How To Stay Warm in Cool New Dwellings: A Socio-Technical Investigation of Building Modernization, Cold Stress, and Redesign Strategies in Northern Pakistan

by

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A dissertation accepted and approved in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

in Environmental Sciences, Studies, and Policy

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Fall 2025

DISSERTATION ABSTRACT

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Doctor of Philosophy in Environmental Sciences, Studies, and Policy

Title: How To Stay Warm in Cool New Dwellings: A Socio-Technical Investigation of Building Modernization, Cold Stress, and Redesign Strategies In Northern Pakistan

Contemporary dwellings, built with concrete, steel, and glass, are widely replacing traditional earth- and vegetation-based construction in developing regions worldwide, while new spatial configurations are also diverging from traditional designs. These changes have diminished dwellings' ability to provide thermal shelter through passive means for residents in both hot and cold climates. Proposals to resolve the issue have primarily taken a technical approach, advocating for the revival of traditional building methods and the adoption of modern, energy-efficient ones. However, onsite, these proposals are rarely adopted due to social and economic factors: traditional methods are seen as outdated, structurally weak, and aesthetically unappealing, while modern solutions are expensive and local builders lack the skills to use them. Yet, thermal stress resulting from housing transitions remains unexplored from a combined social and technical perspective in the developing world. This study aims to propose design and policy strategies, informed by people's lived experiences, practical constraints, and accessible resources, to improve warmth in dwellings of the cold-arid Hunza Valley in Northern Pakistan. First, the changes in construction methods and spatial configuration, residents' thermal experiences, and their thermal adaptation strategies are investigated using housing documentation, field observations, and interviews. Findings reveal that housing transitions occurred iteratively, with residents selectively adopting new elements while making adjustments and retaining traditional strategies guided by experience-based concepts of thermal processes. However, these experience-based understandings were limited, underscoring the need to complement these efforts with scientific knowledge to help residents develop more thermally effective solutions. Next, construction-related decisions of owner-builders are investigated using surveys and interviews, interpreted through Maslow's hierarchy of needs to understand the motivations behind selecting contemporary houses despite thermal stress. Relationship needs were prioritized the most initially, driving the selection of multi-room plans that enabled separate spaces for family interactions, guest reception, and private activities. The resulting large housing footprints led owner-builders to select cheaper contemporary construction materials, resulting in greater heat losses. Nonetheless, thermal stress experiences prompted owner-builders to make post-construction adjustments to their houses and to place greater emphasis on addressing thermal needs for future constructions. Finally, building energy simulations were used to identify heat gain and loss processes in traditional and contemporary structures, and to accordingly improve the adaptation strategies already employed by people to enhance heat retention in houses. The tested retrofit strategies yielded substantial improvements, revealing the potential of supplementing occupant-devised adaptations with scientific knowledge to address the thermal stress problem. The findings highlight the potential relevance of combining social insights with technical analysis for improving housing comfort in other developing contexts.

Supplementary information on interview and survey questions, building materials' thermal properties, and EnergyPlus modeling inputs is included. This dissertation includes previously published and coauthored material.

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Y. Imtiaz, A.R. Rempel, Trading cozy old homes for chilly new ones: How experiences and beliefs guide housing modernization in Northern Pakistan, Energy Res. Soc. Sci. 118 (2024) 103814. https://doi.org/10.1016/j.erss.2024.103814.

ACKNOWLEDGMENTS

I am grateful to my advisor, Professor Alexandra Rempel, for her exceptional guidance and support throughout this Ph.D. Her intellectual, logistical, and financial support enabled me to pursue an ambitious research goal, including in-person and remote fieldwork halfway across the world, and to undertake multiple methodological approaches on my project. Her generosity with time, her rigor in research and writing, and her strong commitment to helping me succeed have shaped every aspect of this work. From conceptual development to research design to writing, revisions, and our first publication together – none of this would have been possible without her guidance, mentorship, and insight.

I am sincerely thankful to Prof. Yizhao Yang for stepping in to support me during the development of my second research paper. Her guidance, encouragement, and kindness were deeply meaningful and played an important role in strengthening my work and in enabling me to present my research internationally at the EDRA conference.

I am grateful to my committee members, Prof. Lamia Karim, Prof. Howard Davis, and Prof. Erin Moore, for their invaluable feedback, perspectives, and support throughout this doctoral journey. I have been fortunate to have a committee that was consistently generous with its time and support whenever I needed it.

I'm especially grateful to my parents and my interlocutors in Hunza, Rohaila Noor, Misbah Noor, Annie Khan, and Malaika Haq, whose time and generosity in assisting with on-ground coordination, instrument installation, and survey facilitation allowed this project to continue across distance. I am deeply grateful to the households in Hunza who welcomed me into their homes. Their openness in sharing their lived experiences and their willingness to allow interviews, surveys, and the installation of field instruments in their houses made this research possible. This work builds on their knowledge, insight, and everyday expertise, and I profoundly appreciate their generosity, trust, and time.

I am grateful to all my friends, and especially Dr. Jamila Baig, for being a part of this journey at different points. Each one provided emotional support that carried me through this work. I want to thank my husband, whose belief in me has been stronger than my own, who encouraged me to pursue this Ph.D. and made personal sacrifices so that I could do this work, and my son, who is a constant source of joy in my life.

I acknowledge the financial support provided by the David Easley Memorial Award, Center for Asian and Pacific Studies (CAPS) Small Professional Grant, Environmental Studies Soderwall Fund, Environmental Studies Summer Research Fellowship, First-year Graduates Fellowship, and Lokey Graduate Science Award. I am thankful to the Pakistan Meteorological Department for providing weather data for my study site, the Hunza Valley.

DEDICATION

This dissertation is dedicated to the people of Hunza; to my community, my roots, and my greatest source of inspiration; and to our ancestors, whose vision and hard work nurtured a community that continues to grow and excel despite many challenges.

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I. INTRODUCTION

1. Background

Traditional buildings: Providing shelter from weather conditions, including heat, cold, rain, and wind, is a fundamental function of housing that is essential to human survival and productivity. Accordingly, traditional housing construction methods worldwide evolved to provide maximum shelter from regional climatic conditions. To do this, they used locally sourced materials, heating and cooling techniques that minimized the need for fuels, and often, designs with separate spaces for use during contrasting seasons [1–3]. For example, in the hot-humid regions of Southeast Asia, traditional houses employed large overhanging reed roofs to shield against solar radiation, and they used elevated floors and perforated walls to promote air circulation [4]. In the hot, arid regions of Sub-Saharan Africa, thick earthen walls with small openings moderated daily temperature fluctuations [5]. Similarly, in Iran, basements and north-facing rooms in traditional houses provided cooler temperatures than other spaces during the hottest periods [6]. In cold sub-Arctic regions, compact buildings combined cooking and living spaces to use internal heat gains for warmth. These were built with earth-bermed walls, turf roofs, and small openings to minimize heat losses [7–9]. In the Andean regions of Peru, likewise, tiled roofs, with local herbaceous plants used as insulation, helped retain the heat [10].

Housing modernization: In developing regions globally, however, climate-specific building techniques are largely being abandoned in favor of new construction methods that utilize industrially produced materials such as concrete, metals, and glass [10–13]. Studies in Africa and South Asia have reported that these materials are favored because they are more durable than natural materials such as mud, wood, and grasses, and they allow construction to take place more easily, cheaply, and quickly, as they require less onsite preparation and labor [13–17]. Additionally, traditional dwellings are often seen as less aesthetically appealing than their contemporary counterparts, as they seem outdated and structurally precarious [18–20].

Furthermore, studies from Africa and Asia have reported that contemporary houses can provide greater daylight, ventilation, and hygiene, since they reduce habitats for pathogens and mold [6,20–22]. Contemporary dwellings are also favored because they often separate areas based on activities, such as cooking, living, and sleeping, to enhance privacy and convenience for the inhabitants [20]. Yet these modern dwellings often lack climate-responsive features and rely heavily on mechanical heating and cooling systems to maintain habitable indoor temperatures.

Mechanical HVAC and fuel poverty: In regions where energy is available for mechanical heating and cooling, this dependence increases building-related energy consumption, which in turn increases global greenhouse gas emissions [23–27]. In cold, energy-poor regions, however, this problem is even more acute. In the absence of reliable electricity or clean energy sources, households often resort to fuels such as kerosene, coal, or biomass for heating, which emit substantial quantities of particulate matter [28,29]. In some cases, even these fuels are not available, leading to extreme thermal stress that compromises occupant well-being [30,31]. Therefore, improving buildings' thermal performance is crucial both for reducing energy consumption and emissions and for alleviating occupants' thermal stress [30,32].

Heat stress in modern homes: The problem of thermal comfort associated with building transitions is widely documented in warm regions. For example, dwellings constructed with metal sheet walls and roofs were 2 to 4 °C hotter than traditional stilt houses with thatched roofs and planked floors in rural Bangladesh and Indonesia [14,33]. In Algeria, vernacular adobe houses were found to be cooler, resulting in almost 40% less energy consumption than contemporary air-conditioned concrete-built houses [24]. In the Middle East, traditional courtyard houses with thick clay walls, well-shaded openings, and effective ventilation were naturally cool, unlike modern apartments and villas that required air conditioning [12,22,25,34]. Contemporary houses built with metal sheet roofs in Sub-Saharan regions remained ~10 °C warmer than traditional houses built with mud walls and thatched roofs [35]. In India's composite climate region, temperatures in vernacular houses built with local materials varied between 19 and 22 °C annually, whereas temperatures in contemporary houses built with bricks and concrete ranged between 12 and 34 °C [36].

Cold stress in modern homes: Although few studies have compared the thermal environments of traditional and contemporary housing in cold climates, those that do exist have found that contemporary construction reduces thermal comfort in these cases, as well. For example, in Nepal and eastern Turkey, residents living in traditional houses reported higher levels of thermal satisfaction [37,38]. In the Tibetan region of China, residents of traditional housing demonstrated better thermal adaptation to cold climates [39]. Additionally, in the Himalayan regions of India, modern houses, built with bricks and concrete, maintained lower indoor temperatures and required greater heating compared to traditional earthen houses [40,41]. Furthermore, in Andean Ecuador, the transition from mud and cane construction to concrete, metal, and glass has led to greater fluctuations in indoor temperatures, presumably due to reduced thermal mass and increased envelope thermal transmittance in the new dwellings [42]. Additionally, the ability of traditional dwellings to capture and retain warmth indoors has been highlighted by various studies. For example, in the Himalayan regions of Nepal and India, compact layouts, sun-facing orientation, and thick, thermally massive walls resulted in warm interiors [43–46]. In contrast, in the cold regions of Pakistan, Nepal, and central Mexico, low indoor temperatures in contemporary houses have been reported to cause thermal stress and a continuous need for indoor heating [47–49].

Proposed solutions: Interestingly, several studies in rural China have reported traditional houses to be cold during winter, and recommended modern interventions such as enhanced envelope insulation and double-glazed windows for better heat retention [50–54]. However, these recommendations reflect rising standards of living in China, as well as growing expectations for indoor temperatures of 20 °C or greater [55,56]. In cold regions of India and Nepal, in contrast, indoor air temperatures as low as 10 °C are often reported to be comfortable in traditional houses, as residents achieve thermal comfort through adaptations such as combining cooking and living, consuming warm foods, and wearing multiple layers of clothing [57,58]. Moreover, modern dwellings in such regions tend to have even lower indoor temperatures and fewer opportunities for behavioral adjustments. Consequently, researchers have proposed two main solutions: modern technical strategies, such as insulating roofs and walls with EPS and XPS foam [9,49,59–63], and reviving traditional architectural practices such as the use of earthen walls, sheep wool, and thatch for insulation [17,64–66].

2. Research gap

Limitations of technical solutions: Despite the thermal stress in contemporary housing, proposals for contemporary technical interventions and the reintroduction of traditional building methods are not widely adopted in practice. Technical solutions are limited by high construction costs and a lack of required construction skills among local builders [52,60,67], while re-adoption of traditional methods is limited by the perception of traditional constructions as structurally weak, requiring greater maintenance [15,16,18,68,69], and aesthetically unappealing [11]. Some studies have also found that re-adoption proposals can be expensive and difficult, as the expansion of contemporary building practices and materials has diminished both access to traditional materials and the cultivation of the skills needed to use them [15,21,70].

No socio-technical studies in the developing world: These limitations show that technological interventions alone are not enough. It is, therefore, essential to address thermal comfort in conjunction with social, behavioral, and technological factors, including housing needs, aspirations, values, everyday living practices, the availability of building materials, and their associated costs. In developed countries, socio-technical studies on the adoption and effectiveness of low-energy homes have highlighted the influences of personal, social, and cultural factors [72,73]. These studies demonstrate that experience-based knowledge plays a pivotal role in shaping the ways in which occupants utilize energy in their homes, and that this knowledge evolves alongside individuals' needs, social norms, and material environments [74,75]. Furthermore, in addition to thermal comfort, factors such as autonomy in modifying one's home, control over indoor conditions, aesthetics, and access to daylight are also important for comfort [76]. In contrast, in developing countries, such interactions between housing and its inhabitants remain largely unexplored.

3. Region of study

This research investigates the thermal stress caused by housing transitions in cold regions, specifically focusing on the Hunza Valley in Northern Pakistan, addressing the gap in the literature described above. The Hunza Valley is a cold desert area located at an average altitude of 2,400 meters within the Karakoram Mountains. Traditional houses in Hunza were constructed with thick stone and mud walls, topped by wooden and earthen roofs [77]. These houses were built in compact clusters to conserve arable land, which provided the inhabitants with food and fuel. Designs typically included a well-sheltered, windowless winter room with small doors, surrounded by other enclosed spaces, as well as a relatively open and airy summer room [78]. These configurations effectively retained indoor heat, providing warmth during the cold months while reducing the need for firewood.

Modern construction materials were introduced in Hunza after the 1970s, when the Karakoram Highway, a trade route connecting Pakistan to China, was constructed through the valley, facilitating the import of concrete, metals, and glass from southern cities in Pakistan. This highway led to the establishment of trade- and service-based industries, allowing people to transition from a self-sufficient, subsistence-farming economy to a monetized, consumer-based economy [79]. These changes eliminated people's reliance on locally available construction materials and instead allowed them to adopt modern building materials, which became widely prevalent in housing construction after the 1990s. Modern houses are built as detached units, with thin concrete and steel walls and roofs, as well as large doors and single-glazed windows, resulting in rapid heat losses to the outdoors [80]. Moreover, spaces are designed to accommodate specific activities such as cooking, receiving guests, and living and sleeping separately year-round, rather than having separate spaces designed for seasonal use [80]. These houses, therefore, require constant indoor heating to maintain comfortable indoor temperatures. At the same time, the electricity shortage is acute in Hunza, especially during winter, as it is generated locally from glacial streams that dry up during this season [81]. Meanwhile, firewood remains scarce due to the cold, arid climate and limited cultivable land [82]. Moreover, access to firewood is becoming increasingly scarce as many orchards are cleared for commercial and residential development to accommodate the growing local population and the influx of tourists [83]. Under these conditions, the residents of Hunza living in contemporary houses experience acute cold stress during winter, yet contemporary building practices remain predominant in the valley [84,85].

At the same time, several traditional dwellings exist and remain inhabited to this day. Several houses in the oldest traditional clustered settlements, built more than 100 years ago, have been conserved by the NGO Aga Khan Cultural Service Pakistan (AKCSP) alongside historic forts designated as heritage sites [86]. Meanwhile, dwellings built outside the cluster settlements around the mid-20th century continue to be inhabited as traditional winter living rooms, with residents extending them with contemporary additions. Furthermore, efforts are being made to reintroduce traditional building methods into modern construction. For example, another NGO, the Building Construction and Improvement Program (BACIP), has introduced construction methods with stonewalls, stabilized mud plasters, and straw insulation [60,87]. Additionally, BACIP has also proposed modern EPS foam-based insulation and double-glazed windows. However, people have not widely adopted their building methods [60].

The coexistence of both traditional and contemporary houses in Hunza, therefore, provides an excellent opportunity to compare their thermal behavior. Moreover, because most residents have firsthand experience of the thermal conditions in both traditional and contemporary dwellings, and technical interventions have been proposed but remain largely unadopted in this region, Hunza provides an ideal context in which to investigate the social and behavioral factors influencing building transitions and the relative acceptance of traditional and contemporary construction practices. While the practical recommendations resulting from this investigation will be specific to Hunza, they will provide valuable insights into the importance of understanding residents, motivations, and behavioral contexts when proposing thermally effective and socially acceptable housing solutions in other settings, an aspect often overlooked in studies focused solely on thermal performance.

4. Research methods overview

This study employed a grounded theory approach to generate knowledge directly from the empirical data collected on-site [88]. This approach is particularly suitable for understudied topics, as it allows patterns, concepts, and relationships to emerge naturally from the data rather than being constrained by pre-existing hypotheses [89,90]. Grounded theory methods begin with a broadly defined topic, about which the researcher begins collecting data from multiple sources, such as in-depth observations, photographic documentation, detailed field notes, and interviews [89]. Data analysis occurs concurrently with data collection, as the researcher continuously interprets data using their analytical and theoretical insight to identify emerging patterns. New information is constantly compared with previous findings and interpretations [90,91]. For example, an interview response can be compared with the general understanding that has evolved by that time. This process leads to the development of an explanation of the phenomenon under study. The subsequent phases of data collection, known as theoretical sampling, aim to verify and further develop plausible explanations using specific research methods and are targeted toward specific samples [92].

Accordingly, this research began with an open exploration of issues related to indoor thermal conditions, housing construction practices, and individual lifestyles in Hunza. This exploratory research, conducted during the summers of 2019 and 2021, included thirty-one open-ended interviews as well as field observations and documentation of construction materials and spatial configurations in sixteen houses. Interview participants included residents, builders, and architects in the Hunza Valley. Insights from these interviews were used to identify focused themes for in-depth explorations. Further investigations were made through surveys with 114 respondents; focused interviews with 17 participants from the open-ended interviews; and indoor temperature monitoring in 12 dwellings. Finally, building energy simulations were conducted for four of the monitored houses, selected to represent the transitions from traditional to contemporary building types.

5. Dissertation structure

The research and findings are organized into three main chapters, each written as a manuscript for publication. Chapter II, titled "Trading cozy old homes for chilly new ones: How experiences and beliefs guide housing modernization in Northern Pakistan", co-authored by Yumna Imtiaz and Prof. Alexandra Rempel, was published in 2024 [84].

Chapter II: The first paper examines the evolution of construction methods, materials, and spatial configurations in Hunza; the influence of these changes on residents' thermal experiences; and the strategies residents use to cope with thermal stress. This study uses data from 31 open-ended interviews with housing residents, on-site observations, and detailed documentation of 16 dwellings. The findings revealed the predominant housing types, the extent of thermal stress associated with each housing type, and the behavioral and architectural adaptations residents use to stay warm.

Chapter III: The second paper investigates the motivations of owner-builders in adopting contemporary building methods despite the thermal stress they experience in these constructions. This study uses survey data, supplemented by focused and exploratory interviews, to understand the relative importance of various needs in guiding building choices in Hunza. The findings are interpreted through the lens of Maslow's Hierarchy of Needs, which suggests that basic physiological needs, such as thermal comfort, must be met before people aspire to higher-level needs, including building relationships and pursuing aesthetic aspirations. Therefore, in addition to highlighting the housing priorities of owner-builders in Hunza, the study reveals the applicability and limitations of Maslow's theory in a non-Western, developing context.

Chapter IV: The third paper builds further on the findings of the first two papers, focusing on the technical aspects of buildings' thermal behavior. Indoor temperature monitoring was initially used to comparatively analyze the indoor thermal conditions of traditional and contemporary housing types. Subsequently, it was combined with dwelling documentation data to develop energy simulation models for four houses. The housing sample included various housing typologies, from fully traditional to intermediate forms that blend traditional and contemporary elements, and finally to fully contemporary houses. The simulation models were initially used to identify the sources of heat gain and the dominant pathways of heat loss in the various housing types. These findings helped identify new opportunities to improve thermal conditions through targeted improvements to existing construction methods, in ways that already meet residents' needs for affordability and durability.

By investigating housing transitions, thermal challenges, and context-appropriate retrofit strategies, this work contributes to the global discourse on mitigating residential thermal stress across developing regions, particularly within the understudied cold-climate context, where rapid housing modernization compromises indoor comfort and increases household energy demands.

6. Positionality Statement

The primary researcher's engagement with this topic is rooted in the lived experiences of thermal stress in Northern Pakistan and observations of challenges faced by housing residents in coping with extreme cold temperatures. These experiences stood in contrast to the thermally comfortable conditions observed by the researcher in Western contexts, where maintaining comfortable indoor temperatures is mandated by building codes, and dominant building-energy performance discourses are primarily shaped by carbon-emissions reduction efforts rather than immediate thermal vulnerabilities. This contrast motivated the researcher to focus on the ways in which building performance can be understood and negotiated in contexts where thermal stress is a daily reality.

In addition to shaping the choice of the research topic, the researcher's positionality is influenced by her identity as someone born in the Hunza Valley and by her social and familial ties to the region. Despite having spent most of her life outside the valley and returning primarily during summer visits, the researchers' understanding of winter thermal conditions is informed by occasional visits to Hunza during colder months and ongoing conversations with residents about challenges they face in winter and long-term observations shared through everyday familial and community interactions.

