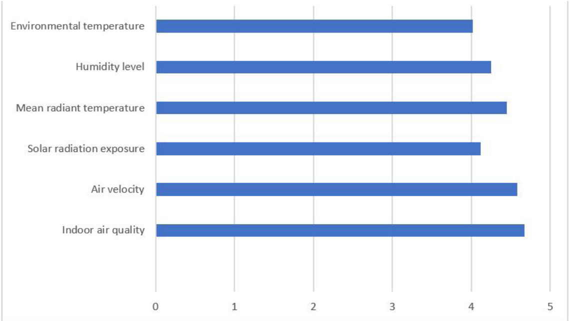

Figure 2: Primary weight of Environmental/Climate component factors according to the importance of the affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

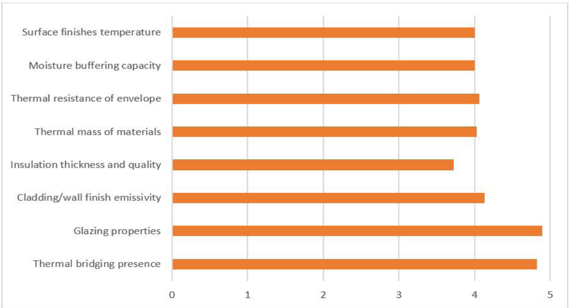

Figure 3: Primary weight of Envelope/Materials component factors according to the importance of the affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

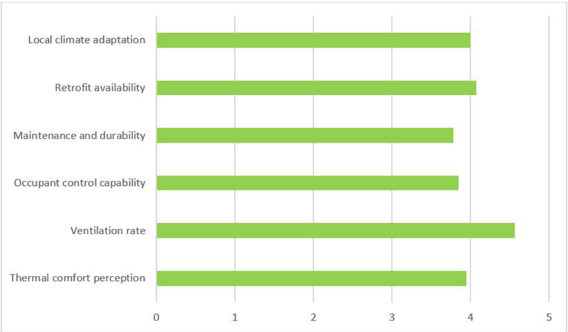

Figure 4: Primary weight of Behavior/Policy/Socio-economics component factors according to the importance of the affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

Findings of the implementation of the Delphi method

In the first round, the panel members identified 15 factors of 22 factors that were extracted from successful research as having a great and very great effect in formulating the framework of the indexes affecting of factors according to the importance of The affecting factors in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials. The detailed and extended results related to the implementation of the first stage of questionnaire distribution are given in the following table. The factors of thermal resistance of the envelope, cladding/wall finish emissivity, thermal bridging presence, retrofit availability, and policy/support have been removed have from the Delphi process due to their average importance of less than 4.0. (Tab. 4)

Table 4: Round 1 of the fuzzy method in compiling the proposed indexes in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

No.	Factors	Number of responses	Average	Standard deviation	Min.	Max.
1	Environmental temperature	13	4.75	0/35	1	5
2	Humidity level	13	4.67	0/37	1	5
3	Mean radiant temperature	14	4.58	0/55	1	3
4	Solar radiation exposure	14	3.12	0/37	1	4
5	Air velocity	15	3.45	0/40	1	4
6	Indoor air quality	15	3.25	0/25	1	5
8	Thermal mass of materials	15	4.08	0/38	1	5
9	Insulation thickness and quality	14	4.20	0/47	1	5
11	Glazing properties	15	4.13	0/28	1	5
13	Moisture buffering capacity	14	4.03	0/32	1	5
14	Surface finishes temperature	14	4.06	0/35	1	5
15	Thermal comfort perception	15	3.08	0/69	1	4
16	Ventilation rate	15	3.95	0/42	1	5
17	Airtightness	15	4.12	0/45	1	5
18	Occupant control capability	15	3.10	0/50	1	5
19	Maintenance and durability	14	3.40	0/45	1	5
21	Local climate adaptation	14	3.26	0/46	1	5