Kinship networks and broader social relations played an important role in facilitating access to the field. Although most research participants were not personally known to the researcher prior to the study, existing social networks helped establish rapport, enabled introductions, and shaped the nature of interactions. This familiarity influenced the content and depth of conversations and also required attentiveness to the way in which these relations shaped participants' willingness to engage in research activities. Therefore, to avoid any sense of obligation, the voluntary nature of participation was emphasized while obtaining informed consent. Furthermore, informed consent was approached as an ongoing process by clarifying that participants may choose to discontinue their involvement in the study at any time. To build rapport, detailed information about the purpose of the project, the nature of data collection, and the intended extent and venues of data and research dissemination was communicated in accessible language. In cases where digital tools such as photography and temperature data loggers were used, these were explained thoroughly, and when requested, their outputs were shared with residents to promote transparency and mutual understanding.

The researcher is aware that an insider perspective can simultaneously offer advantages such as trust and access, as well as limitations, including the possibility of overlooking details and interpretive biases. To address these limitations, the researcher has attempted to foreground participants' voices through direct quotations wherever possible. This approach was intended to ensure that participants' accounts of their ideas and experiences remain central to the analysis.

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II. TRADING COZY OLD HOMES FOR CHILLY NEW ONES: HOW EXPERIENCES AND BELIEFS GUIDE HOUSING MODERNIZATION IN NORTHERN PAKISTAN

Co-authored by Yumna Imtiaz and Alexandra Rempel, published in Energy Research and Social Science, 2024

1. Introduction

In the Hunza Valley, in the high desert mountains of northern Pakistan, contemporary houses built of concrete, steel, and glass are rapidly replacing traditional homes of stone, earth, and wood [1–3]. This building transition echoes those occurring in developing regions worldwide [4–11], with the striking contrast that it is inflicting extreme indoor cold stress on the occupants: not only do the new dwellings lose heat rapidly [12], but firewood and natural gas are too scarce or expensive to allow most people to compensate [13,14]. Paradoxically, however, the transition continues, raising important questions and offering new insights regarding the factors that propel building transitions forward despite the apparent interests of their occupants.

Analogous transitions are underway across tropical, subtropical, and temperate regions of Asia, Oceania, Africa, and South America, in which dwellings built of local earth, stone, and fibers are similarly undergoing replacement by new buildings of concrete, steel, aluminum, and glass [4–10]. Because traditional building materials and forms become adapted to their local climates through centuries of experimentation, acquiring the ability to maintain livable indoor temperatures throughout both hot and cold seasons, new building methods have imposed thermal stress on occupants in these regions as well. Recent studies have established the intensity of indoor heat stress in both tropical climates, in which reed-and-grass huts have been replaced by concrete buildings with corrugated metal roofs [7,15–17], for example, and in subtropical regions in which traditional "cool rooms" (i.e., facing away from the equator or positioned beneath other rooms) have been omitted [18,19]. The elimination of traditional elements such as extensive eaves for shading in sunny climates, screened but otherwise open walls for natural ventilation in humid climates, courtyards for radiant cooling to cold night skies in dry climates, and thick earthen envelopes with minimal openings for thermal stability in hot dry climates, has contributed further to residential heat stress, especially among people with limited access to air conditioning [7,15,16]. Additionally, the replacement of traditional multi-purpose spaces with contemporary dedicated spaces (e.g., bedrooms for sleeping) has inhibited the seasonal relocation of activities among rooms, limiting options for adaptation [18,20,21].

While building transitions are occurring throughout cold developing regions, as well, these have been studied far less. Among these, to our knowledge, only two have evaluated such transitions in light of the resulting indoor cold stress: one did so through surveys, revealing greater thermal satisfaction among occupants of traditional eastern Turkish dwellings than of contemporary homes [22], while the other combined surveys with on-site temperature measurements to develop an adaptive thermal comfort model specific to Tibetan people [23]. As a result, the current understanding of transitional factors that either intensify or ameliorate indoor cold stress is extremely limited.

In both warm and cold climates, a central factor promoting transitions from traditional to contemporary buildings is widely agreed to be economic pressure: mass-produced concrete masonry units, kiln-fired bricks, and corrugated metal sheets, in particular, have become more convenient to acquire [1,8,24,25], and in some cases less expensive, than their hand-formed counterparts of stone blocks, unfired earth bricks, and natural-fiber roofing [26–28], even as they require more fossil energy to produce and transport [29]. Their assembly into walls and roofs is also generally more rapid and requires less skill [3,25,26]; further, they allow thinner walls to be formed, conserving valuable space [6,30]. In developing regions where resources are scarce, therefore, these transitions are often described as the inevitable result of market forces overwhelming a vulnerable population; residents are then regarded as passive recipients of these new, thermally stressful buildings.

Another factor promoting housing modernization is understood to be social and cultural: people are attracted by the outward appearance of contemporary buildings [4], as well as the convenience of indoor plumbing and sanitary facilities [26] and the privacy afforded by multi-roomed configurations [10]. As these new materials, forms, and construction methods are adopted over time, they come to be seen as symbols of progress [4,5,10], creating further social pressure favoring adoption; this pressure remains effective even when occupants expect the accompanying thermal stress [26,27,31].

The building transition in the Hunza Valley, however, challenges these ideas. First, the residents are largely middle-class, rather than poor: most families own their own detached homes; the population is well-nourished and educated; and unemployment is low [32]. Additionally, because home ownership is high [32], and because houses tend to remain within families for many decades, residents are closely involved in decisions regarding construction materials and building forms. Many residents participate directly in home construction, as well, as owner-builders [1,3]. Further, contemporary homes are typically larger, with more rooms and greater window area, than traditional dwellings [1,3]. In other words, economic vulnerability does not appear to be driving this transition.

The social and cultural pressure to adopt new building methods may be a stronger explanatory factor, since the winter cold stress experienced in contemporary houses is locally well-known [12]: clearly, the people are actively choosing new building materials and methods, even as they suffer from them afterward. At the same time, a broad prioritization of social and aesthetic needs over thermal shelter would be surprising in a population so closely involved in the construction of their own homes, particularly under such frigid conditions, suggesting that the residents must be engaged in alternative coping strategies that are not yet recognized.

The likely strength of the social and cultural dimension suggests that parallels exist between housing transitions in developing countries, in pursuit of modernization, and transitions in developed countries striving to reduce greenhouse gas emissions. In the latter transition, occupants have similarly been regarded as detached, necessitating either technological solutions to bypass the need for lifestyle changes or financial incentives to promote the desired, rational energy consumption behavior [33]. Investigations of low-energy home adoption and operation, however, are rapidly revealing the extent of personal, social, and cultural influences in this transition [34], finding that practical knowledge derived from everyday experience is a central factor guiding energy-use decisions [35,36]. Additionally, such knowledge has been found to develop and evolve with an occupant's personal needs, social environment, and material surroundings [37]. Further, among these needs, autonomy in modifying one's home, and controlling the conditions in it, have emerged alongside thermal comfort, aesthetics, and light as important dimensions of comfort construed more broadly [33]. In housing transitions in developing countries such as Pakistan, however, the interactions of occupants with their buildings are largely unexplored.

The purpose of this study is, therefore, to reveal the human factors that are promoting and shaping the housing transition in the Hunza Valley, illuminated by the material and construction transition itself. Although Hunza's traditional architecture has been studied for conservation purposes [38–40], and its urbanization has been explored for environmental purposes [2,41], this topic has not yet been investigated. To address these questions, this study has first documented numerous dwellings representing the transition from traditional (>80 years old) to contemporary (<30 years old) through measurements, photographs, and drawings to reveal salient characteristics of the transition itself. Concurrently, interviews were conducted to discover residents' motivations underlying construction decisions made in building their homes, their winter thermal experiences, and the practices they adopted to survive these conditions. Together, these lines of evidence suggest that the ongoing, active roles of homeowners and builders, both in new construction and adaptation to new construction, as well as occupant motivations, both in pursuing new methods and designing thermal adaptations, have been greatly under-estimated.

Prevailing views of contemporary home dwellers in developing countries as powerless, uninvolved, or unsuspecting have supported diverse proposals advocating outside intervention in the form of retrofits, including the revival of traditional building methods, to alleviate thermal stress [24,26,29]; several have addressed the study area, as well [12,42]. The view revealed here, in contrast, highlights the agency and ingenuity of owner-builders in ways limited primarily by knowledge, suggesting that educational support may be the most effective approach in restoring thermal well-being to populations experiencing housing modernization in developing regions.

2. Methods

This study used a grounded theory approach, a method that supports the creation of new theories that are 'grounded' in empirical data [43,44]. This approach is appropriate in cases for which established theoretical frameworks are lacking; it also minimizes the influences of previous researcher experiences and knowledge, while maximizing the potential to reveal unexpected insights, in such contexts [45]. Following this approach, the initial stages of data collection used open-ended interviews and field documentation; review of these data allowed themes to emerge; and these themes informed subsequent, more structured data collection (Fig. 2.1). This process was repeated until new themes no longer appeared [44].

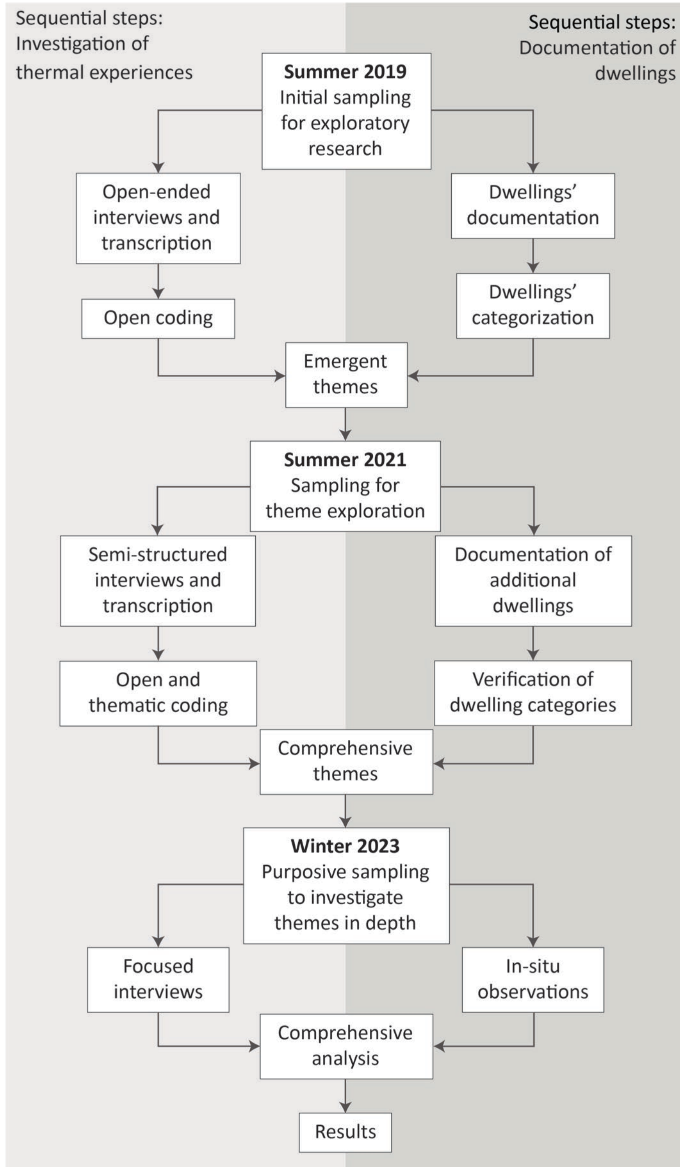


Figure 2.1. Research design, showing the sequence of interviews, field documentation, and analytical activities.

2.1. Site and context

The Hunza Valley, at an average elevation of 2438 m above sea level, has a cold desert climate (*BWk*) [46] in which the heating season extends from October through May (Fig. 2.2). Winters are very cold, with average outdoor temperatures of approximately 0-5°C from December through February; precipitation is limited and occurs in the form of snow. Summers are warm but rarely hot, with average temperatures often exceeding 20°C; most rainfall occurs in summer, as well [47,48]. As winter is the more severe season, space heating needs greatly exceed cooling needs [12].

Traditionally, dwellings were built in clustered settlements using locally available stones, mud, and wood, and located on elevated lands [1,40], both to preserve agricultural fields and orchards and to provide protection from the attacks of rival groups [1,28]. In 1891, British conquest ended these attacks, allowing construction to occur outside the cluster settlements; additionally, new dirt tracks connected the region to the south [49], allowing the exchange of building practices [1]. These changes intensified with the annexation of Hunza to Pakistan in 1947 and the construction of the first dirt road in the 1960s [1,50], accelerating further after 1978, when the Karakoram Highway connected Hunza to the markets of southern Pakistan [1,28,50]. At the same time, the Aga Khan Cultural Services Pakistan (AKCSP), an international non-governmental organization, strived to conserve the area's architectural heritage; as a result, historic housing settlements have been well-preserved, albeit with the addition of sanitation, electric, and plumbing facilities, and are inhabited to this date [38,50].

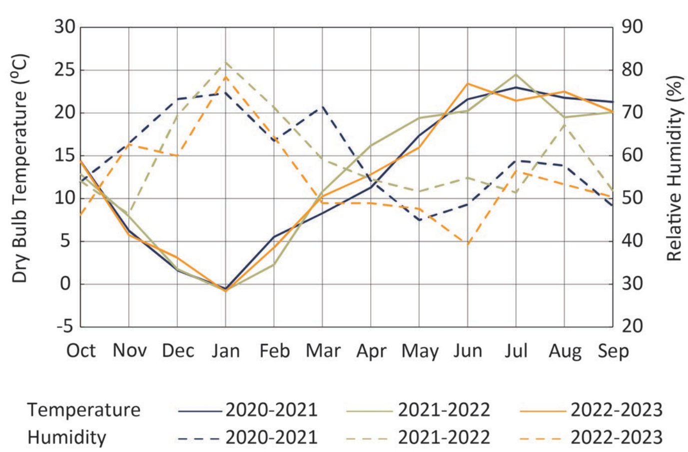


Figure 2.2. Annual climatic conditions in the Hunza Valley, as shown by weather data collected by the Pakistan Meteorological Department [48].

2.2. Study participants

The scope of interest encompassed housing built over the previous 400 years; middle and low economic status among owner-builders; and nuclear and extended family sizes, where nuclear families comprised parents and children, and extended families included additional relatives. Building owners were recruited initially by purposive sampling [51] in which they were sought on the basis of their homes' ages; community gatekeepers assisted in this process. Additional participants were recruited through snowball sampling, using the recommendations of the initial participants. While such sampling typically reduces the generalizability of the immediate results [52], here it provided access to the entire scope of interest, supporting the development of questions to explore the themes that emerged, including quantitative survey investigations, in the future. The resulting participant group represented a range of ages, genders, family sizes, and socioeconomic status, in which the latter was inferred by interviewee comments regarding their access to fuels and by the observed dwelling sizes and conditions (Table 2.2). In each case, informed consent was obtained before data collection began.

2.3. Building investigation

Twenty-three dwellings were studied in total (Fig. 2.3), representing ages and construction types from ca. 1600 to the present. In sixteen of these, residents permitted detailed documentation of materials, construction, design, orientation, and landscape features through drawing, photography, and measurement. In the remaining seven, residents described the corresponding elements in interviews. Investigation of these dwellings, as well as interviews with builders (Section 2.4), indicated that structures built within a given time period were constructed with similar configurations and materials [1,12]. As a result, the twenty-three sites showed sufficient redundancy, within their age bands, to characterize the housing transition from traditional to contemporary forms.

Original dwellings and subsequent additions were categorized on the basis of their ages and materials as Traditional (built in or before the 1940s), Hybrid (1950s-1980s), or Contemporary (1990s-2020s). Each dwelling is further identified by a code expressing the original year of construction, e.g., 1900-, followed by its traditional, hybrid, or contemporary categorization, e.g., T, H, or C, respectively. In dwellings with subsequent additions, a second letter is included (e.g., 1900-T-c). In each code, the portion used for winter living is highlighted with an upper-case letter. In addition, a case number at the end of the code distinguishes dwellings that shared the same age, construction, and winter living space type (Table 2.1).

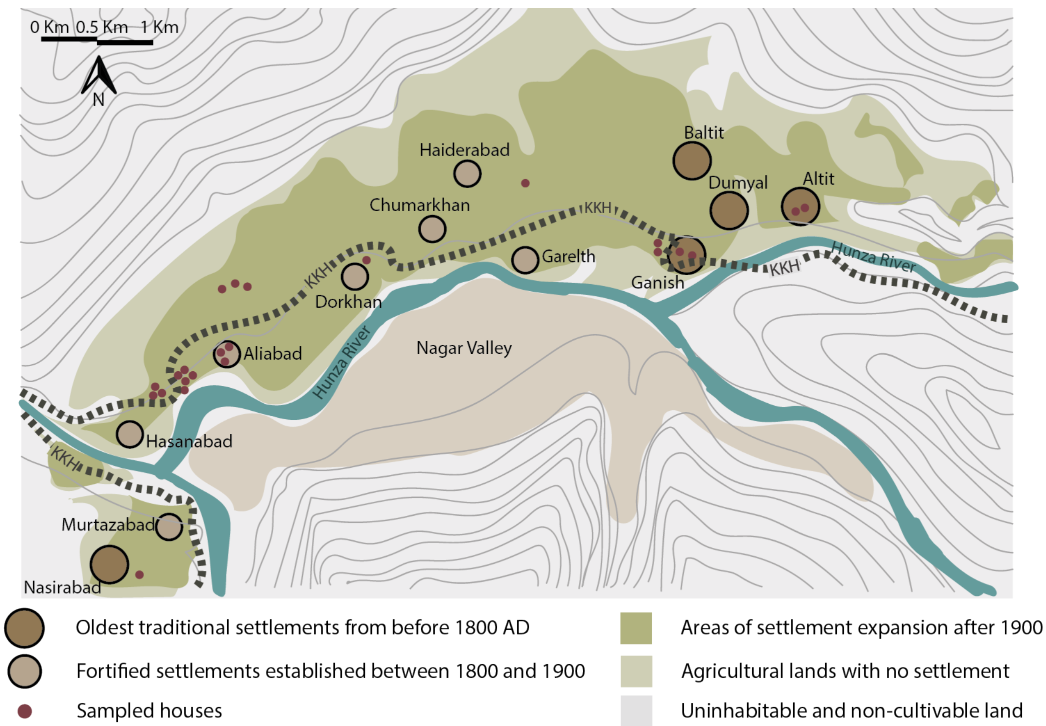


Figure 2.3. Map of central Hunza showing the locations of traditional cluster settlements, subsequent settlement expansion phases [28], and sampled houses.

Table 2.1. Dwelling codes

Dwelling code[a]	Year of original construction	Construction type(s)[b]	Case number (if multiple)
1600-T	1600	Traditional	
1800-t-C	1800	traditional + Contemporary	
1900-T-c1	1900	Traditional + contemporary	1
1900-T-c2	1900	Traditional + contemporary	2
1900-T-c3	1900	Traditional + contemporary	3
1940-t-C	1940	traditional + Contemporary	
1950-H-c	1950	Hybrid + contemporary	
1950-h-C	1950	hybrid + Contemporary	
1960-H-c1	1960	Hybrid + contemporary	1
1960-H-c2	1960	Hybrid + contemporary	2
1975-H-c	1975	Hybrid + contemporary	
1979-h-C	1979	hybrid + Contemporary	
1995-C	1995	Contemporary	
1997-C	1997	Contemporary	
2000-C	2000	Contemporary	
2010-C	2010	Contemporary	
2015-C	2015	Contemporary	
2017-C1	2017	Contemporary	1
2017-C2	2017	Contemporary	2
2017-C3	2017	Contemporary	3
2019–C1	2019	Contemporary	1
2019-C2	2019	Contemporary	2
2020-C	2020	Contemporary	

[a] Code format: Year-Construction type-Case number.

[b] First letters of primary winter living space types are capitalized.

2.4. Interviews

All interviews were conducted in person in the local languages, Burushaski and Urdu, over durations of 15-30 minutes; recorded on a hand-held voice recorder; transcribed into English; annotated with on-site observations; and coded using QDA Miner 5.0 [53], as detailed below.

Exploratory, open-ended interviews were conducted in the summer of 2019 (Tables 2.2 and 2.3). In fourteen of these, residents of the houses studied were asked to describe residential construction methods and trends, interior space utilization, general and thermal comfort perceptions, and space heating practices. In three others, building professionals and a community gatekeeper were asked to explain current and recent construction methods and trends; topic-initiating questions are shown in the Supplementary Information. Interview transcripts were coded using open coding, in which each line or phrase is assigned a code based on its content [54]. Interviewee age, gender, and income group were associated with each transcript in QDA Miner, as well. Similar codes were grouped into 30 categories, which were further grouped into five themes: building descriptions, factors affecting housing choices, winter adaptations, occupants' observations and beliefs, and the problems faced in different housing types (see Supplementary Information). Interviews in 2021 and 2023 then focused on these themes.

Further interviews, informed by the results of the exploratory interviews, were conducted in the summer of 2021; among these, eight involved newly enrolled housing residents, two involved original 2019 participants, and five involved architects and craftspeople. Questions are shown in the Supplementary Information. These contained both semi-structured and unstructured portions: semi-structured questions were designed to reveal greater detail regarding residents' experiences of thermal (dis)comfort and cold stress, residents' beliefs regarding the causes of this stress, the nature and effectiveness of adaptation methods, and craftspersons' views on the popularity and limitations of traditional and contemporary building practices. Open-ended (unstructured) questions were included to reveal themes that had not emerged in the 2019 interviews. These open-ended questions revealed that the original 2019 interviews had, in fact, achieved data saturation with respect to the topics of housing construction methods and indoor cold stress.

Interview transcripts were coded, and codes were categorized as above. Because several new codes emerged from the semi-structured questions in the form of greater detail, the 2019 transcripts were re-coded to ensure consistency among all transcripts. This coding process was instrumental in revealing connections between key themes and highlighting their importance through frequency counts.

Finally, in the winter of 2023, thirteen people were interviewed in seven of the dwellings themselves to reveal individuals' experiences and perceptions under the specific conditions of interest. This approach has been found to improve accuracy and detail in ethnographic studies [55], and here, it allowed observation and verification of interview statements. These questions focused on thermal comfort, thermal stress, and residents' thought processes in making housing design-related decisions (see Supplementary Information for questions). In analyzing these interviews, selective coding was applied using a codebook developed from the interviews of 2019 and 2021, with continued attention to any new codes that might emerge.

Table 2.2. Interviews: Building owners and occupants

Interview season	Dwelling code[a]	Income group[b]	Family size[c]	Interviewee gender	Interviewee age
Summer 2019	*Summary: Total buildings: 14; Total respondents: 16; Original construction dates: 1800-2019*				
	Traditional: 4	*Middle: 10*	*Extended: 11*	*Female: 7*	*Ages 18-40: 5*
	Hybrid: 4	*Low: 4*	*Nuclear: 3*	*Male: 9*	*Ages 41-60: 5*
	Contemporary: 6				*Ages 61-80: 5*
	1800-t-C	Middle	Extended	Female	27
	1900-T-c1	Low	Extended	Male	22
	1900-T-c2	Middle	Nuclear	Female	50
	1940-t-C	Middle	Extended	Female	50
	1950-h-C	Middle	Extended	Male	69
	1960-H-c1	Middle	Nuclear	Female	50
				Male	33
	1975-H-c	Low	Extended	Male	36
	1979-h-C	Middle	Extended	Male	70
	1995-C	Low	Extended	Female	65
				Male	75
	1997-C	Middle	Extended	Female	50
	2000-C	Middle	Extended	Female	60
	2010-C	Middle	Extended	Male	70
	2015-C	Middle	Nuclear	Male	50
	2019–C1	Low	Extended	Male	40
Summer 2021	*Summary: Total buildings: 10; Total respondents: 14; Original construction dates: 1800-2020*				
	Traditional: 2	*Middle: 5*	*Extended:3*	*Female: 10*	*Ages 18-40: 7*
	Hybrid: 2	*Low: 5*	*Nuclear:7*	*Male: 4*	*Ages 41-60: 6*
	Contemporary: 6				*Ages 61-80: 1*
	1800-t-C	Middle	Extended	Female	27
				Female	65
	1900-T-c3	Low	Nuclear	Female	52

Table 2.2. Continued

Interview season	Dwelling code[a]	Income group[b]	Family size[c]	Interviewee gender	Interviewee age
	1950-H-c	Low	Nuclear	Female	25
	1960-H-c2	Middle	Nuclear	Male	40
				Female	36
	1997-C	Middle	Extended	Female	50
	2017-C1	Low	Extended	Female	50
				Male	18
	2017-C2	Low	Nuclear	Female	20
	2017-C3	Low	Nuclear	Male	55
	2019-C2	Middle	Nuclear	Male	18
				Female	50
	2020-C	Middle	Nuclear	Female	37
Winter	*Summary: Total buildings: 7; Total respondents: 13; Original construction dates: 1600-2019*				
2023	*Traditional: 3*	*Middle: 5*	*Extended: 2*	*Female: 8*	*Ages 18-40: 7*
	Hybrid: 3	*Low: 2*	*Nuclear: 5*	*Male: 5*	*Ages 41-60: 6*
	Contemporary: 1				*Ages 61-80: 0*
	1600-T	Low	Nuclear	Female	23
	1800-t-C	Middle	Extended	Female	27
				Female	40
	1900-T-c3	Low	Nuclear	Female	52
				Male	60
	1950-h-C	Middle	Extended	Male	45
				Female	40
	1960-H-c1	Middle	Nuclear	Female	50
				Male	33
	1960-H-c2	Middle	Nuclear	Male	40
				Female	36

Table 2.2. Continued

Interview season	Dwelling code[a]	Income group[b]	Family size[c]	Interviewee gender	Interviewee age
	2019-C2	Middle	Nuclear	Female	50
				Male	50

[a] For dwelling codes, see Table 2.1.
[b] Income groups were inferred from interviewee comments regarding access to fuels, income, and expenditures, as well as observations of house sizes and conditions.
[c] Nuclear families include only parents and children; extended families refer to nuclear families living with additional relatives.

Table 2.3. Interviews: Community gatekeepers and building professionals

Year	Interviewee
2019	Community gatekeeper actively involved with AKCSP[a] conservation projects
	Architect at AKCSP[a]
	Local carpenter
2021	Senior architect at AKCSP[a]
	Local architect engaged in commercial and residential building
	Local mason
	AKPBSP[b] trained mason working primarily on AKPBSP[b] buildings
	Mason contractor from a neighboring valley working in Hunza

[a] Aga Khan Cultural Services Pakistan (AKCSP), a non-governmental organization (NGO) of the Aga Khan Foundation that has worked extensively on architectural conservation in Hunza.
[b] Aga Khan Planning and Building Service, Pakistan (AKPBSP), another NGO of the Aga Khan foundation that focuses on housing design and construction, institutional construction management, village planning, and natural hazard mitigation.

3. Study limitations

This study is exploratory and qualitative, with a regional focus, imposing certain limitations on the interpretation of results. As an exploratory study, it did not attempt to test specific hypotheses; instead, it relied on themes to emerge from interview questions through transcript coding and from field investigations through observation. The themes that emerged, therefore, depended on the scope of interest, with the consequence that potentially relevant themes beyond this scope are not represented. Further, this exploration depended on the participation of numerous families in a somewhat invasive process documenting their homes, their practices, and their beliefs. Sampling was therefore accomplished through targeted recruitment rather than random selection, biasing the participants toward those most open to such investigation. As a qualitative study, this work could not control quantitatively for factors affecting interviewee responses; instead, however, it ensured that responses from a range of ages, socioeconomic status, and genders were represented among interviewees of each housing type, allowing relevant themes (Section 5) to emerge from each demographic (Table 2.2). Finally, as a study with a regional focus, the specific themes that emerged are not necessarily directly applicable to other locations. At the same time, however, the main conclusions highlight human thoughts, motivations, and activities that have been neglected elsewhere, suggesting that its findings should be considered carefully before technological solutions to heat or cold stress in contemporary buildings are imposed on populations undergoing building transitions.

To understand the Hunza Valley building transition in detail, and to reveal occupants' roles in guiding and responding to the transition, twenty-three dwellings built between 1600 and 2020 were investigated through direct observations and interviews with occupants as well as eight additional interviews with building professionals (Section 2; Fig. 2.3; Tables 2.2 and 2.3).

4. Dwelling designs and thermal significance

4.1. Traditional dwellings

Six of the dwellings investigated were built in cluster settlements in or before 1940; these were categorized as "traditional". Four of these homes were observed in the field (Fig. 2.6), while the other two homes were documented through interviews (Table 2.4).

4.1.1. Spatial configurations

These clustered buildings were originally surrounded by adjoining neighbors, shielding them from outdoor conditions in a manner often found in severe climates [56]. The entrances were further sheltered from the outdoors by sheds housing cattle, originally [1]; one interviewee recalled that these had also served as warm spaces for bathing. The primary winter living space in each case was a large square room known as a *haa*, entered through a low doorway (1.2-1.5m) and vestibule in one corner; these small doors, and the absence of windows, echoed practices of minimizing building openings in other cold climates [23,26,56]. At the center of each *haa* lay a recessed floor for food preparation, with raised floors on either side for seating and sleeping (Figs. 2.4 and 2.5). Traditionally, open wood combustion had occurred in these hearths [1], but metal wood-burning stoves were in place at the time of observation (Fig. 2.4). As the *haas* provided common areas for cooking, eating, socializing, and sleeping, they led families to congregate around their central fires, occupants reported, combining the warmth of both people and fuels.

An open skylight above each hearth allowed smoke to exhaust, providing a conduit for air exchange but also heat loss. Above the *haa* in most cases (except 1900-T-c3) was a second-story room known as a *baldi* that reflected the layout of the *haa* below, albeit with a flat floor, larger skylight (Table 2.7), and stove placed in a corner or outside the room altogether. Some b*aldis*, as in 1800-t-C, originally held unglazed windows with wooden shutters, as well. The *baldis* were therefore positioned to shield the lower floors from winter cold to some extent and also to provide skylit, airy summer living spaces.

Figure 2.4. Interiors of traditional haas a) as they existed in the 1950s, drawn by author Y.I. to show elements described in [1,57], and b) as preserved in their original configuration by the Aga Khan Cultural Services Pakistan in 2010, photographed by author Y.I. in 2021.

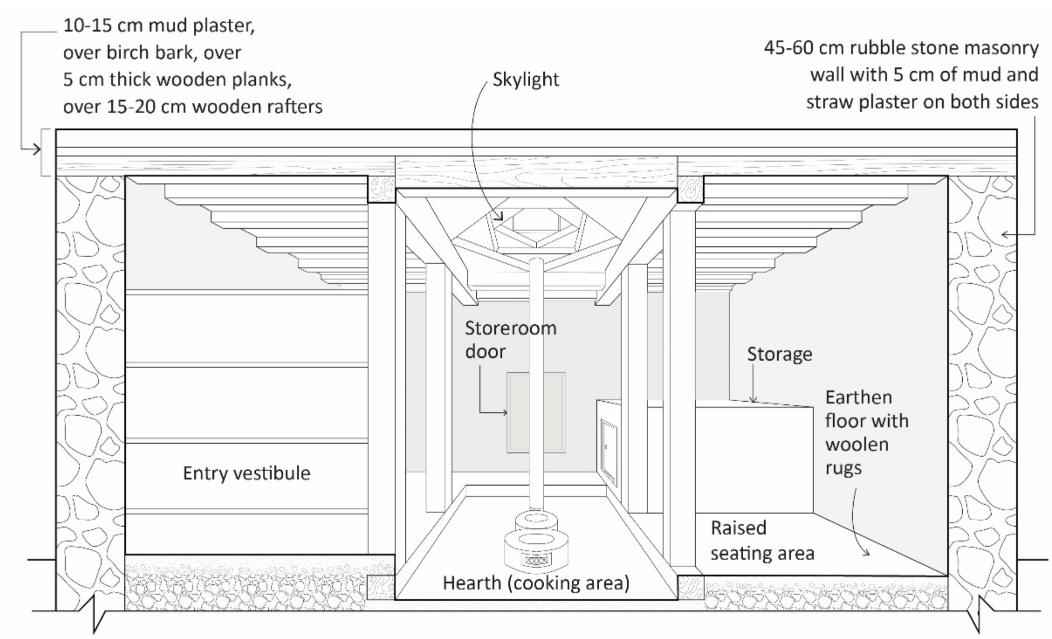


Figure 2.5. A typical traditional haa, shown without a baldi.

4.1.2. Walls, floors, roofs, and windows

Despite their sheltered interior positions and modest structural loads, the walls of the traditional dwellings were nearly ½ meter thick, built of rough, undressed stone (presumably local granodiorite and gneiss [40]), bound with mud and finished with mud-and-straw plaster (Fig. 2.11a and b; Table 2.7). Interviews suggested that these may have been designed for warmth (Section 5.3.1); consistently, massive walls such as these are known to have substantial heat-storing capacity [56,58], reducing diurnal temperature swings [56,58,59]. Roofs were also constructed with heat-storing materials, primarily earth in 10-15 cm layers, supported by wooden planks and birch tree bark (Fig. 2.5; Table 2.7). Floors were massive, as well, consisting of stones and loose gravel sealed with earthen finishes; for seating and insulation, however, they were covered by sheep-wool rugs and elongated cushions.

4.1.3. Retrofits

Interviewees reported that numerous alterations had been made to these homes since their construction, reflecting transitions in building methods similar to those in the contemporary homes below (Section 4.3). Entry sheds for housing cattle, for example, had been demolished or repurposed, increasing the exposure of entries to the outdoors; in 1600-T, however, the original shed was converted to an entrance lobby and bathroom in a historical conservation project [38], and a similar retrofit occurred in 1940-t-C. Surrounded by adjacent buildings, these two retained nearly original forms. Original structures adjacent to the other traditional buildings had been partly or wholly demolished, however, exposing previously interior walls. In 1900-T-c3, the original entry door was replaced by a larger contemporary opening, as well. Finally, multiple bedrooms and bathrooms had been added to 1900-T-c2 and 1900-T-c3, and new detached units had been added to 1800-t-C, 1900-T-c1, and 1940-t-C, each following contemporary multi-roomed patterns described further below (Fig. 2.6; Table 2.4).

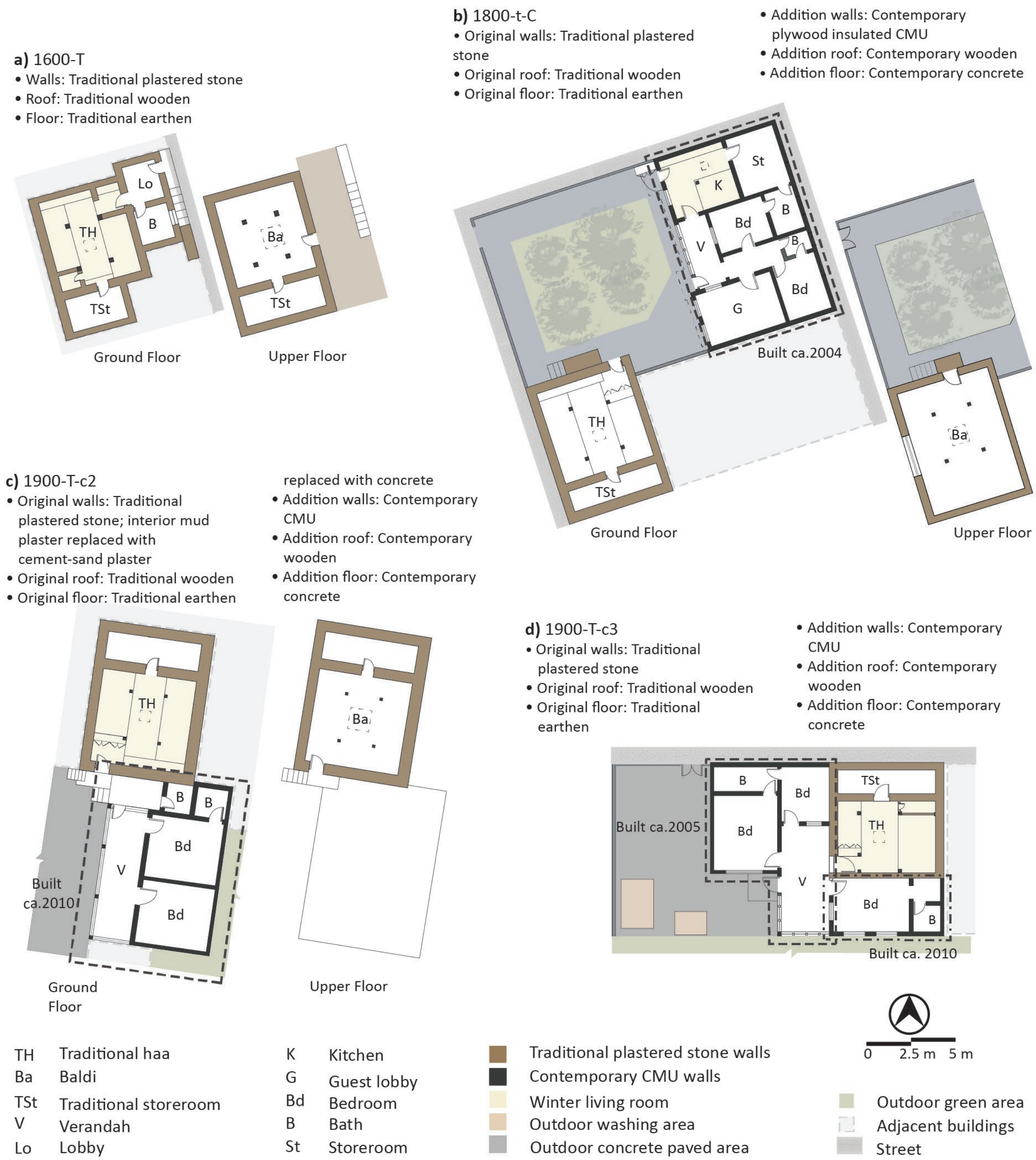


Figure 2.6. Traditional dwellings and subsequent additions, built in a) ca. 1600; b) 1800, with a contemporary 2004 addition; c) ca. 1900, with a contemporary 2010 addition; and d) ca. 1900, with contemporary additions in 2005 and 2010. Winter living spaces are highlighted. See Section 2.3 for code explanations and Table 2.7 for construction details.

Table 2.4. Traditional dwellings documented through interviews

Code	Year	Design	Walls[a]	Roof[a]	Floor[a]
1900-T-c1	Pre-1920	2-story; traditional *haa*[b] with *baldi*	Traditional plastered stone No windows	Traditional wooden	Traditional earthen
	1995	Living room, bedrooms, bathrooms, kitchen, and verandah	Contemporary CMU Windows not mentioned	Not mentioned	Not mentioned
1940-t-C	1940	2-story; traditional *haa* with *baldi*	Traditional plastered stone No windows	Traditional wooden	Traditional earthen
	~2018	2-story; kitchen[b], bedrooms, and bathrooms	Contemporary CMU Windows not mentioned	Not mentioned	Not mentioned

[a] See Table 2.7 for construction details.
[b] Winter living space.

4.2. Hybrid dwellings

Construction of dwellings for full-time occupancy outside of the cluster settlements began in the early 20th century [28,60], and by 1920, new forms and building methods began to emerge alongside traditional elements [1]. Six of the dwellings investigated, built between 1950 and 1990, represented such early transitions and were categorized as "hybrid". Four of these homes were observed in the field (Fig. 2.7), while the other two homes were documented through interviews alone (Table 2.5).

4.2.1. Spatial configurations

All six hybrid houses were built as detached units, increasing their walls' exposure to outdoor conditions compared to traditional construction in ways known to increase vulnerability to heat loss [56,61–63]. Three of these were designed with *haas* (1950-H-c, 1950-h-C, 1975-H-c), although residents did not necessarily use these spaces for winter living. In contrast to traditional *haas*, these hybrid *haas* were single-storied, lacking *baldis* and increasing their roofs' vulnerabilities to heat loss accordingly [64–66]. Entry sheds and vestibules were eliminated, as well; instead, open verandahs served as summer living spaces, exposing the entries of the hybrid *haas* to the outdoors and increasing their susceptibility to air infiltration. At the same time, each verandah held an indoor bathing room, sheltering bathing activities from outdoor cold.

The other three hybrid dwellings (1960-H-c1, 1960-H-c2, 1979-h-C), in contrast, were configured as sets of multi-purpose rooms, illustrating a prominent trend in the building transition away from *haa*-centered designs. These dwellings were originally intended solely for summer use and were therefore built to release rather than retain heat: ceilings were higher than in traditional construction, doorways were larger, and windows had been introduced to facilitate ventilation (Table 2.7). Additionally, daily activities and thus metabolic heat were dispersed across multi-purpose rooms and verandahs, and cooking was done outdoors.

4.2.2. Walls, floors, roofs, and windows

Following traditional construction methods, walls of the hybrid *haas* were again nearly ½ meter thick, built of rubble stone bound with mud mortar and plaster; roofs and floors likewise used traditional construction and possessed traditional heat-storing properties (Fig 2.11c; Table 2.7). Multi-purpose rooms, however, were constructed with ashlar stone masonry, in which hand-shaped stones were fitted tightly together in interlocking layers (wythes) (Fig. 2.11d). The resulting walls were similar to traditional walls in thickness and thermal behavior, but the exclusion of exterior mud plaster and the reduction of mud mortar modestly increased the walls' thermal transmittance (U-value), or tendency to transfer heat across itself (Table 2.7). Additionally, the large doors, wood-framed single-pane casement windows, and skylights increased the rooms' vulnerability to heat loss, both through air leakage around the openings and through conduction, convection, and radiation from the glass [67,68].