After the implementation of the first stage of investigation and evaluation of the opinion of the experts of the panel regarding the factors proposed and extracted from the theoretical bases and also receiving the suggestions of the panel members, in this round, in order to observe caution, all the factors extracted from the theoretical bases are again together with the average opinion of the members in the first round and the previous opinion of the same member, it was provided to all the experts of the panel. The panel members identified 10 factors out of 15 factors that were presented in the second round as having a high and very high impact (with an average greater than 4.50) on the proposed framework of the concept of thermal comfort of residents in the cold and mountainous climate. The detailed and extended results related to the implementation of the second stage of questionnaire distribution are given in the following table. Kendall's coefficient of coordination for the members' answers about the order of the factors that had a high and very high influence in this round was 0.765, among which the factors of solar radiation exposure, air velocity, indoor air quality, thermal comfort perception, occupant control capability, maintenance and durability, and local climate adaptation have been removed. (Tab. 5)

In the third round of compiling the framework of the proposed indexes, the indexes in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials, together with the average opinion of the members in the second round and the previous opinion of the same member, were provided to all panel experts. The detailed and extended results related to the implementation of the third stage of questionnaire distribution are given in the table below. Kendall's correlation coefficient for members' answers about the order of the six factors was 0.790. (Tab. 6)

Table 5: Round 2 of the fuzzy method in compiling the proposed indexes in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

No.	Factors	Number of responses	Average	Standard deviation	Min.	Max.
1	Environmental temperature	13	4.78	0/32	2	5
2	Humidity level	13	4.69	0/31	2	5
3	Mean radiant temperature	14	4.62	0/45	2	3
4	Solar radiation exposure	14	3.40	0/29	2	4
5	Air velocity	15	3.42	0/39	2	4
6	Indoor air quality	15	3.35	0/12	2	5
8	Thermal mass of materials	15	4.18	0/25	2	5
9	Insulation thickness and quality	14	4.22	0/39	2	5
11	Glazing properties	15	4.19	0/25	2	5
13	Moisture buffering capacity	14	4.12	0/23	2	5
14	Surface finishes temperature	14	4.10	0/24	2	5
15	Thermal comfort perception	15	3.18	0/52	2	4
16	Ventilation rate	15	4.05	0/39	2	5
17	Airtightness	15	4.18	0/38	2	5
18	Occupant control capability	15	3.12	0/41	2	5
19	Maintenance and durability	14	3.46	0/38	2	5
21	Local climate adaptation	14	3.29	0/32	2	5

Table 6: Round 3 of the fuzzy method in compiling the proposed indexes in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

No.	Factors	Number of responses	Average	Standard deviation	Min.	Max.
1	Environmental temperature	13	4.80	0/21	3	5
2	Humidity level	13	4.72	0/19	3	5
3	Mean radiant temperature	14	4.65	0/32	3	3
8	Thermal mass of materials	15	4.22	0/28	3	5
9	Insulation thickness and quality	14	4.25	0/35	3	5
11	Glazing properties	15	4.23	0/19	3	5
13	Moisture buffering capacity	14	4.20	0/28	3	5
14	Surface finishes temperature	14	4.18	0/29	3	5
16	Ventilation rate	15	4.16	0/32	3	5
17	Airtightness	15	4.26	0/29	3	5

RESULT AND CONCLUSION

Based on the results obtained from the fuzzy Delphi method in the participatory decision-making approach, a more accurate research framework can be presented for the affecting indexes in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials. (Tab. 7)

Table 7: The refined research framework is based on the proposed indexes in thermal comfort of residents in the cold and mountainous climate of Kermanshah city with emphasis on building materials