4.2.3. Stoves and cement use

The opening of the Karakoram Highway in 1978, connecting the Hunza Valley to southern

Pakistan, introduced two further changes that soon became widespread. First, open fireplaces in *haas* were largely replaced by metal wood-burning stoves with smoke exhaust ducts, reducing fuel needs and improving indoor air quality [69,70]; these allowed skylights to be sealed at night, substantially reducing cold air infiltration. Second, cement and ceramic water fixtures first became available [1,28]. Interviewees reported that cement-sand plaster was initially used for waterproofing in bathrooms; later, flush toilets were adopted, ending the need for frigid outdoor facilities:

> We got a little (cement) from one place or another, but it was not common. We brought one (20 kg cement) bag and smeared it over (the bathroom floors) so that the water could drain without (water damage) problems…. Later, when toilets came around 1990, we installed them… (Before that) for the toilet we had to go outside in the cold.

Quote 2.1: 1950-h-C

4.2.4. Retrofits

Interviewees reported that the hybrid dwellings had experienced several thermally significant retrofits by the time of this study. The year-round rather than summer-only habitation of 1960-H-c1 and 1960-H-c2, for example, necessitated new winter living spaces. Accordingly, one multi-purpose room in each house was reconfigured to create a kitchen: the addition of wood-burning stoves restored the traditional practice of combining cooking and winter living, while the addition of indoor plumbing eliminated the need for outdoor visits to access water. Counteracting these thermal measures, however, the interior mud plasters on walls and floors were replaced with cement plasters to prevent moisture damage, slightly reducing the walls' heat retention capabilities (Table 2.7).

Numerous additions had also been made to the hybrid dwellings in the forms of kitchens, bedrooms, storerooms, verandahs, bathrooms, and in one case, even a *haa* for use as a guest lobby (Fig. 2.7, Table 2.5). These were each built using contemporary materials, with limited heat-retaining properties (Table 2.7, Section 4.3), and as a result their use was limited primarily to the summer months. At the same time, the indoor plumbing of the contemporary kitchens allowed residents to avoid cold outdoor visits for collecting water and washing, favoring their use over (or alongside) the plumbing-free *haas* as winter living spaces (1950-h-C, 1950-H-c; Fig. 2.7).

Table 2.5. Hybrid dwellings documented through interviews

Code	Year	Design	Walls[a]	Roof[a]	Floor[a]
1960-H-c1[b] (addition only)	2019	1-story: living room, bedrooms, verandah, kitchen, and bathrooms	Contemporary CMU Single-glazed wooden windows	Contemporary insulated metal sheet	Contemporary concrete
1975-H-c	1975	1-story; traditional *haa*[c]	Hybrid plastered stone No windows	Hybrid wooden	Hybrid earthen
	1999	1-story: living rooms, bedrooms, verandah, and bathrooms	Contemporary CMU Single-glazed wooden windows	Contemporary metal sheet	Contemporary concrete
1979-h-C	1979	1-story: multi-purpose rooms, verandah, and bathrooms	Hybrid plastered stone Windows not mentioned	Hybrid wooden	Not mentioned
	2018	1-story; living room, bedrooms, kitchen[c], bathrooms; 3-story construction planned	Contemporary CMU Windows not mentioned	Contemporary RCC	Contemporary concrete

[a] See Table 2.7 for construction details.
[b] Original structure shown in Fig. 2.7.
[c] Winter living space.

*Figure 2.7. Hybrid dwellings and their additions, built in a) ca. 1950, with a 2010 addition; b) ca. 1950, with additions in 1974 and 2017; c) ca. 1960, (*2019 addition listed in Table 2.5); and*

d) ca. 1960, with additions in 2000 and 2010. See Section 2.3 for code explanations and Table 2.7 for construction details.

4.3. Contemporary dwellings

By 1990, the Karakoram Highway had caused industrially produced building materials and southern building methods to become widely available throughout northern Pakistan [1,2,28,71]. Eleven of the dwellings investigated were fully contemporary, built in 1990 or later, of which eight homes were observed in the field (Fig. 2.10) and three homes were documented through interviews (Table 2.6). Additions to the traditional and hybrid houses above (Figs. 2.6, 2.7; Tables 2.4, 2.5) were also largely built during this period.

4.3.1. Spatial configurations

Contemporary dwellings were designed with multiple rooms, as the hybrid homes had been, but with designated roles as living rooms, kitchens, guest lobbies, or bedrooms. As a result, the warmth created by human metabolic heat and appliances was dispersed over greater areas during the winter, especially at night. On the other hand, these homes contained multiple bathrooms, each typically adjacent to a bedroom, eliminating the need for cold outdoor bathroom visits.

*Haa*s built with contemporary materials were present in several cases (1995-C (Fig. 2.10a), 1997-C (Fig. 2.10b), and 1960-H-c2 (Fig. 2.7d)) but were used for entertaining guests; a *haa* served as the winter living space only in 2017-C3 (Fig. 2.10f), because that home occupied the footprint of a traditional cluster house with intact neighbors. Instead, in most cases, kitchens served as the primary winter living spaces (Fig. 2.10). In these, a seating area occupied one side; a contemporary countertop, sink, and natural gas cookstove occupied the other; and a wood-burning stove for cooking and heating occupied the center (Fig. 2.8). Like the traditional *haa*, this configuration invited people to gather in a central location, combining their warmth with that of fires for cooking and space heating. In homes without kitchens to accommodate cooking and seating simultaneously (e.g., 2010-C, 2019-C1, and 2020-C), living rooms heated with LPG gas heaters were used for winter living.

Figure 2.8. Interior of a contemporary kitchen with a wood-burning stove in the center, kitchen counter on the left, and seating space on the right (photographed by author Y.I., 2021).

4.3.2. Walls, floors, roofs, and windows

Wall and roof construction in contemporary homes was dominated by cement-based materials, including concrete masonry unit (CMU) blocks and cement-sand mortar in walls (Fig. 2.11g and 2.11h), cement-sand plasters and grouted tiles on interior surfaces (Fig. 2.8), reinforced cement concrete (RCC) in roofs, and poured concrete in floors. This transition from earth and stone was driven by convenience and durability: unlike stone, which required labor-intensive extraction from quarries and hand-shaping, CMU blocks could be purchased or molded on-site [71,72]. Cement mortars and plasters resisted moisture damage, as well, unlike mud-based materials, eliminating the need for annual replastering [3]. At the same time, the CMU and RCC construction used was much thinner and more thermally conductive than traditional wall and roof construction (Table 2.7), increasing vulnerability to heat loss.

Exposed chiseled stone (Fig. 2.11e and 2.11f) was a secondary material, found in the exterior walls of three dwellings (2000-C, 2015-C, and 2019-C2; Table 2.6, Fig. 2.10). This construction was intermediate, thermally, between traditional stone and CMU (Table 2.7). In an unusual variation, one dwelling (1995-C; Fig. 2.10a) held interior walls of stone, giving that building uniquely high thermal storage mass and therefore resistance to diurnal temperature swings [58]; another (1997-C; Fig. 2.10b and 2.11i) was built partially of baked mud bricks, with greater thermal resistance than CMU walls (Table 2.7).

In roof construction, corrugated metal became common, supported by wooden beams and plywood ceilings (Fig 2.11h). These assemblies were far more thermally transmissive than traditional roofs of wood and earth, even in insulated versions (Table 2.7). Reinforced cement concrete slab roofs emerged, as well, with similarly poor thermal performance, while wood-and-earth roofs remained prevalent but in a thinner, more thermally transmissive form (Table 2.7). Most contemporary dwellings (Fig. 2.10; Table 2.6), as well as contemporary additions to older buildings (Figs. 2.5 and 2.6; Table 2.4 and 2.5), used a mixture of metal, RCC, and contemporary wooden roofs. Together, the greater thermal transmission of these assemblies, and the general lack of second-floor *baldis*, created roofs with substantially greater susceptibility to heat loss than observed in traditional dwellings (Table 2.7) [65].

These thermal weaknesses were intensified by the presence of large doors and windows in all contemporary houses, as well as the single-paned construction of the windows and the lack of weatherstripping around doors or window sashes [68]. In some cases, windowpanes were missing glazing stops, and cracks were visible in window and door assemblies (Fig. 2.9), providing conspicuous air leakage pathways. At the same time, the skylights in contemporary dwellings were often glazed [73], unlike those in traditional and hybrid dwellings, partly counteracting the influences of larger doors and windows.

Figure 2.9. Windows in a contemporary structure showing: a) visible gaps between window sash and frame, and b) missing glazing stops (photographed by author Y.I., 2021).

4.3.3. Retrofits

Originally, most kitchens did not include woodstoves and large seating areas (i.e., in 2000-C, 2010-C, 2017-C2, 2019-C1, 2019-C2, and 2020-C). Occupants subsequently added these elements, however, either in the kitchens or in adjacent rooms (e.g., 2019-C2), highlighting their importance (Fig. 2.10, Table 2.6). In some houses (e.g., 1997-C and 2000-C), entirely new rooms were even constructed for installing woodburning stoves. Additionally, several households had added 1-3 cm thick plywood panels or polyurethane sheets to the lower halves of their winter living room walls. This measure was likely to reduce both conductive heat loss through the walls (Table 2.7) and radiant exchange with occupants, improving thermal comfort. At the same time, the contemporary wall, roof, and floor constructions; the single-pane windows; and the absence of entry vestibules and *baldis* on the upper floors of these winter living spaces increased their vulnerability to heat loss compared to that of the traditional *haas* (Table 2.7), resulting in persistently low indoor temperatures.

Together, this evidence establishes the architectural language of dwellings spanning the transition, revealing consistent patterns characterizing traditional, hybrid, and contemporary buildings. Notably, most older buildings had been modified using contemporary methods, while contemporary buildings had been modified to restore certain traditional elements. These adjustments and adaptations revealed the dynamic, ongoing roles of occupants in the transition, motivated by factors explored below through interviews.

Table 2.6. Contemporary dwellings documented through interviews

Code	Year	Design	Walls and windows[a]	Roof[a]	Floors[a]
2000-C	2000	2-story; living room, kitchen, bedrooms and bathrooms	Exterior walls contemporary exposed stone walls; interior walls contemporary CMU Single-glazed wooden windows	Contemporary RCC	Contemporary concrete
	2005	1-story; kitchen[b]	Contemporary CMU	Contemporary metal sheet	Contemporary concrete
2010-C	2010	1-story; living room[b], kitchen, bedrooms, and bathrooms	Contemporary CMU	Contemporary wooden	Contemporary concrete
2019–C1	2019	1-story; living room[b], bedrooms and bathrooms; verandah, kitchen under construction	Contemporary CMU Single-glazed wooden windows	Contemporary wooden	Contemporary concrete

[a] See Table 2.7 for construction details.
[b] Winter living space.

Figure 2.10. Contemporary houses built after 1990. a) ca. 1995; b) ca.1997, with 2017 addition; c) ca. 2015; d) ca. 2017; e) ca. 2017; f) ca. 2017; g) ca. 2019; h) ca. 2020. See Section 2.3 for code explanations. See Table 2.7 for construction details.

Table 2.7. Thermal properties of building materials and assemblies

	Traditional		Hybrid		Contemporary		IECC recom-mended U-values (W/m²K)[g]
	Assembly (exterior to interior)	U-value (W/m²K)	Assembly (exterior to interior)	U-value (W/m²K)	Assembly (exterior to interior)	U-value (W/m²K)	
Wall	**Plastered stone:** 2-3 cm mud plaster o/ 38-45 cm stone with mud mortar o/ 2-3 cm mud plaster	1.88[a] 2.55[b] [12]	**Plastered stone:** 2-3 cm mud plaster o/ 8-45 cm stone with mud mortar o/ 2-3 cm mud plaster	1.88[a] 2.55[b] [12]	**CMU:** 1 cm cement sand plaster o/ 20 cm CMU block with cement:sand: silt 1:2:2 mortar o/1 cm cement sand plaster	3.42[a] 3.02[c] [74]	0.34
					Polyurethane insulated CMU: 1 cm cement sand plaster o/ 20 cm CMU block with cement:sand: silt 1:2:2 mortar o/1 cm cement sand plaster o/ 1 cm of polyurethane sheet	1.31[a]	
					Plywood insulated CMU: 1 cm cement sand plaster o/ 20 cm CMU block with cement:sand: silt 1:2:2 mortar o/1 cm cement sand plaster o/ 1.5 cm of plywood panels	2.29[a]	
			Exposed stone: 38-45 cm stone with mud mortar o/ 2-3 cm mud plaster	2.1[a]	**Exposed stone:** 38-45 cm stone with cement mortar o/ 2-3 cm cement plaster	3.09[a]	

Table 2.7 Continued

	Traditional		Hybrid		Contemporary		IECC recommended U-values (W/m²K)[g]
	Assembly (exterior to interior)	U-value (W/m²K)	Assembly (exterior to interior)	U-value (W/m²K)	Assembly (exterior to interior)	U-value (W/m²K)	
			Retrofitted exposed stone: 38-45 cm stone with mud mortar o/ 2 cm cement plaster	2.55[a]	**Brick:** 12mm cement sand plaster o/ 23 cm brick with cement:sand: silt 1:2:2 mortar	2.1[a] 2.09[c]	
Roof	**Wood:** 1-2 mm clay o/ 10-15 cm mud plaster o/ birch bark o/2.5-4 cm wooden planks o/ 10 × 15 cm wooden beams (45 cm o.c.)	1.14[a] 0.55[b] [12]	**Wood:** 1-2 mm clay o/ 7-10 cm mud plaster o/ irch bark o/2.5-4 cm wooden planks o/ 10 × 15 cm wooden beams (45 cm o.c.)	1.43[a]	**Wood:** 1-2 mm clay o/ 6-8 cm earth o/ polyethylene sheet o/ 2.5 cm wooden planks o/ 10 × 15 cm wooden beams (45 cm o.c.)	1.83[a] 1.18[b] [12]	0.136
					Uninsulated corrugated metal: 0.7 mm corrugated sheet metal o/10 × 15 cm wooden beams (45 cm o.c.) o/ 5mm plywood	3[a]	
					Insulated corrugated metal: 0.7 mm corrugated sheet metal o/10 × 15 cm wooden beams (45 cm o.c.) 1 cm polyurethane sheet o/ 5mm plywood	1.3[a]	

Table 2.7 Continued

	Traditional		Hybrid		Contemporary		IECC recommended U-values (W/m²K)[g]
	Assembly (exterior to interior)	U-value (W/m²K)	Assembly (exterior to interior)	U-value (W/m²K)	Assembly (exterior to interior)	U-value (W/m²K)	
					Reinforced cement concrete (RCC): 15 cm thick concrete slab o/ 1 cm cement sand plaster	2.25[d] [74] 4.37[a]	
Floor	**Earthen:** 4-6 cm mud plaster o/ > 15 cm sand and gneiss aggregate o/ compacted earth **Floor coverings:** 1 cm synthetic rug o/ 1-2 cm woolen rugs; 5 cm thick elongated floor seating cushions on seating areas	1.25[e] (bare floors) 1.01[e] (with floor coverings) 0.87[e] (with floor coverings and cushions)	**Earthen:** 4-6 cm mud plaster over > 15 cm sand and aggregate o/ compacted earth **Floor coverings:** 1 cm synthetic rug o/ 1-2 cm woolen rugs; 5 cm thick elongated floor seating cushions on seating areas	1.25[e] (bare floors) 1.01[e] (with floor coverings) 0.87[e] (with floor coverings and cushions)	**Concrete:** 1.5 cm cement-sand plaster o/ 10 cm plain concrete o/ >15 cm sand and aggregate o/ compacted earth **Floor coverings:** 1-2 cm synthetic carpets and rugs o/ 7 mm polyurethane sheet; 5 cm thick elongated floor seating cushions on seating areas	1.5[e] (bare floors) 0.85[e] (with floor coverings) 0.75[e] (with floor coverings and cushions)	0.173
Door	0.6 × 1.2 m doors; sill height at 45-60 cm; lintel height 1.8 m; 10 cm wide × 13 cm deep door frame; 5 cm thick door panel	3.79[b] [12]	0.9 m × 2.1 m doors; 10 cm wide x 13 cm deep door frame; 5 cm thick door panel	3.79[b] [12]	0.9 m × 2.1 m doors; 4 cm wide × 10 cm deep door frame; 4 cm thick door panel	3.79[b] [12]	1.703

Table 2.7 Continued

	Traditional		Hybrid		Contemporary		IECC recommended U-values (W/m^2K)[g]
	Assembly (exterior to interior)	U-value (W/m^2K)	Assembly (exterior to interior)	U-value (W/m^2K)	Assembly (exterior to interior)	U-value (W/m^2K)	
Window and skylight	**Unglazed skylights:** *Haa*: 45 cm × 45 cm opening in the roof *Baldi*: 1.2 m × 1.2 m opening in the roof	n.a.	**Glazed skylight:** Single clear glass in 1 inch wide wooden frame.	6.55[f]	**Glazed skylight:** Single clear glass in 1 inch wide wooden frame.	6.55[f]	
			Wooden windows: 10 cm wide × 10 cm deep wooden frame, 10 cm × 5 cm wooden sash, 5 mm single glazing	4.7[f] 5.7 [75]	**Wooden windows:** 10 cm wide × 10 cm deep wooden frame, 10 cm × 5 cm wooden sash, 5 mm single glazing	4.7[f] 5.7 [75]	1.703
					Aluminum windows: 2 cm wide × 10 cm deep aluminum frame; 5 cm × 2.5 cm aluminum sash, 5 mm single glazing	6.9 [76]	

[a] U-values calculated using corresponding materials' thermal properties in Therm 7.8 [77]; see Supplementary Information.
[b] U-values estimated by Sullivan based on generic thermal properties of the construction materials [12].
[c] U-value of a comparable CMU wall constructions reported in CIBSE-Guide A [74].
[d] U-value of a comparable concrete roof slab, but with an additional 7.5 cm layer of cemnt screed reported in CIBSE – Guide A [74].
[e] Representative value calculated as shown in the Supplementary Information.
[f] U-values calculated in WINDOW v8.0.33 using values for generic clear glass [78] ; see Supplementary Information.
[g] International Energy Conservation Code (IECC) recommended values for components' maximum U-values [79].

a) Traditional wall: Mud and straw plaster on a traditional wall.

b) Traditional wall: Close-up of mud and straw plaster revealed beneath chipped white paint.

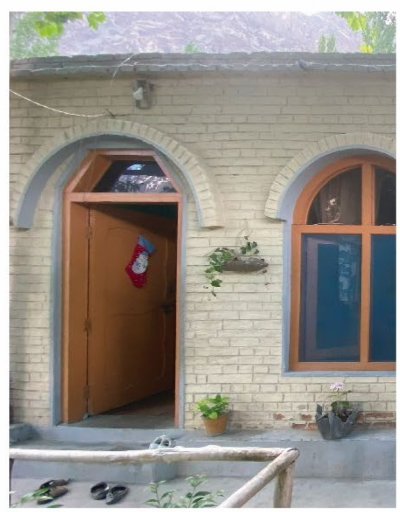
c) Hybrid plastered wall: Mud plaster removed, exposing stone structure and mud mortar.

d) Hybrid exposed stone wall: Ashlar masonry wall bonded with mud mortar.

e) and f) Contemporary exposed stone walls: Polygonal masonry walls built with hand-chiseled stones fitted together tightly and bonded with cement mortar.

g) Contemporary CMU wall: Wall built with CMU and plastered with cement-sand plaster on both interior and exterior.

h) Contemporary CMU wall with metal sheet roof: Under construction metal sheet roof and CMU wall.



i) Contemporary brick wall: Baked mud brick wall; plastered on the interior with cement plaster and painted on the exterior.

Figure 2.11. Photographs of typical traditional (a-b), hybrid (c-d), and contemporary (e-i) wall constructions observed in Hunza.

5. Thermal experiences and adaptations

Residents' motivations for pursuing the adaptations described above, originating with their thermal experiences in their homes, were next investigated through interviews (Fig. 2.1). These began with open-ended questions to allow themes to emerge; subsequent, semi-structured interviews explored these themes in greater detail (Section 2.4; Fig. 2.1). Most interviewees had experienced winter conditions in both traditional and contemporary homes, allowing them to compare the two, although they did not always distinguish between hybrid and traditional *haas* in their comments. Clarification has been added where necessary.

5.1. Thermal stress

Interviewees highlighted the warmth and comfort of traditional *haas*, compared to the intense cold stress they experienced in contemporary winter living spaces, in 19 of the 23 interviews:

> (The) old traditional *haa* constructed with clay is mostly used in winter because it doesn't get too cold inside. It stays warm. We use it (the *haa*) more in winter, but the other rooms, like the hall (living room), etc., we use them in the summers because (CMU) block structures are colder than the old house. (The *haa*) has more warmth inside.

Quote 2.2: 1975-H-c

> I think [the *haa*] is much better than a new house. It is cool inside this house in summer, and in winter, it stays warm.

Quote 2.3: 1600-T

Accordingly, residents used traditional or hybrid *haas* for winter living in six of the nine dwellings in which *haas* were present (Figs. 2.6, 2.7, 2.10; Tables 2.4, 2.5, 2.6):

> When it is warm outside in the summer, [the *haa*] is colder inside. And in winter it is warm. So that is the benefit for us. That is why we haven't demolished it yet…

Quote 2.4: 1900-T-c3

Contemporary kitchens, in contrast, were consistently reported to be agonizingly cold and difficult to heat:

> Believe me, it becomes doomsday when winter is here. It gets hard for us. (With) the fire in front of us, our faces warm up a little. (But) the cold from the walls tears up our backs.

Quote 2.5: 1979-h-C

> (A concrete house) is extremely cold during winter… and in summer (it is) very hot. That is the (property of a) cement block. It will be very cold in the winter, and in the summer, it will be very hot.

Quote 2.6: 2010-C

> People don't consider it when they decide to build with concrete… but in winter it is extremely troublesome, then they become worried. It becomes too cold for them.

Quote 2.7: Local carpenter

This central theme, namely the prevalence of cold stress in contemporary buildings, focused the subsequent explorations. These addressed spatial and behavioral adaptations, the beliefs and motivations underlying these adaptations, and their limitations.

5.2. Space heating

Space heating is essential for survival in Hunza, even in the most thermally sheltered traditional houses [1,70,73]; the prevalence of central hearths among winter living spaces of all ages attested to this need (Section 4). Accordingly, space heating practices emerged in every open-ended interview and were explored further in semi-structured interviews (Section 2.4).

5.2.1. Heating fuels

Wood and biofuels, including sea buckthorns and nut shells, have historically provided the majority of domestic fuels in Hunza [69,80,81]. Accordingly, 20 of the 23 studied households used wood for heating: fifteen households acquired wood from the homeowner's land; four households purchased it from the local market; and one household depended on donated wood. The other three dwellings (2010-C, 2017-C2, and 2019-C1) had no spaces to install wood-burning stoves, and the occupants heated with liquid petroleum gas (LPG) instead. LPG cylinders and cooking stoves were introduced in Hunza in the 1980s; later, LPG-powered portable heating stoves also became common [70,80]. However, interviewees regarded LPG as inferior to wood because it could not provide sufficient heat:

> We mostly cook and heat using LPG. Burning firewood is not possible: we do not have a *haa*. The rooms have no systems for installing a wood-burning stove… we hardly subsist—sometimes (with) a gas heater, sometimes electricity, which is limited here.

Quote 2.8: 2010-C

Additionally, LPG cylinders had to be imported from southern Pakistan, and the distance and frequent landslides on the Karakoram Highway [13] caused supplies to be expensive and unreliable. Finally, gas combustion was considered hazardous:

> Gas stoves have many detriments; because of gas heaters, we get respiratory problems, coughs, and breathing problems… Wood burning has never been harmful, but there have been many incidents with LPG; many people have died... Last year, there were incidents in Gulmit, …Sost, and …Karimabad.

Quote 2.9: 2019-C1

Electricity was used as a secondary heating source in three households (1800-t-C, 2010-C, and 2017-C2), but this source was limited, since the local hydropower stations were powered by glacial streams that became intermittent in winter [13,14]:

> We do not get enough electricity. That is why we cannot use electric appliances such as heaters … people of Hunza are in the dark for 18 to 20 hours (each day).
>
> Quote 2.10: 2015-C

Interviews, therefore, revealed that wood and biofuels were critically important for thermal survival, echoing findings from other developing regions in which access to natural gas and electricity is unreliable [82].

5.2.2. Heating systems

Despite this importance, owners of five contemporary houses (2000-C, 2010-C, 2017-C2, 2019-C2, and 2020-C) originally excluded wood-burning systems to avoid the accumulation of soot on indoor walls and the passage of smoke ducts through second-story rooms:

> (Wood-burning) makes smoke, causing many problems. For a smoke exhaust pipe, you must drill a hole of appropriate shape and size (in the roof).… Here on the ground floor, it is not possible (to pass a smoke pipe through the roof due to the room above).
>
> Quote 2.11: 2019-C2

These households faced extreme thermal stress as a result, necessitating further spatial adjustments. In 2000-C and 2020-C, the owners constructed new low-budget detached kitchens with CMU walls and uninsulated metal roofs to accommodate wood stoves. Unfortunately, however, these thermally transmissive constructions (Table 2.7) were difficult to heat:

> We have a detached kitchen, which we use as a living room during winter… We use the traditional heating system and have a raised seating area in the kitchen. It is built of (CMU) blocks… We must heat the room throughout the day due to the intense cold; staying without burning is impossible.

Quote 2.12: 2000-C

In 2019-C2, a family of five installed a wood-burning stove in a small storeroom to create a winter living space (Fig. 2.10g). To avoid interrupting the upper floor, the owners passed the exhaust pipe through an exterior wall, but the horizontal positioning was so ineffective that smoke accumulated indoors, and soot covered both interior and exterior wall faces:

> (To install a smoke vent pipe) we had to get a grinder and make a hole through the stone wall. There were no other solutions … but the smoke outside caused problems. Sometimes, smoke came back inside; sometimes, it came in through the windows; sometimes, it just went sideways in the direction of the wind, and that caused a disturbance.

Quote 2.13: 2019-C2

In 2017-C2, a rental unit, the landlord likewise restricted wood burning originally to avoid soot accumulation. However, considering the extreme thermal stress, he eventually permitted the tenants to install a wood-burning stove and cut a smoke exhaust hole through the metal sheet roof:

> There was nowhere to put the smoke exhaust pipe. The (rental's) owner restricted us from cutting a hole (in the roof). He does not want the walls blackened because of smoke. But he has permitted us to cut a hole for the upcoming winter.

Quote 2.14: 2017-C2

However, these adjustments in contemporary houses did little to provide thermal relief, as reflected by reports of thermal stress:

> During winters it is cold… Only if there is a proper traditional heating system with insulation (in the walls and roof), then there would be no problem. (Feeling) cold during winters is a constant situation.

Quote 2.15: 2019-C2

5.2.3. Heating extents

Strikingly, interviewees noted that traditional *haas* required the least heating among all housing types. In these dwellings, cooking fires provided adequate heating:

> (During winters) we light a fire to prepare breakfast in the morning; tea at 10:00 am; lunch in the afternoon; evening tea; and dinner. Unlike other people, we do not light a fire (specifically) for heating.

Quote 2.16: 1900-T-c3

Hybrid *haas*, in contrast, required additional heating to supplement cooking fires:

> [We heat] for approximately six hours every day. If we feel cold, we burn a fire to keep the house warm and to maintain a normal temperature. (It remains warm) for around one and a half hours, and after that, it cools down again.

Quote 2.17: 1950-H-c

Furthermore, contemporary homes required continuous heating, especially when their families included elders or infants. Even so, the occupants experienced thermal stress and sometimes needed to burn two fires simultaneously:

> We must keep burning fires throughout the day because we have kids in the house.

Quote 2.18: 1800-t-C

> [My mother-in-law] cannot stand the cold... One fire is inadequate; we must use two wood-burning stoves in the kitchen—one for cooking and another for heating. We used to light up (both stoves) together for her.
>
> Quote 2.19: 1997-C

This extensive heating approximately doubled the fuel needed in contemporary houses compared to their traditional counterparts:

> 20-25 maund (~800-1000 kg) will not be enough. We burn even more (wood). It is hard to know when you continuously burn wood… The fire keeps burning during winter.
>
> Quote 2.20: 1950-h-C

> We use less wood than those who have concrete houses. Other people (contemporary home residents) tell us they use several trucks (loads of) wood. For us, my son got only 10 maund (~400 kg) of plumeria wood, and we spent our winter with that.
>
> Quote 2.21: 1900-T-c3

As a result, cold stress was extensive among low-income households living in contemporary houses with limited firewood resources. These families survived on the natural gas and wood they could purchase, supplemented by wood donated by their families:

> Last winter was freezing… We somehow managed by burning fires, using a wood stove and an additional gas heater. We hardly survived. We used more wood (than in the old *haa*) … Buying wood is a problem for us. We survive on the wood provided by others. If we do not have it, then we use gas. (Last winter) we used my uncle's cherry trees, and my aunt gave us wood.
>
> Quote 2.22: 2017-C1

In traditional homes, in contrast, low-income households found thermal comfort more accessible:

> Everyone appreciates this house of ours during winter for comfort. They say it is warm... Our house gets warm easily with a little wood (burning).
>
> Quote 2.23: 1900-T-c3

The convergence of extreme cold, spatial limitations, and fuel poverty peaked in the upper-story rental unit of 2019-C2. Without a woodstove or the ability to afford natural gas, and living in a thermally transmissive building envelope, the tenants resorted to open coal combustion to survive.

5.3. Architectural responses

The factors above led residents to pursue numerous modifications to their buildings, relying on their thermal experiences as well as ongoing experimentation to ameliorate the relentless indoor cold, particularly in hybrid and contemporary homes.

5.3.1. Floors and walls

The practice of sitting on the floor and leaning back against a wall was observed in all dwellings (Figs. 2.4 and 2.8); as a result, wall and floor thermal properties figured prominently in daily experiences. Occupants of contemporary dwellings described persistently cold concrete floors despite coverings of polyurethane foam sheets, synthetic carpets and rugs, and elongated floor cushions. In contrast, such experiences were not noted in traditional or hybrid *haas,* in which earthen floors were covered by woolen rugs and floor cushions (Table 2.7):

> The floor is mostly cold. It might be because it is cement (concrete). There is carpet underlay, too. Still, we feel cold from the floor.
>
> Quote 2.24: 2017-C1

Similarly, interviewees experienced contemporary cement-plastered CMU walls as cold, and mud- and straw-plastered traditional walls as intrinsically warm:

> During winter, we could not lean our backs against the cement-plastered wall. It got freezing (cold) on our back.

Quote 2.25: 1997-C

> Straw has insulation in it. When straw is used in wall construction, and you lean on it… it is very warm. Its nature is warm.

Quote 2.26: 1979-h-C

These cues gave the interviewees specific beliefs about the influences of building materials on indoor thermal environments:

> Walls that are made of stone… for example these houses of the ancient times… the thick stone (in them) does not bring the outdoor cold inside and does not allow the inside (heat) to go out. I mean it acts as an insulation. Therefore, the traditional *haa* is very durable, even for the cold it's very good.

Quote 2.27: Community gatekeeper

> The walls are huge; they are built of mud and stone instead of (concrete) blocks. It is also in the (sheltered) corner, so cold winds cannot enter directly. The roof is wooden... That is why (this room) heats up very quickly.

Quote 2.28: 1960-H-c2

> (A concrete house) is extremely cold during winter… and in summer (it is) very hot. That is the (property of) CMU. It will be very cold in the winter, and in the summer, it will be very hot.

Quote 2.29: 2010-C

> [When] the sun shines outside (a CMU), it reaches inside, into the room. And when it is

> cold (outside)… it easily brings in the cold inside… (The *haa*) used to be warmer due to mud plaster. You know mud plaster is warmer than cement.

Quote 2.30: 1950-h-C

In contemporary kitchens, the coldness of concrete walls contrasted with the heat from central stoves, creating thermal asymmetries that intensified perceptions of the intrinsic coldness of concrete (see Quote 2.5, above).

These understandings are consistent with the materials' known properties: the thermal conductivity of cement plaster is substantially greater than that of earthen plaster, for example, causing cement-plastered surfaces to feel cooler to touch than earthen surfaces of the same temperature [83,84]. The related property of thermal transmittance (U-value) is also substantially greater in contemporary walls than in traditional walls, causing them to lose heat more rapidly. For context, however, the thermal transmittance of traditional walls is itself far greater than that specified by the International Energy Conservation Code (IECC) for climates like that of Hunza [46,48], exceeding the recommended value by a factor of approximately 5 (Table 2.7).

To avoid contact with cold concrete, residents of 1800-t-C, 1995-C, and 1997-C lined the lower halves of their walls with wooden panels, while residents of 2017-C2 used polyurethane foam sheets. All households used bolster pillows and backrest cushions, as well (Fig. 2.4b and 2.8):

> Our backs froze (when leaning on concrete walls). But after installing wooden panels inside, we can easily lean on the wood.

Quote 2.31: 1997-C

> Most of the cold comes from the walls. That is why we have installed (polyurethane) underlay on the walls. It has made a difference. It is warmer after that.

Quote 2.32: 2017-C2

Reducing direct contact with wall surfaces relieved thermal stress substantially, because it interrupted conduction from warm skin to cold wall surfaces. At the same time, this strategy could not have considerably lowered the buildings' overall heat loss rates, because it did not appreciably lower the walls' thermal transmittance, even on the covered portions (Table 2.7), revealing a limitation of the occupants' perception that may have discouraged further action.

In a second response to the perception of stone as warmer than concrete, residents of 2019-C2 and 2015-C decided to build stone walls as an adaptation:

> The walls are made of stone with very little cement to keep the house warm in winter… it is not as cold as other houses, and the reason is that in my house, stone is used.
>
> Quote 2.33: 2015-C

> We built our house with stone because it keeps the house warm.
>
> Quote 2.34: 2019-C2

Residents had evidently not perceived, however, that contemporary stone walls were more thermally transmissive than traditional walls, as the result of their tightly-fitted stones and cement-based mortar and plasters (Table 2.7). Still, the greater thickness of the stone walls presumably did reduce their thermal transmittance compared to CMU walls, and their higher thermal mass presumably captured heat from fires during the day more effectively, maintaining warmer nighttime temperatures according to known thermal properties and heat transfer mechanisms [58].

Based on their experiences with mud plasters, some owner-builders had also considered using stabilized mud blocks, with significantly lower thermal transmittance than CMU blocks [74,85]. They ultimately chose CMU, however, because they believed mud blocks were too structurally weak to support vertical construction:

> My brothers were thinking of using mud blocks for walls, but they had to build with RCC

> because they needed more rooms and had little space (implying the need for multiple stories) … Those mud and sawdust blocks would have been better if they could have done that.

Quote 2.35: 1960-H-c2

Similarly, the owner of 1997-C opted to build with baked mud bricks, which had recently been introduced to Hunza at the time, believing they would maintain indoor warmth more effectively:

> At that time, bricks were famous; they were new. We also heard that the brick walls are stronger and that for weather, it is not too cold in cold seasons or hot in warm seasons. So that is why we used these bricks.

Quote 2.36: 1997-C

Ultimately, however, the closure of the local brick manufacturing kiln compelled 1997-C's residents to resort to CMU assemblies for subsequent room additions. Both of these cases illustrate accurate perceptions regarding thermal properties of materials, as bricks and mud blocks are indeed more thermally resistant (i.e., insulating) than CMU [74,85,86], that were nevertheless thwarted by external limitations.

5.3.2. Roofs

Interviewees believed that traditional, hybrid, and contemporary wooden roofs retained indoor warmth well in winter, whereas contemporary RCC and metal sheet roofs did not:

> (Contemporary) wooden roofs are very nice for Hunza, just like the traditional ones. There is less cold inside. Reinforced concrete (roofed) homes are durable and easier to build but ineffective against cold.

Quote 2.37: 2010-C

> It becomes cold if we use (metal) sheet (roofs). It becomes hot under the (metal) sheet in

summer and cold in winter.

Quote 2.38: 1960-H-c1

Considering these experiences, a majority of residents built wood and earthen roofs in their contemporary constructions as protection against the cold:

> I built the house using a combination of new and traditional methods... It is weather resistant because in winter, it is not very cold, and in summer, it is not too hot… the techniques include using poplar wood for the roof, because of which the temperature inside our house is maintained.… so the house can stay warm in winter.

Quote 2.39: 2015-C

This perception aligned with known thermal properties: RCC and metal sheet roofs have considerably higher thermal transmittance than wooden roofs (Table 2.7). Contemporary wooden roofs, however, were twice as thermally transmissive as traditional roofs (Table 2.7) due to their thinner layers [12]. Interviewees evidently could not perceive these differences, however. For context, these wooden roof assemblies exceed IECC-prescribed thermal transmittance values for climates like that of Hunza by eight-fold or more (Table 2.7).

Considering the thermal stress of living under metal sheet roofs, residents of 1960-H-c1 installed polyurethane foam sheets, commonly used as carpet underlays, between metal exteriors and plywood ceilings of their newly built addition:

> If you use that underlay (above the plywood ceiling) and the metal sheet on top of it, (the roof) resists heat and cold.

Quote 2.40: 1960-H-C1

Although these new layers reduced metal roofs' thermal transmission by approximately one-third, their thermal transmittance values remained far greater than prescribed IECC values (Table 2.7).

5.3.3. Doors, windows, and skylights

When asked about fenestration, interviewees primarily commented on airflows associated with openings in building envelopes. All interviewees living in traditional *haas* reported low air leakage, attributing this to the lack of windows and the shelter against prevailing winds provided by surrounding earth:

> The *haa* had a system (i.e., configuration) with a low height. Its (floor) height was 1 or 2 feet (30-60 cm) below the ground level. Due to its being further down (embedded in the ground), the wind went around it... (The *haa*) did not have any windows. There was only one skylight, which used to be closed (with a plastic sheet)... That is why it remained warmer during the winter.

Quote 2.41: 2019-C1

In contrast, residents of contemporary and hybrid dwellings reported substantial thermal stress due to air leakage through doors, windows, skylights, and smoke vents. Cold gusts through the doorways were particularly pronounced. Additionally, detached contemporary houses built on elevated locations were more exposed to prevailing winds:

> Most of the cold enters from the clerestory windows or when we open the doors… It is freezing cold in December and January. As soon as you open that door, a cold gust of air enters.

Quote 2.42: 1950-H-c

> When we stop (burning fire), the cold comes in through the smoke vent and flows out through there (stove).

Quote 2.43: 1800-t-C

> The new houses have many windows. Through the windows, the air can cross (ventilate) more.
>
> Quote 2.44: 2019-C1

> Our old house was warmer because it was made of mud. This house is much colder because it is made of CMU blocks and built in a higher location.
>
> Quote 2.45: 2017-C1

To reduce airflows, residents of contemporary and hybrid dwellings used doors as little as possible. For example, the residents of 1800-t-C (Fig. 2.6b) accessed their kitchen only from the verandah in winter, keeping the door to the outdoors locked, while residents of 1950-H-c (Fig. 2.7a) primarily entered their hybrid *haa* through the kitchen, avoiding access from the verandah:

> We use only one door in the winter because it would get cold. The way to enter the *haa* was through this kitchen. The other door opening towards the verandah remained closed.
>
> Quote 2.46: 1950-H-c

To further reduce air entry, skylights in all contemporary and retrofitted kitchens were glazed; whereas all hybrid *haas'* unglazed skylights were sealed with polyethylene sheets. Smoke vents, however, remained open:

> If the skylight is sealed with plastic, and the doors are kept closed, then the *haa* stays heated… the only thing that we do is use plastics on windows, ventilators, and skylights to cover the areas where air flows in.
>
> Quote 2.47:1950-H-c

To reduce airflow through gaps in window frames (Fig. 2.9), residents applied clear polyethylene sheets to the outer window surfaces of half of the dwellings with windows (11 of 22). They installed interior curtains as well, reporting that these measures effectively reduced thermal stress:

> We seal the windows (during winter). Inside, there are curtains, and outside we put plastic.
>
> Quote 2.48: 1800-t-C

> We seal all the windows with plastic. There are ventilators; we seal them with plastic as well. For some reason, when we tightly seal everything with plastic (polyethylene sheets), the stove makes a big difference... In winter, we put plastic outside (the windows) to stop the air. And inside we have curtains.
>
> Quote 2.49: 1997-C

The primary benefit of attaching polyethylene sheets to window exteriors was the reduction of outdoor air leakage [87,88]; interviewees perceived this problem accurately and responded effectively, allowing them to realize substantial thermal improvement. However, they could not recognize that cold indoor air drafts were created in part by indoor airflow across cold window surfaces, which were unaffected by the sheets [37,89]. Believing that these drafts also resulted from outdoor air leakage, they employed free-hanging curtains, which they regarded as barriers to such airflow. In contrast, however, such curtains improve thermal comfort largely by blocking radiant exchange between people and cold surfaces [90]. Despite this limited understanding, however, the combined use of exterior polyethylene sheets and interior curtains substantially improved occupants' thermal experiences.

In the most unusual window adaptation observed, occupants of 1997-C reported operating curtains on their detached kitchen's south-facing windows to promote passive solar heating:

> The sun rises in front (of the window) and falls directly inside, and when it comes in through the glass, we do not need to burn too much (fire for heating) inside the house. There are big windows on either side (of the kitchen). The sunlight falls on the windows

from either side. And it remains warm inside in the winter.

Quote 2.50: 1997-C

This practice was consistent with the known passive solar heating potential in comparable climates [91], showing the accuracy of the underlying perceptions and highlighting a potentially promising accessory heating strategy in Hunza.

5.3.4. Exposure to the outdoors

Interviewees reported that frequent outdoor trips for retrieving water and for washing, due to the absence of indoor plumbing in traditional *haas*, were significant causes of thermal stress:

> If there were a system to install a wash basin here (indoors), it would be very nice... Taking the dishes outside and washing them causes discomfort because it gets cold outside.

Quote 2.51: 1900-T-c3

In contrast, they noted that contemporary and retrofitted hybrid kitchens with indoor plumbing facilities alleviated this stress:

> Water was a problem in the old *haas*. We had to bring it from outside and store it inside. Now, every facility is available inside (the kitchen). So, it is better in that sense.

Quote 2.52: 1800-t-C

> It feels warmer (in the kitchen) because of the facilities. It was much colder earlier. It used to snow, and we had to bring water from wells, and there were many troubles like that. But now, thankfully, the water comes inside the kitchen, and everything is available here.