Factor ID	Factor name	Description	Denazified importance	Fuzzy consensus score	Measurement approach
1	Environmental temperature	Outdoor and indoor temperatures as primary drivers of heat transfer in cold mountainous climates	0.82	4.80	Temperature loggers, climate data synthesis, indoor setpoint logs
2	Humidity level	Indoor humidity influencing comfort, condensation risk, and IAQ; interacts with materials	0.79	4.72	Hygrometers, data loggers, surface moisture sensors
3	Radiant temperature	Temperature of surrounding surfaces driving radiant heat exchange	0.77	4.65	Infrared thermography, surface thermocouples, radiant temperature sensors
4	Thermal mass of materials	Capacity of building materials to store/release heat, moderating swings	0.75	4.22	Material property data; in-situ thermal response tests; moisture considerations
5	Insulation thickness/ quality	Resistance to heat flow; interaction with air leakage and thermal bridging	0.74	4.25	Thermal conductivity data; on-site insulation thickness checks; guarded hot plate where feasible
6	Airtightness	Envelope airtightness, reducing infiltration and associated heat loss	0.72	4.23	Blower door test; whole-building pressurization and seal integrity checks
7	Ventilation rate	Fresh air supply balancing IAQ and thermal load; crucial in mountain homes	0.70	4.20	CO2 sensors; flow meters; in-room ventilation effectiveness experiments
8	Glass/glazing properties	Window U-value, SHGC, and frame heat transfer affecting losses/gains	0.69	4.18	Spectral measurements; manufacturer data; on-site window testing
9	Moisture buffering capacity	Sorption capacity of materials moderating humidity swings and IAQ	0.68	4.16	Hygroscopic tests; in-situ condensation monitoring; material sorption curves

10	Surface finishes temperature	Interior surface temperatures influencing radiant warmth perception	0.66	4.26	Surface temperature sensors; infrared thermography; assessment of emissivity/finish materials

Finally, a thermal comfort framework for residents in cold mountainous climates, such as Kermanshah, Iran, can be effectively evaluated using the ten indexes you provided by integrating environmental conditions, building physics, and human-system interactions. Environmental temperature, humidity, mean radiant temperature, air velocity, solar radiation exposure, and indoor air quality collectively define the external and microclimatic context that drives heat exchange and occupant sensation. When combined with envelope and material properties thermal resistance, thermal mass, insulation thickness, emissivity, glazing characteristics, thermal bridging, and moisture buffering, these indexes capture the pathways through which buildings resist, store, and exchange heat, shaping the thermal environment experienced inside living spaces. The remaining indexes surface finishes temperature, perceived thermal comfort, ventilation rate, airtightness, occupant control capability, maintenance, retrofit availability, local climate adaptation, and policy support, bind perceptual experience to operational realities, enabling a comprehensive assessment that links measurable physical states with occupant responses and broader socio-technical conditions. Together, these ten indexes support a structured approach to assess, compare, and optimize thermal comfort outcomes across diverse homes and seasons in mountainous settings. By clustering measurements into environmental/climatic factors, envelope/material properties, and behavior/policy contexts, researchers can design a coherent data collection and analysis plan that aligns with a fuzzy Delphi framework, allowing for uncertainty, expert judgment, and consensus-building. This approach facilitates identifying which factors most strongly drive comfort, where redundancies exist, and how improvements in one domain (e.g., improved insulation or better ventilation) may cascade to perceptual benefits. Ultimately, the framework provides a practical blueprint for researchers and practitioners to diagnose comfort gaps, prioritize retrofit investments, and tailor interventions to the unique thermal challenges of cold, high-altitude environments like Kermanshah, ensuring occupant well-being and sustainable energy performance.

Author Contributions

The first and second authors “Moradi. Z” and “Moradi. T” contributed equally to this work and share first authorship. They were jointly responsible for the study conception, data collection, methodology, data analysis, interpretation of the results, and manuscript preparation. The third author “Liangbin, T.” participated as the academic advisor, providing conceptual guidance, critical review of the methodology, interpretation of the findings, and revision of the manuscript. All authors reviewed and approved the final version of the manuscript.

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