Quote 2.53: 1960-H-c1

Therefore, residents of 1800-t-C, 1940-t-C, and 1950-h-C preferred using contemporary kitchens instead of their *haas*:

> In a traditional *haa*, we must bring water in buckets like in ancient times. Instead of facing that problem, we use the kitchen. There is water in the kitchen, and... the bathroom and kitchen doors are side by side. So, because of those facilities, we live in the kitchen… I do not want to be thankless towards the traditional *haa*, but then we had to carry water into that *haa*. There was no plumbing system. To use the bathroom, we had to step outside. To avoid facing those difficulties, we do not use the traditional *haa*.
>
> Quote 2.54: 1950-h-C

> Water was a problem in the old *haas*. We had to bring it from outside and store it inside. Now, every facility is available inside (the kitchen). So, it is better in that sense.
>
> Quote 2.55: 1800-t-C

However, the installation of plumbing systems in the entry lobby of 1600-T (Sections 4.1.3; Fig. 2.6a) and in the kitchen (attached to the *haa*) in 1950-H-c, (Section 4.2.4; Fig. 2.7a) allowed residents to continue living in their *haas* without making frequent trips to the cold outdoors, improving residents' comfort and convenience:

> We bring dishes inside (the kitchen) into the basin. (The kitchen temperature) is not very different (from the *haa*s). It is definitely much colder in December and January. Still, it is better than (washing dishes) outside.
>
> Quote 2.56: 1950-H-c1

5.3.5. Space and volume

In 1800-t-C and 1950-h-C, interviewees reported that the smaller volumes of contemporary kitchens compared to traditional *haas* were a prominent thermal benefit, allowing kitchens to warm rapidly when fires were lit. Based on these perceptions, the residents used their kitchens for winter living despite having traditional *haas*:

> The old *haa* is too big, so it will not heat, no matter how much fire we make. This (contemporary) kitchen is small, so it warms up quickly when we burn a fire. That is why we use this (kitchen).

Quote 2.57: 1800-t-C

In contrast, all other interviewees reported *haas* to be warmer than contemporary kitchens and to retain heat for longer periods, reducing heating fuel needs:

> We live there (in the *haa*) during winter because less wood gets used. In a (modern) cement house, more wood gets used, and they cool down very quickly… [Our traditional *haa*] is very warm in the winter… So that is a benefit for us.

Quote 2.58:1900-T-c3

The combined effects of material thermal properties, spatial volumes, and fuel availability may explain these divergent opinions among interviewees. While contemporary kitchens held small volumes of air that warmed quickly [63,92], their thermally transmissive envelopes (Table 2.7) also lost heat rapidly, causing them to require continuous heating. While households 1800-t-C and 1950-h-C had ample fuel resources and could maintain fires in their contemporary kitchens throughout each day (Quote 2.20), low-income families could not sustain continuous heating in such spaces (e.g. 2017-C1, 2017-C2, 2017-C3), leading to extreme thermal stress (Quote 2.22).

Accordingly, the contemporary *haas* of 2017-C3 (used for winter living) and 1960-H-c2, 1995-C, and 1997-C (used as guest lobbies) posed the disadvantages of both larger volumes as well as thermally transmissive contemporary walls and windows. However, people attributed the indoor cold primarily to their larger volumes:

> (The *haa*), it is very spacious, and there are not many people to stay there and burn more fires than needed. We can cook and heat simultaneously in the kitchen (instead).

Quote 2.59: 1960-H-c2

> (The *haa*) It is too wide (spacious), and it does not get warm inside for us. Here, the kitchen is (comparatively) smaller; it warms up quickly. But in the *haa*, it is not like that.
>
> Quote 2.60:1997-C

In contrast, the retrofitted kitchens of 1960-H-c1 and 1960-H-c2 offered the benefits of both traditional materials and smaller volumes, and their inhabitants reported feeling warm at all times with little wood burning:

> [Compared to the *haa*], even here is fine. Even here, it is warm in winter.
>
> Quote 2.61: 1960-H-c1

> Female interviewee: Well, we did not feel it (cold) much unless we stepped outside. Because we lit fires, we did not feel (cold).
>
> Male interviewee: I did not feel cold. I could stay comfortable without lighting a fire for more than an hour.
>
> Quote 2.62: 1960-H-c2

5.4. Personal responses

Personal responses such as changing clothing, altering activity levels, consuming hot or cold food and beverages, and relocating to different spaces are known to important mechanisms of coping with thermal stress [93]; these were actively pursued by the interviewees, as well.

5.4.1. Space use patterns

Seasonal variation in the use of spaces was found in all dwellings except the single-room dwelling, 2017-C3. In 18 of the remaining 22 cases, interviewees used only their cooking spaces for winter living, reserving the cooler *baldis*, verandahs, and living rooms for summer (Quote 2.2):

> In summer, we live upstairs in the *baldi*; we cook and do everything there. If it gets too

> hot, we come down to the verandah. Otherwise, we live in the *haa* during winter, from December until March.

Quote 2.63: 1900-T-c2

The remaining households either heated summer living rooms for winter use, or lived in unheated living rooms with brief retreats to cooking spaces for warmth, showing less rigid distinctions between summer and winter space use.

Traditional and hybrid *haas* supported the shared use of winter living rooms with varied floor levels that distinguished sub-spaces, allowing multiple activities to occur in the same room simultaneously. The two raised seating areas on either side of the hearth, for example, provided nooks for individual and small group activities:

> (For studying) I did not face any problems related to space. I just used to sit on a side (seating area).

Quote 2.64: 1600-T

Contemporary and hybrid kitchens, however, were more compact, with single seating areas. Sharing common spaces, therefore, often clashed with individual needs. For example, children studying needed quieter spaces, compelling them to use colder rooms heated only with LPG gas heaters:

> The kids sometimes studied in a separate room with a heater. For our chit-chats, we are used to the disarray; we do not ask each other to be quiet. We spend our time hooting and laughing.

Quote 2.65: 1997-C

Contemporary dwellings, without kitchens to accommodate both cooking and heating, challenged traditional seasonal space-use patterns significantly. Dwellings 2010-C and 2019-C1, for example, provided no space for wood burning, compelling families to gather in minimally (LPG) heated living rooms that were designed for summer living. 2019-C2 and 2020-C held small spaces with wood-burning stoves for cooking, but these were too cramped for living. As a result, 2020-C residents lived in their LPG-heated living room, while 2019-C2 residents primarily used unheated bedrooms, visiting the small cooking areas briefly for warming. Consequently, these four households experienced more thermal stress compared to those with adaptable space use.

Daily patterns in space use with thermal significance also emerged. During the day, residents cooked, conversed, and watched television in the *haas* and kitchens, concentrating all internal heat gains from people, electric appliances, and fires in one location. Interviewees found this strategy helpful in providing warmth and reducing fuel needs:

> We use it (*haa*) for cooking. It stays warm due to cooking.

Quote 2.66: 1975-T-c

> I prefer having them (family) closer to the cooking area. If I cook here, and they are over there (in another room), it costs double the fuel.

Quote 2.67: 1960-H-c2

At night, in hybrid and contemporary homes, most nuclear families slept together in their kitchens on removable floor bedding to conserve warmth, consistent with the traditional practice of sleeping in the *haas* [1]. In extended families, however, children and adults slept in bedrooms for privacy, allowing people more sensitive to cold, including infants and elders, to sleep in the kitchens:

> We use the kitchen for sleeping. It is not possible to sleep in bedrooms in the extreme cold.

Quote 2.68: 2000-C

> My mother gets migraines if exposed to extreme cold, so my younger brother sleeps with her in the kitchen. The rest of us sleep in the (bed)rooms.
>
> Quote 2.69: 2019-C2

Bedrooms were reportedly frigid because they were either unheated or heated only briefly with electric or gas heaters before sleeping. Occupants therefore used multiple layers of bedding to stay warm:

> We only heat the bedrooms for around 15 minutes, and afterward, we turn the heater off and go to bed. It is not as warm there as it is in the kitchen.
>
> Quote 2.70: 2017-C2

> We do not heat our bedrooms. It is only bearable when we sleep in many layers of quilts and blankets. We feel warm when we use two blankets and two quilts.
>
> Quote 2.71: 1940-t-C

Sleeping in contemporary kitchens reduced nighttime thermal stress substantially, but it was less effective than sleeping in traditional *haas* and hybrid kitchens:

> (We use) a wool blanket and a quilt. It is still very cold, and the bedding feels inadequate. The temperature feels fine with two mattresses (under us). If we use one mattress, it feels cold.
>
> Quote 2.72: 2017-C1

> We slept in the same room (hybrid kitchen) during winter. It was unlike (other houses in) Hunza, where they use lots of bedding. A blanket and a comforter were enough... We (once) slept there (in the detached contemporary kitchen) for 3 or 4 days. Even though we used to sleep with three or four warm blankets and many (mattress) layers underneath us and would put caps and other clothing on, I had to wake up at night to light a fire.

Quote 2.73: 1960-H-c2

5.4.2. Activities and food

Residents of contemporary dwellings described huddling together in blankets, watching television, and engaging in conversation around fires as strategies for staying warm:

> (At home), our children need blankets. They stay in blankets not too close to the stove but a little back (farther from the furnace). They put blankets on their feet while watching TV.

Quote 2.74: 1997-C

They also ate high-energy and/or hot foods, including dry fruits, fatty foods, soups, and meat, to stay warm:

> We store dry fruits for the winter, like dried apricots and almonds. They are not as enjoyable during summer as they are during winter. When we eat them during winter, we feel warm.

Quote 2.75: 2017-C2

> We need wood and a wood-burning stove during winter, and we must keep sipping warm soup. (Other than that) we need powerful meals, like meat. They might not be suitable for summer. During winter, we use apricot seeds and oils.

Quote 2.76: 2017-C3

In traditional and hybrid dwellings, residents did not report using blankets during the daytime, as indoor temperatures were adequately warm (Quote 2.3, 2.4, and 2.2). However, consuming high-energy food remained an important adaptation:

> We used to store apricots, and we used to have dry apricots at our home. We used to make soup and juices out of dried apricots. Then we had apricot nuts; our mothers used to grind the nuts, make dechirum (a dish prepared with ground nuts and bread), and give it to us. Before bedtime, my mother would roast some nuts and give them to us with dried apricots. We ate it all together.

Quote 2.77: 1600-T

> We use things that cause the body temperature to remain high; for example, soups or soupy noodles are cooked more because they keep the body warm.

Quote 2.78:1975-H-c

5.4.3. Clothing

Winter clothing needs varied substantially among the dwelling types, reflecting indoor thermal conditions. In traditional and hybrid dwellings, inhabitants reported feeling comfortable wearing only single layers:

> It is so warm inside that I sometimes wear a single tee shirt… While going outside, I wore a long coat and hung it when coming in. I spent most of the winter in a single shirt or just a shawl over it.

Quote 2.79: 1960-H-c2

> Even in a single layer of clothing, it is warm inside. This house is well sheltered, so (cold) air does not come into the house.

Quote 2.80: 1900-T-c3

In contrast, occupants of contemporary houses wore multiple layers of warm clothes indoors, yet still experienced thermal stress:

> [We wear] a sweater, another sweater on top of it, and another one over that, and a coat…inside (the house).
>
> Quote 2.81: 2017-C1

> We must put coats on top of coats—multiple layers. Even when the fire is burning, it is very cold.
>
> Quote 2.82: 2017-C3

> We wear a lot of layers, sweaters, and coats. We keep them on all the time, even when we are inside. For kids, it is around three to four layers. The little one even had five layers on because he had pneumonia… One sweater is not enough; at least three to four layers, or when it is the coldest in January, even five.
>
> Quote 2.83: 2020-C

5.5. Summary

Together, the findings above document a marked increase in thermal stress associated with the transition from traditional to contemporary housing forms, consistent with the use of more thermally transmissive building materials to construct smaller, more thermally separate spaces. Nevertheless, the benefits offered by contemporary dwellings, including durability, convenience, privacy, and indoor plumbing, as well as the opportunities for thermal adaptation, prompted vigorous experimentation rather than avoidance of contemporary building methods. Residents were therefore actively involved in the transition, adopting contemporary methods intentionally and experimentally in ways reminiscent of the experimentation that gave rise to traditional buildings. Further, they guided their experimentation with thermal concepts that were effective, if incomplete, highlighting the potential of information rather than technical solutions to address the resulting thermal stress. These findings challenge the prevailing academic view that neglects the roles of owner-builders and residents in traditional-to-contemporary housing transitions, regarding the people instead as passively receiving these changes [15,16,27,94], and suggest instead that active networks of social and technical processes may inform and shape building transition processes more generally.

6. Conclusions

The adoption of contemporary building materials and methods is progressing throughout the developing world, displacing traditional buildings that evolved to provide thermal comfort in their corresponding climates with modern structures that require far more heating and cooling energy [15,17,18,20,94]. Because such energy is often not readily available, indoor heat and/or cold stress frequently result [7,16,17,95]. Nevertheless, these building transitions continue, previously attributed to a combination of economic factors, promoting the adoption of cheaper materials [24,26,27,96], and social pressures, promoting the pursuit of progress symbolized by the new forms [4,10,27]. In both cases, individuals have been regarded as relatively powerless to affect the nature of these modernizing transitions. In the transition underway in cold, arid northern Pakistan, however, the owner-builder culture calls these beliefs into question; likewise, evidence from analogous transitions to low-energy housing in the global North highlights the importance of individual experience, know-how, and resulting action [33–37]. Here, we have investigated the paradoxical situation in which people living in a severely cold winter climate willingly compromise their thermal needs in favor of contemporary homes, focusing on the ways in which they cope with the resultant thermal stress. From this work, two central discoveries have emerged.

6.1. Building transitions may occur incrementally and intermittently.

Investigations of thermal stress resulting from transitions in housing typically treat traditional and contemporary buildings as separate, distinct categories [97–99]. In contrast, this study revealed a piecemeal evolution of contemporary dwellings, reflecting owners' responses to both socio-economic and thermal conditions. Throughout these transitions, homeowners incorporated changes individually or in related groups, hoping to enhance their homes' privacy, economy, durability, and aesthetic appeal. They then assessed the thermal implications of each change and responded either with further spatial adjustment to mitigate the thermal stress caused or by rejecting the new element in favor of the traditional elements. For example, multi-roomed dwellings replaced single-roomed *haas* because they offered greater space and privacy; in winter, occupants nevertheless lived in their kitchens exclusively, incorporating the traditional use of cooking spaces for living. The introduction of modern amenities including plumbing in these kitchens further reduced occupants' thermal stress by eliminating the need for frequent outdoor visits. Likewise, industrially manufactured concrete, metals, and glass were viewed as more aesthetically pleasing and durable than mud, stone, and wood, yet people continued to build mud-plastered timber roofs because they perceived them as warmer than metal sheet and RCC roofs. This study therefore revealed that people thermally adapted their houses throughout the transition process, playing more dynamic roles in shaping their environments than previously understood.

6.2. Occupants create thermal concepts of their homes and respond accordingly.

Interviews also revealed that occupants developed beliefs about the thermal behavior of their houses based on specific perceptible thermal sensations, and that these beliefs both guided and limited their experimentation to alleviate thermal stress. For example, in the hybrid *haas*, people recognized that cold air drafts from skylights resulted from direct airflow from the outdoors and that these drafts could be reduced by covering the skylights at night. The analogous belief that cold air drafts from windows also originated in outdoor air, however, reflected the difficulty of perceiving indoor airflow over cold glass that created similarly cool air currents. This, in turn, limited the effectiveness of the analogous response: covering windows with plastic to exclude outdoor air did not warm the glass, and the cool drafts persisted. Similarly, occupants observed concrete surfaces to be cold, responding by lining wall interiors with wood or polyurethane and by constructing roofs with traditional mud and timber instead of RCC. While these modifications alleviated direct exposure to cold surfaces, improving comfort, they did not reduce the thermal conductivity of the wall and roof materials themselves, allowing conductive heat losses to continue.

Strikingly, occupants' novel adaptations, combined with their selective retention of traditional elements, gave rise to new and distinct building practices. Although these were clearly constrained by a lack of understanding of building thermal behavior, their origin in occupants' personal thermal experiences nevertheless allowed them to respond to thermal needs effectively, within limits. This evidence suggests that education, providing greater understanding of building thermal properties, may be a promising path by which to empower these homeowners further, allowing them to develop adaptive strategies to address the neglected heat transfer pathways. Educational approaches may be similarly valuable in other locations in which owner-built homes dominate the housing stock, uninfluenced by building codes or guidelines, and in which external interventions have failed due to their incompatibility with the forces driving housing modernization.

6.3. Future work

The evidence above suggests that much remains to be learned about the social and behavioral factors underlying housing transitions in developing countries worldwide, which threaten to raise energy demands and thermal stress among large population groups. First, the roles of residents in general, and owner-builders in particular, in determining the thermally significant elements of their transitional buildings appear to be greatly under-appreciated. These deserve further study, as they will ultimately determine the intensity of the resulting energy demands and thermal suffering. The roles of fuel scarcity and energy poverty in determining these outcomes also deserve further investigation, especially as they affect occupants' adaptation decisions and ultimate experiences. These decisions and experiences are likely to be affected by social demographics, as well, including age, gender, household role, family structure, education, and occupation, in addition to income. The potential of education to supplement homeowners' existing know-how in designing thermal adaptations is an intriguing possibility to emerge from this study, and one that could be investigated directly through work with local non-profits already engaged in outreach. The potential of residents' expertise to inform local building policies, in turn, is a similar possibility, perhaps allowing such policies to avoid the rejection they often encounter. Finally, greater understanding is needed of the distinction between social factors that persist across climates and building cultures and those that are unique to certain contexts. While appreciable idiosyncrasy is expected among locations due to climatic variation, human factors may be more consistent, and identifying these would support efforts to develop intervention strategies that are likely to be broadly effective.

7. Bridge

This chapter explored the incremental process of housing evolution in Hunza, the ways in which these changes affected residents' thermal experiences, and the ways in which occupants respond to thermal stress by making specific construction choices and adjustments to enhance indoor warmth. At the same time, it also revealed that these adjustments are limited and indoor thermal stress remains a common concern in contemporary houses. This raises an important question: if contemporary homes remain cold despite residents' adaptation efforts, why do they continue to choose this type of construction? The next chapter takes up this question by examining the motivations behind these construction choices and the factors that guide owner-builder decisions in housing construction.

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III. PROGRESS OR COLD STRESS: BEHAVIORAL DRIVERS UNDERLYING THE SHIFTS FROM TRADITIONAL TO MODERN HOUSING CONSTRUCTIONS IN NORTHERN PAKISTAN

1. Introduction:

In the rural areas of the developing world, dwelling constructions are primarily undertaken by the homeowners themselves [1,2]. Traditionally, these were built using earth- and vegetation-based materials in configurations that limited undesired heat gains and losses in their respective climates [3–5]. In addition, they were designed with distinct spaces for use during warm and cold periods to enhance occupants' thermal comfort [6,7]. However, rural owner-builders are now increasingly abandoning traditional materials in favor of industrially manufactured alternatives, such as concrete, steel, and glass, in configurations that are less effective at moderating heat flows [8–10]. In addition, they are adopting spatial configurations that segregate spaces based on activities (e.g., cooking, living, and sleeping) instead of designing them for seasonal use to maximize thermal comfort [6,11]. Studies in developing regions of Asia and Africa have highlighted that owner-builders are drawn to contemporary constructions because they offer the benefits of durability [9,12], spaciousness, privacy, convenience [13–15], and modern aesthetics [16]. However, the poor thermal performance of contemporary houses increases the need for mechanical heating and cooling. Unfortunately, many of the rural areas lack clean and affordable energy resources to support these heating and cooling needs, leading to extreme indoor thermal stress [17,18].

This trend, of homeowners compromising thermal comfort to fulfill other aspirations, appears counterintuitive when viewed through Maslow's Hierarchy of Needs, which suggests that basic physiological needs should be fulfilled before individuals pursue higher-level goals like privacy, aesthetics, or modern conveniences [19]. Maslow's theory has been widely used in urban housing studies to inform policies and design that better align with residents' aspirations, support a higher quality of life, and encourage adoption of energy-efficient construction technologies [20–28]. However, its applicability has not been tested in a rural developing region. Examining these seemingly paradoxical housing choices made by rural owner-builders from Maslow's perspective offers an opportunity to understand the usefulness and limitations of this widely used approach in guiding housing policies and designs to improve thermal comfort in developing areas.

This study explores the decision-making processes that led to the thermally disadvantageous transition from traditional to contemporary housing construction in the Hunza Valley, a cold desert region in northern Pakistan. This area is chosen because it has both traditional and contemporary houses, which give local owner-builders firsthand insight into the cold stress caused by this housing shift. The study uses mixed methods, including interviews, surveys, and on-site observation, to explore the needs that owner-builders consider and prioritize during home construction; the influence of these priorities on material and house plan selection; the resultant thermal experiences; and the role of thermal stress in shaping residents' housing motivations and priorities.

The findings revealed that owner-builders' decisions are motivated by the efforts to fulfill their physiological, safety, love and belonging, and self-esteem needs. However, the relative prioritization of these needs is not strictly hierarchical. Instead, the prepotency of needs is primarily determined by people's lived experiences. In Hunza, owner-builders initially prioritized relationship needs, which necessitated multi-room configurations with distinct spaces to support private, familial, and communal relationships. Thermal concerns were crucial as well; however, the lack of affordable, thermally efficient construction methods forced owner-builders to use low-cost contemporary materials, which were known to result in cold interiors. Nonetheless, lived experiences of thermal stress have heightened residents' awareness and their intent to prioritize thermal comfort in future construction, presenting a timely opportunity for targeted policy interventions that can align housing practices with climatic needs.

These findings contribute to sustainable housing policy by identifying the ways in which overlapping needs and constraints shape owner-led construction decisions in Hunza. They highlight that any policies aimed at reducing thermal stress must also support owner-builders in achieving what they value the most, including spatial requirements for communal and private use, affordability, and durability. Although these findings are specific to one context, similar context-sensitive approaches are necessary elsewhere to bridge the gap between policy intentions and on-ground construction practices to account for particular material, informational, and technical barriers that exist in each setting.

Worldwide, over 3.4 billion people live in rural areas of the developing world, where 80-90% of the housing is owner-built [1,29,30]. Many of these areas are undergoing unplanned urbanization, population growth, and increased construction, where the growing use of contemporary building materials and methods is posing threats to the health and well-being of inhabitants [31] while also contributing to local pollution [32,33] , resource depletion [34], and greenhouse gas emissions [18]. Policies for improved thermal performance in housing in these areas are thus critical for advancing the sustainable development goals of improved housing quality, reduced biomass dependency, and enhanced climate resilience [35,36].

Subsequent sections review literature on housing modernization, thermal challenges, and housing motivations, followed by a description of the site context, research methods, findings, and a discussion on the relevance of Maslow’s theory in the context of Hunza. The paper concludes with policy recommendations for encouraging climate-responsive housing adoption in Hunza with broader implications for similar rural contexts globally.

2. Literature review:

2.1. Housing modernization:

Building transitions and the social and economic trends driving them in urbanizing rural areas of the developing world are well-documented [9,16,37–39]. Historically, most rural societies were subsistence-based. Thus, they relied on locally available construction materials and, over centuries, devised methods of using them as shelter against local climatic conditions. For example, in cold Himalayan regions of Nepal and India, thick stone and mud walls, low ceiling heights, and small opening sizes helped retain indoor heat [5,40,41], whereas in warmer regions of South-East Asia, reed and grass roofs with large overhangs sheltered against solar radiation and perforated walls with extensive openings supported ventilative cooling [42–44]. Housing layouts were influenced by both cultural norms and thermal considerations: for example, central hearths in cold regions fulfilled thermal needs, and served as the cooking area, while also serving as a focal point for family interactions [5,14]. Similarly, traditional subtropical houses featured separate summer and winter living spaces, arranged around a central courtyard used as a shared space for carrying out multiple daily activities [6,11].

The ongoing building modernization in developing rural areas is linked to the broader socio-economic changes occurring in these regions. As communities shift from subsistence to market-based economies, industrially manufactured concrete, metal, and glass, along with disposable incomes to buy them, have become widely available [14]. These materials are preferred over traditional ones because they require less on-site processing, making construction easier and quicker [45], and they offer better durability and moisture resistance [8,9]. In addition, evolving social customs such as the rise of nuclear families, growing individualism, and increased exposure to urban lifestyles are leading to a higher emphasis on privacy, convenience, and modern aesthetics, which leads to a departure from traditional multi-functional climate-responsive spaces and the selection of layouts with separate rooms for sleeping, cooking, and socializing [14,15,46,47].

2.2. Thermal stress in modern housing

Thermal stress caused by housing modernization in developing regions is widely recognized [8,10,39,42,48]. For example, the replacement of reed and grass roofs with metal sheet ones in tropical regions is known to increase indoor heat gains, while the use of baked brick and concrete walls instead of perforated reed and bamboo is known to retain heat and reduce opportunities for nighttime cooling through ventilation [42,44,49]. In cold regions, the use of modern thermally transmissive wall and roof materials, such as uninsulated concrete, and large window sizes, is known to increase heat losses [50], whereas traditional houses are known to offer better heat retention, thermal satisfaction, and more opportunities for thermal adaptation compared to contemporary houses [5,17,40,51].

Building on these insights, existing studies propose technical solutions, such as the continued use of traditional materials, compact layouts, deliberate solar orientation, and strategic placement of thermal mass to alleviate indoor thermal stress [40,45,52]. Some also propose the use of wall and roof insulation techniques, using both locally available and industrially produced materials [18,53,54]. However, these approaches are developed without adequate attention to owner-builders' needs, aspirations, and priorities that shape their construction decisions. For example, prior research suggests that proposals advocating for the revival of traditional materials are often perceived as structurally weak or aesthetically unappealing, and contemporary solutions are expensive and require skills that owner builders do not possess [9,14,46]. As a result, these solutions often fail to align with what owner-builders value, and therefore, remain unlikely to be adopted on a wider scale.

This study, therefore, begins by examining the motivations and priorities that drive owner-builders' construction decisions. It uses Maslow's Hierarchy of Needs as an analytical framework to understand the ways in which various needs are prioritized. This understanding is then used to inform design and policy interventions that can better support enhanced indoor thermal comfort in ways that align with owner-builders' aspirations.

2.3. Maslow's hierarchy of needs and Housing choices:

2.3.1. Maslow's theory and housing:

Maslow organizes human needs into hierarchical levels: starting with physiological needs, followed by safety, love and belonging, self-esteem, self-actualization, and finally, self-transcendence. He theorizes that lower-level needs must be satisfied before higher-level needs become a priority [19]. Housing, being a core component of human environments, intersects with all these need categories [55]. On a basic level, it fulfills physiological and safety needs by providing an environment where occupants can control indoor temperature, hygiene, and air quality, thus protecting them from physical and environmental threats [56]. Further, houses act as venues for relationship building by offering spaces for family interaction and community engagement [25]. They also foster self-esteem by reflecting their occupants' achievements, values, and social status [20]. For example, people may take pride in owning their homes or in their aesthetic expressions [57,58]. Finally, homes may provide environments necessary for personal growth; a study or art room may be a place where one can work toward realizing their interests, thus catering to self-actualization needs [59].

2.3.2. Housing needs and housing choices:

Previous empirical work has shown that housing residents choose housing attributes and make housing modifications in ways that reflect the prioritization of certain needs. For example, in Jordan, privacy needs led people to reorient house entrances in ground-floor units of public housing to separate house access routes from shared corridors in buildings. In these cases, people also added partitions to open-plan layouts to limit visibility and acoustic intrusion between spaces [60]. While in other homes, residents added balcony covers and used landscaping features to minimize the visibility of the internal space [60,61]. In Bahrain, people were reported to increase the height of parapets and boundary walls to enhance privacy [62].

Aesthetic preferences, aspirations to reflect one's identity, and desires to signal high social status have been shown to influence choices of interior furnishings, façade finishes, and materials as well [16,58,63]. For example, in Bahrain, residents expressed a preference for simple modern designs, trendy materials, and large windows to achieve contemporary aesthetics [64]. In Bali and Nigeria, villagers increasingly favor modern materials over bamboo and thatch for reasons including aesthetic preference and modern appearance [16,65]. In China, rural residents associated the choice of modern construction materials with their aspirations for urbanizing identities [66].

In flood-prone regions of Bangladesh, households have also prioritized structural durability and physical security by choosing corrugated metal sheet constructions, which are perceived as more durable than traditional bamboo homes [8,67]. Similarly, in Rwanda, the adoption of contemporary baked brick houses with metal sheet roofs was also reported to be driven by a need to enhance housing durability [9]. These studies therefore show that need priorities affect material and spatial decisions, but they typically examine a single need in isolation rather than how multiple needs are negotiated together.

2.3.3. Maslow's theory in housing studies:

In urban settings, where housing is built by private developers or through government programs, Maslow's theory has been widely used to understand occupants' needs and preferences. In such contexts, the hierarchical framing of needs has been beneficial. In these settings, building regulations tend to guarantee basic physiological and safety needs, including adequate insulation, light sanitation, and structural integrity. Once these basic requirements are met, the focus shifts to opportunities for social interaction and personalization to support the fulfillment of relationship, self-esteem, and self-actualization needs [20–27]. Some studies have also used Maslow's theory to show that adopting energy-efficient practices is related to higher-level needs of self-esteem and self-transcendence, as they foster a sense of achievement, and individuals often make these choices based on altruistic reasoning. These studies, therefore, advocate for the necessary fulfillment of all the basic-level needs as a means to tap into housing residents ' motivations of self-esteem and self-transcendence, which may drive energy-efficient choices [28,68,69].

While Maslow's theory has been valuable in urban contexts, the findings cannot directly apply to rural settings as these regions operate under a very distinct set of dynamics. Unlike urban housing, rural dwellings are often unregulated, and owner-builders oversee all aspects of construction, including material and layout selection and execution of the construction activities [1,29]. Some research suggests that this autonomy leads to greater housing satisfaction as people can tailor their houses according to their specific needs [2,23]. At the same time, rural housing often falls short of meeting the basic construction standards to meet the physiological and safety needs of its inhabitants due to a lack of building regulations and technical and financial limitations [8,70]. In rural areas, policy interventions are therefore necessary to improve housing conditions. Maslow's theory can provide a framework to understand owner builders' decisions in relation to their needs, preferences, and motivations, which is essential for designing policies that not only promote climate-responsive housing but also resonate with the expectations and aspirations of the people they intend to serve. However, its applicability first needs to be analyzed in non-Western, rural, developing regions, as it has not yet been tested in such settings.

2.3.4. Critiques of Maslow's theory

Although Maslow's hierarchy continues to be widely used as a conceptual framework in housing studies, newer psychological research has suggested refinements, indicating that needs may coexist and that situational pressures may influence shifts in priorities [71]. Recent housing research has begun to reflect this direction as well, showing that needs can be negotiated together through dwelling practices and everyday living, rather than unfolding in a strict sequence [22]. For example, a study of social housing in Arctic regions shows that while government housing schemes focus primarily on fulfilling basic physiological and safety needs, for housing residents, social needs are of greater importance [23]. Similarly, a study on public housing in Korea suggests that a non-hierarchical model of Maslow's theory better explains residents' satisfaction [72]. However, most of these studies examine public or government housing schemes, whereas there is limited work on how these dynamics are expressed in owner-built housing. Maslow's theory, therefore, remains a useful starting point in the study because it allows the different types of needs to be clearly identified and compared, which is necessary to understand how these needs influence material and spatial decisions in owner-built housing, and how such patterns can inform context, appropriate designs, and policy interventions.

3. Site context

The Hunza Valley is a rapidly urbanizing rural area in Northern Pakistan [73] with a population of over 65,000 [74]. The region, classified as a high-altitude cold desert (BWk) according to Koppen's climate classification, experiences extreme cold winters with temperatures consistently falling below the freezing point from November to February [75]. Historically, Hunza was a subsistence society. However, in 1979, the construction of the Karakoram Highway (KKH) enhanced its connectivity to southern Pakistan, leading to economic diversification as people engaged in trade, tourism, and the service industries [76]. These changes had a profound impact on built environments, as the availability of expendable income and the import of building techniques and materials from southern urban centers led to a shift from traditional to contemporary construction.

3.1. Traditional housing

Traditionally, people built their houses by themselves with help from kin and occasionally with some assistance from skilled craftsmen [77]. These houses were built in the clustered settlements (Fig. 3.1a), each typically consisting of an entry vestibule (which also housed cattle), a winter living room, and a storage room on the ground floor, and a summer living space on the upper floor (Fig. 3.2). The compact configuration protected the winter living room from all four sides and the top, eliminating exposure to cold outdoor air. Furthermore, the doors were small, and there were no windows, which reduced cold air infiltration [78]. Walls were built with 0.5-1m thick stone and a thick mud plaster finish, and roofs were wooden with 10-15 cm thick mud plaster as well, offering excellent resistance to heat loss. The winter living room featured a cooking hearth in the center with a skylight above it for light and smoke exhaust (Fig. 3.1b). The space around the fire was designated for cooking and family conversations, while raised floors on either side were used for seating and sleeping [14]. This arrangement converged internal gains from cooking and human metabolic heat into the central living space [78].

3.2. Housing transitions

Changes to housing in Hunza Valley began as early as the 1920s [14], in the following aspects:

Settlement patterns and housing layouts: After the 1920s, households started building detached single-story houses outside the clustered settlement. These houses still used traditional materials and were designed as *h*aas, but these now incorporated verandahs for summer living instead of baldis on the upper floor (Fig. 3.3). Over time, the internal layouts evolved from concentrated living in the haa to multi-roomed arrangements. Around the 1960s, people started building multi-purpose rooms with verandahs for summer living (Fig. 3.3). From the 1990s onwards, houses were constructed primarily as multi-roomed units with separate spaces for cooking, living, receiving guests, and sleeping (Fig. 3.4). In most contemporary houses, kitchens are large enough to accommodate living alongside cooking during the winter. However, some recently built houses do not keep such allowances in their kitchen [78].

Figure 3.1. Typical traditional house: a) Entrance to a traditional house in a cluster settlement b) Interior of a haa

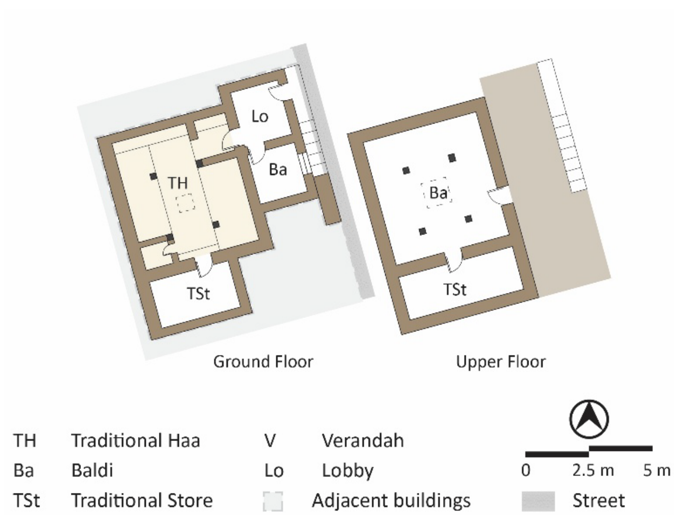

Figure 3.2. A plan for a 400-year-old traditional house located in the cluster settlement of Altit Hunza, adapted from Imtiaz and Rempel (2024) [78]

Construction materials and methods: Changes in construction materials were observed alongside the introduction of multipurpose rooms in the 1960s. These rooms were typically built with ashlar stone masonry, in which the exterior stone surface was left exposed, while the interior surface was finished with mud plaster, sometimes stabilized with lime [79]. The roofing system in these houses generally remained the same as in traditional constructions.

More pronounced changes began in the 1980s with the advent of the Karakoram Highway, which facilitated the import of industrial construction materials such as cement, steel, ceramics, and glass [14,78]. Since then, contemporary houses commonly use Concrete Masonry Unit (CMU) walls with cement-sand mortar and plaster on both the interior and exterior [47]. Some contemporary houses are also built with 0.5 m-thick stone walls, bonded with cement mortar. The exterior walls are of exposed stone with a chiseled finish, while the interior walls are cement plastered [78].

Most houses today still use a traditional wooden roofing structure, but with some modifications. Polyethylene sheets have replaced the birch bark for waterproofing, and the mud plaster layer on top of the roof is now much thinner than in traditional houses. Additionally, Reinforced Cement Concrete (RCC) slab roofs are becoming common, especially in double-story constructions. Similarly, uninsulated metal sheet roofs have also been adopted in several contemporary constructions. Floors in contemporary houses are typically finished with cement-sand plaster. And wet surfaces, such as in kitchens and bathrooms, are commonly finished with ceramic tiles.

Fenestrations: Changes in fenestration began appearing in the 1960s, when households started using larger doors than in traditional houses, and single-glazed windows were introduced into multi-purpose rooms. Since the 1990s, facilitated by the import of large glass panes, window openings have increased substantially in both number and size.

Figure 3.3. Plan of a house built in the 1950s with a subsequent contemporary addition in 2010. Adapted from Imtiaz and Rempel (2024) [78]

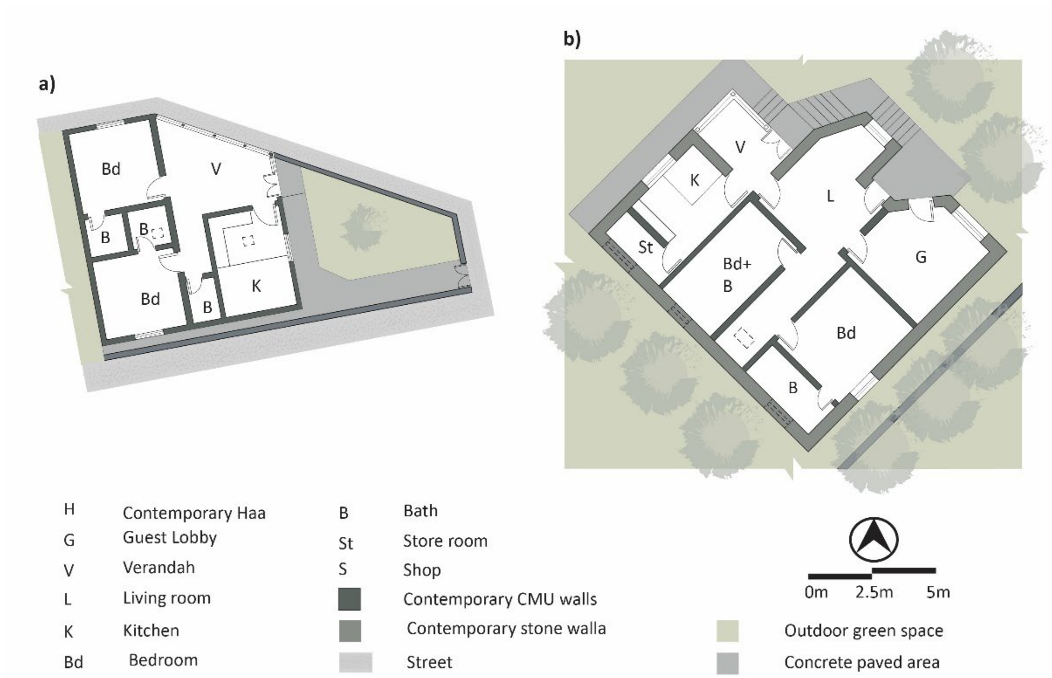

Figure 3.4. Plans of contemporary houses. a) A low-income house built with CMU Block Walls b) A middle-income house built with contemporary stone walls. Adapted from Imtiaz and Rempel (2024) [78]

3.3. Thermal effects of building transitions:

Overall, these transitions have increased opportunities for heat losses in contemporary houses. Detached houses have a greater exposed surface area to the outdoors, contemporary walls and roofs have substantially higher thermal transmittance values than traditional thick mud plastered walls and roofs, and the large windows in contemporary houses further accelerate indoor heat losses [54]. While the combined cooking and living strategy helps households remain warm by using cooking heat for space heating, the contemporary design of these kitchens leads to rapid heat loss, requiring continuous heating inputs during winter [78]. Moreover, households typically continue to sleep in unheated rooms at night for privacy, which exposes residents to significant cold stress. In recently built houses, where combined winter kitchens have been completely omitted, residents consistently report extreme thermal discomfort during winters due to their inability to heat the living rooms sufficiently [78].

Fuel scarcity exacerbates thermal challenges. Electricity is available for only two to four hours daily during winter. Natural gas cylinders and kerosene are imported from southern regions via the KKH, but the long travel distance and frequent road landslides make their supply unreliable and expensive. Therefore, wood burning remains the primary source of heating. However, local wood resources are declining fast. While many families source wood from their orchards, those without landholdings must purchase it from markets. This makes heating especially challenging for low-income households.

3.4. Incremental additions and mixed materials constructions:

Housing units in Hunza often combine different construction types within the same dwelling. These mixed assemblies arise from the incremental nature of construction over time, as well as from owner-builders making different material choices for different parts of the house. For example, traditional haas were first expanded with multipurpose rooms built in ashlar masonry, and later with additional bedrooms, bathrooms, and kitchens built with CMU block walls (Fig.

3.3). In such cases, the original traditional portions are used for winter living, whereas more recent additions are used intensively in the summer. In some cases, original mud plasters in multi-purpose rooms and traditional haas have been replaced with cement plasters during subsequent alterations [78]. Similarly, in contemporary houses, even if the main house uses metal sheet roofing, the kitchen, where winter living occurs, often uses traditional wooden roofs.

3.5. Relevance of studying owner-builders' housing decisions in Hunza

In Hunza, traditional and contemporary dwellings coexist side by side, providing residents with firsthand experience of the thermal disadvantages of housing transitions. Despite this awareness, people choose to build contemporary structures. This situation highlights the need to better understand owner-builders' decision-making processes, rather than assuming they lack knowledge of building thermally efficient houses and focusing solely on providing design solutions.

Enhancing residential constructions has become especially important in Hunza as the region undergoes rapid urbanization [73]. Migration from remote surrounding areas to the central Hunza Valley for better access to education and job opportunities, as well as the growth of the tourism industry, has led to a drastic increase in the construction of houses intended for use as rentals and guest houses, using the same informal, thermally inefficient practices as those used for private homes [73]. This rapid expansion risks locking in poor construction quality that will be costly both socially and environmentally. Therefore, it is imperative to implement planning strategies that provide sustainable building solutions for thermal comfort while reducing heating energy demand.

4. Research questions

In this study, we address four main research questions informed by Maslow's theorization that human actions are motivated by the pursuit of need fulfillment in a hierarchical manner where satisfaction of basic needs precedes higher-order aspirations. The questions are as follows:

- How did owner-builders prioritize various needs during the construction and/or upgradation of their homes?
- Did relative prioritization of owner builders' needs (thermal, light/ventilation, safety) influence their choice of specific housing attributes associated with traditional or contemporary approaches?
- How do different housing attributes contribute to the thermal comfort of residents?
- Do the experienced conditions of thermal stress (affect or) lead to a reprioritization of thermal considerations for future constructions?

5. Research Methods:

5.1. Overview:

Housing choices and decision-making are understudied in developing rural areas, and prior research has not tested the applicability of Maslow's theory in these settings. To address this, we adopted an exploratory mixed-methods approach. We started with open-ended interviews to understand housing construction processes and people's experiences. Through inductive coding, we identified key themes for further study. Surveys were then used to gather quantifiable data on broader patterns, followed by focused interviews to interpret those findings. This iterative approach allowed us to gain a deeper understanding of complex decision-making processes, enhancing the reliability and depth of our results. Fig. 3.5 presents a timeline of the data collection and analysis activities.

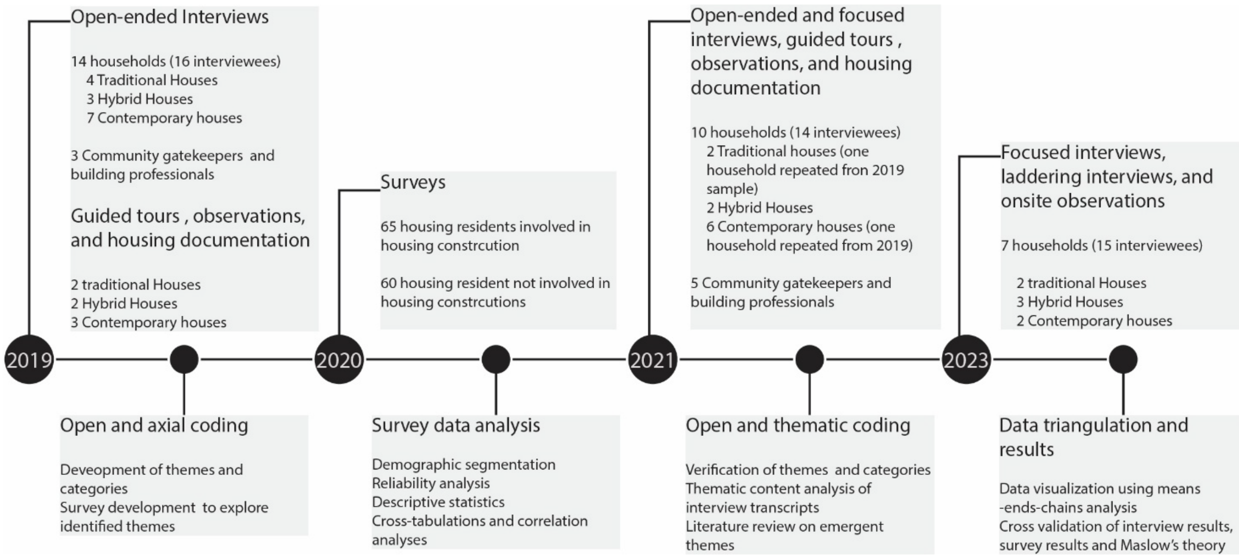

Figure 3.5. Research timeline showing the chronological order of data collection (above timeline), and data analysis (below timeline) activities.

5.2. Open-ended interviews 2019 and 2021:

Data collection: The research began with exploratory interviews in 2019 to gather broad information on the modernization of buildings and indoor thermal conditions in Hunza. The sample included fourteen households, identified through interlocutors and snowball sampling. In seven of these houses, occupants offered guided tours and allowed photography. Three additional interviews were conducted with building practitioners and community gatekeepers to gain diverse perspectives on common construction trends. A second round of open-ended interviews was conducted in 2021 as well. The sample included fifteen participants, of whom two were 2019 participants, and five were building practitioners. Guided tours and building documentation were conducted in eight new houses. For these interviews, participants were approached through snowball sampling to diversify housing types and household income levels. All interviews lasted 20-40 minutes. They were conducted in the local language, voice-recorded, and later transcribed into English. Field observations and housing plans were recorded alongside the transcripts to complement the interview data.

Interview coding and analysis: The 2019 interviews were analyzed using open coding in QDA Miner [80], with each text segment assigned a code based on its content. Similar codes were grouped into parent categories and further organized into overarching themes based on the connections made by interviewees and observations of code co-occurrences. Multiple rounds of coding were conducted to ensure validity. The analysis highlighted the key factors and concerns that shaped construction decisions in Hunza, further informing both survey designs and the focus of subsequent interviews.

5.3. Surveys 2020

Data collection: Findings from the open-ended interviews guided the development of a pilot survey in 2020, which was created in Qualtrics and distributed via social media to the residents of Hunza and neighboring areas. This survey aimed to collect data from a larger sample to gain further insight into prevalent construction types, the thermal experiences of housing residents, the thermal adaptation practices used by housing residents, and the factors affecting decision-making, which were the primary themes emerging from the interviews. The survey received 144 responses. The responses revealed discrepancies in question format and language. These issues were addressed through a refined online survey shared with interlocutors and 2019 interview participants, who in turn shared it among their networks. Interlocutors also went door-to-door to improve inclusivity by collecting responses from individuals with limited literacy and internet accessibility. The survey received 133 responses, of which 50% were collected in person by the interlocutors.

Survey variables: The survey included questions derived from themes emerging from open-ended interviews. In this research, we draw our findings based on the following variables:

Demographics: These included inquiries about the respondents' gender, age, family size, and income status.

Housing Types: In Hunza, housing exhibited diverse combinations of traditional and contemporary features (Table 3.1), making distinct typological categorizations impractical for statistical analysis. Therefore, we focused on three categories of housing attributes: wall materials, roof materials, and winter living room layouts (Table 3.2).

Furthermore, because in many dwellings, construction materials used in the winter living rooms differed from those used in the rest of the house (Section 3.4), the wall and roof material categories were evaluated separately for the main house and the winter living rooms. This separation was essential to capture the choices made specifically for winter living spaces, which would otherwise have been obscured if the entire house were treated as a single uniform construction category.

Table 3.1. Combinations of attributes found in the dwellings in Hunza, representing various configurations, ranging from traditional to hybrid to fully modern.

Element	Type	Traditional			Hybrid configurations						Contemporary		
Wall Materials	Stone with mud plaster and mortar	X	X										
	Stone with cement plaster and mortar			X	X	X	X	X					
	CMU blocks with cement plaster and mortar								X	X	X	X	X
Roof Materials	Wooden	X	X	X	X	X			X	X	X		
	RCC or metal						X	X				X	X
WLR Layout	Haa	X		X					X				
	Kitchen with a living space		X		X		X			X		X	
	Living room and kitchen are separated					X		X			X		X
Fenestration	Small door and only one skylight	X											
	Large doors with several windows, vents, and skylights		X	X	X	X	X	X	X	X	X	X	X

Table 3.2. Description of survey variables and their corresponding value categories

	Variable	Coding	Description
Housing Attributes	House walls	1 = Contemporary 2= Hybrid 3 = Traditional	CMU with cement plaster Stone with cement plaster Stone with mud plaster
	WLR walls	Same as above	Same as above
	House roof	1 = Contemporary 2= Traditional	Reinforced concrete or metal sheet roof Wooden roof
	WLR Roof	Same as above	Same as above
	WLR Layout	1 = Contemporary living room 2 = Contemporary kitchen 3 = Traditional haa	Separated cooking and living space Kitchen with combined cooking and living Traditional haa with combined cooking and living
Past priority ranking	Relationships	Ranking scale 1 to 6	6 is the most important, and 1 is the least important
	Affordability	Same as above	Same as above
	Thermal comfort	Same as above	Same as above
	Strength and durability	Same as above	Same as above
	Aesthetics	Same as above	Same as above
	Light and ventilation	Same as above	Same as above
Future priority rankings	Same as above	Same as above	Same as above
Thermal comfort	Mean thermal comfort value	Scale variable with values ranging between 1 and 5	The mean score of the four thermal comfort scale items ranges from 1, translating to very cold, to 5, translating to very comfortable.

Housing needs prioritization: Need categories were identified through open coding of the open-ended interviews. Two survey questions asked participants to rank needs by importance. The first one asked owner builders to rank these categories when constructing their existing homes, using a scale from 1 to 6. The second question asked all respondents to rank the needs they would prioritize most in future housing construction using the same scale.

Thermal Comfort: Thermal comfort was assessed using five items, each rated on a five-point Likert scale (See supplementary information). An internal reliability analysis of the scale revealed acceptable reliability (Cronbach's $\alpha = 0.65$), given the small number of items. However, removing one reverse-scaled item improved the reliability to a widely accepted α value of 0.70. We, therefore, proceeded with the four-item scale. The average score of the four-item scale was used as the measure of thermal comfort for further analysis, with lower values indicating thermal distress and higher values indicating thermal comfort (Table 3.2).

Survey data analysis: The survey data were primarily analyzed using mean ranking analyses to identify trends in the higher prioritization of needs and to explore relationships among housing attributes, need prioritization, and thermal comfort. The sample size was limited, and the data did not follow a normal distribution. Therefore, we used the Mann-Whitney U test and the Kruskal-Wallis test as non-parametric alternatives to the T-test and ANOVA for mean comparisons.

5.4. Focused interviews 2023

Data collection: Focused interviews were conducted in 2023, along with onsite observations in seven houses. Six of these were selected from the 2019 and 2021 samples, and one additional house representing a 400-year-old construction was added. These interviews aimed to gain an in-depth understanding of construction-related decision-making processes. The interviews had two parts. First, housing residents were asked to describe their aspirations for a comfortable home, followed by prompts on the importance of Maslow's five categories of needs in shaping their vision of an ideal home. For instance, they were asked how essential it was to have a separate guest lobby and private bedrooms for comfortable living, as well as how important it was to stay warm and have adequate light and ventilation in the house. The second part used laddering interviews, a qualitative technique widely used to identify the motivations behind selecting product attributes. Respondents were asked why they chose specific housing attributes, such as concrete blocks for wall construction or building separate bedrooms. The response was followed by a chain of "Why is that important for you?" questions to identify the basic underlying needs these attributes fulfilled. The interviews provided an in-depth understanding of personal preferences shaping housing choices.

Data analysis: Focused interviews were first qualitatively analyzed to understand how each need category corresponded to Maslow's hierarchy of needs. Next, the data were used to create means-end chain diagrams that visually represented the connections between housing attributes and Maslow's need categories. These diagrams, alongside insights from open-ended interviews, were used to provide context and interpretation for the survey responses.

6. Results

6.1. Descriptive analysis of sample responses

6.1.1. Demographics:

The demographic characteristics of survey and interview respondents are summarized in Table 3.3 to illustrate the representativeness of our sample with respect to the broader Hunza population. In both surveys and interviews, there was a slight overrepresentation of men, attributed to their greater access to technology and higher engagement in construction activities observed on-site. During interviews, it was noted that women often participated less actively, frequently deferring construction-related inquiries to their male family members, which further underscores this trend.

Representation of income groups in the survey aligned with Hunza's demographics. Interviews, however, overrepresented the low-income households in a deliberate effort to balance respondents across income levels. In interviews, income levels were inferred from comments on earnings, financial stress, and expenditures, as well as from observations of housing conditions.

The household size distribution in the sample also reflected regional patterns, with the majority of respondents living in medium-sized households (5-10 members). Finally, the sample represented a diversity of respondents across age groups and housing types. However, demographic data for Hunza on these variables is not available to compare the representativeness of our sample.

Table 3.3. Comparison of the survey and interview sample demographics with Hunza's population.

Demographic variable	Surveys	Interviews	Hunza *
Population	114	42	65,497*
Households		23	11,186*
Gender			
Male	65.8%	55%	51%*
Female	34.2%	45%	48.6%*
Income groups			
Low-income	24.8%	43.48 %	21.6 % *
Mid- and high-income	75.2%	56.5 %	78.4
Age groups			
Youth (18-25 years old)	21.4 %	15.6 %	-
Adults (26-59 years old)	65.8 %	59.4 %	-
Seniors (60 and above)	11.1 %	25 %	-
Household size			Average HH size
4 or less	19.7 %	27 %	5.85*
5-10	61.5 %	51 %	16.4**
10 or more	18.8 %	22 %	59.2**
			24.4**

*Source: Planning and Development Department – Govt of Gilgit Baltistan [81]

**Source: Final Report - Multiple Indicator Cluster Survey 2016-17 [82]

6.1.2. Representation of housing attributes:

The observed frequencies of different housing attributes in surveys and interviews are reported in Table 3.4. The most commonly reported wall type was CMU walls with cement plaster, which accounted for nearly half of the houses in both surveys and interviews. This was followed by contemporary stone-wall houses, which made up about one-third of the total. Both of these wall types are typically used in modern constructions. In contrast, traditional stone walls with mud plaster are only found in old constructions that are still inhabited. These comprised nearly 20% of the cases. Interestingly, this percentage increased in winter living rooms across both interview and survey samples, indicating a trend of retaining older structures for winter use.

Among roofing types, wooden roofs with mud plasters were the most commonly observed, found in approximately two-thirds of the houses and almost 80% of the winter living rooms. In terms of WLR layouts, combining cooking and living in contemporary kitchens was the most common practice. The traditional haa layout was used in only 20% of the houses in the survey sample and in 35% of the dwellings in the interview sample. Living rooms separated from winter living areas were observed in 27% of survey cases and in ~10% of interview cases.

Table 3.4. Frequencies of construction characteristics of the houses and winter living rooms (WLRs) as reported in surveys and interviews

Housing attribute	Construction type	Surveys (*n*=114)		Interviews (*n*=23)	
		Frequency	%	Frequency	%
House Wall type	Stone with mud plaster	20	17	5	22
	Stone with cement plaster	38	33	7	30
	CMU with cement plaster	57	49.6	11	48
WLR Wall type	Stone with mud plaster	28	24	8	35
	Stone with cement plaster	41	36	6	26
	CMU with cement plaster	45	39	9	39
House Roof type	Wooden with mud plaster	70	61.4	16	69.5
	RCC or metal sheet	44	38.6	7	30.5
WLR Roof type	Wooden with mud plaster	90	79	18	78
	RCC or metal sheet	24	21	5	22
WLR Layout	Traditional haa	23	20	8	35
	Kitchen with living space	60	53	13	56.5
	Separated cooking and living	32	27	2	8.5

6.2. Prioritization of needs during housing construction

6.2.1. Identification of needs and their relation to Maslow's need categories:

To understand the decision-making processes guiding housing construction in Hunza, our first objective was to identify the needs motivating owner-builders' choices of construction materials and spatial configurations. Open-coding analysis of the exploratory interviews (Section 5.2) revealed six key needs (Table 3.5). These needs were evaluated both in terms of the frequency with which they were discussed, indicating their intensity within individual narratives, and the number of participants citing them, indicating their prevalence across the samples (Fig. 3.6). The identified needs were then mapped onto Maslow's categories using interview descriptions, which enabled an assessment of how these expressed priorities aligned with or diverged from the established categories in the framework (Fig. 3.7).

Table 3.5. Need categories derived from open-coding of exploratory interviews

Need category	Description
Relationship	Need for spaces that support family interaction, privacy for couples, and hosting guests.
Thermal	Need to maintain warmth during winter and coolness during summer to support basic health and comfort.
Natural light and ventilation	Need for openings to allow natural light for daily activities and ventilation to manage indoor heat and smoke.
Strength and durability	Need for strong and durable structures to withstand earthquakes, rain, and deterioration, and to minimize health risks like mold.
Aesthetics	Needs for visually appealing, clean, and well-maintained housing that reflects one's social standing and sense of self-worth.
Affordability	Constraints on housing choices due to the costs of materials, labor, and land lead to prioritization of more critical needs.

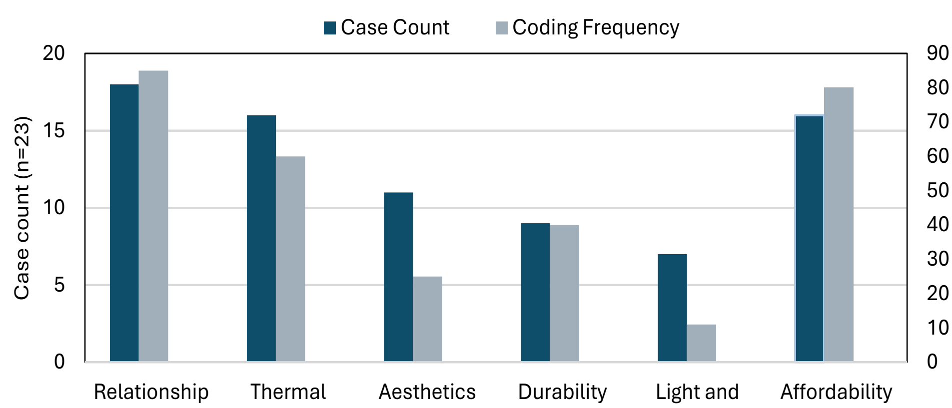

Figure 3.6. Coding frequencies and case counts of the needs identified in interviews. Interviews were conducted in 23 households (cases). Case counts represent the number of distinct households in which a specific need was identified at least once, indicating the prevalence of that need across the sample. Coding frequency refers to the total number of times a need category was mentioned across all interviews, reflecting the intensity with which it was discussed.

The need for having separate living spaces for spending family time, bedrooms as private spaces, particularly for couples in joint families, and guest lobbies for hosting guests and larger gatherings emerged as the most frequently and intensively discussed category in the interviews (Fig. 3.6), and their descriptions strongly corresponded with Maslow's love and belonging needs. In this study, we refer to these concerns as relationship needs because family members deemed these spaces important for establishing and maintaining relationships, including those with one's spouse, extended family, relatives, and community members. Interviewees noted that, while spatial segregation for privacy and having designated spaces for hosting guests were less important in the past, they have now become necessary.

> Nowadays, everyone prefers privacy. Young couples need privacy. The fact that there was very little privacy in earlier times is not hidden.
>
> Quote 3.1

> [We need] a separate room for our daughter-in-law when she comes into our family… So that we can sleep in separate rooms and live in a separate space when needed… It is essential to provide them with their own space where they can do as they please.
>
> Quote 3.2

> The advantages of our new house are that, if some guests come, it's easier. Nowadays, whoever comes as a guest, friend, or relative, it's very important to have a separate room and bathroom for them.
>
> Quote 3.3

> For receiving guests, for marriages, even if there is some suffering, we thought that this (contemporary) *haa* (built to be used as a guest lobby only) is very important… (because)it is big.
>
> Quote 3.4

Concerns about thermal comfort were the second most frequently mentioned issue (Fig. 3.6). Interviewees acknowledged a strong link between keeping their homes warm during winter and their physical survival and well-being, aligning with Maslow's physiological needs category.

> For life, warmth is important, right? In the winter, it's like minus 25 or minus 26 (^{o}C). That's the coldest it gets. To protect ourselves from that, we need a method to survive.

Quote 3.5

Aesthetics, durability, and light and ventilation were mentioned as important considerations as well, however, less frequently (Fig. 3.6). Aesthetic concerns were raised in nearly half of the cases. Interviewees linked visually appealing structures and well-maintained interiors to a positive family image, viewing such homes as reflecting contemporary living standards and social and economic progress. This fostered a sense of pride, aligning aesthetic needs with Maslow's self-esteem category.

> When we see it (a beautiful house), we feel happy… And everyone likes cleanliness. That's what we've always learned. When we visit places that are clean, we like them. So, we think that if someone visits our house and sees cleanliness, they will also like it.

Quote 3.6

Durability, on the other hand, was mentioned in less than half of the cases. It was described in terms of protection against natural hazards, such as earthquakes and heavy rainfall, and the prevention of structural deterioration and pathogen accumulation, which may pose health risks, including mold and rodent infestations, aligning it with safety needs.

> We were mostly focused on the pillars and the beam. I wanted it to be stronger... It should be strong enough to stay as it is for our grandsons.

Quote 3.7

> The issue with that was moisture and rats. Insects and rats are common in traditional

buildings, so we used an alternative.

Quote 3.8

Light in ventilation needs were mentioned in fewer than a third of the cases, and these needs corresponded closely with Maslow's physiological needs, as people considered them a necessary condition for habitability in their homes.

Without windows, how can we live in the dark? It's like living in a grave.

Quote 3.9

Interviewees mentioned affordability as an important factor influencing their decision-making as well. However, rather than functioning as an internally driven motivation, it represents external factors that shape people's ability to act on their needs by constraining or enabling access to resources.

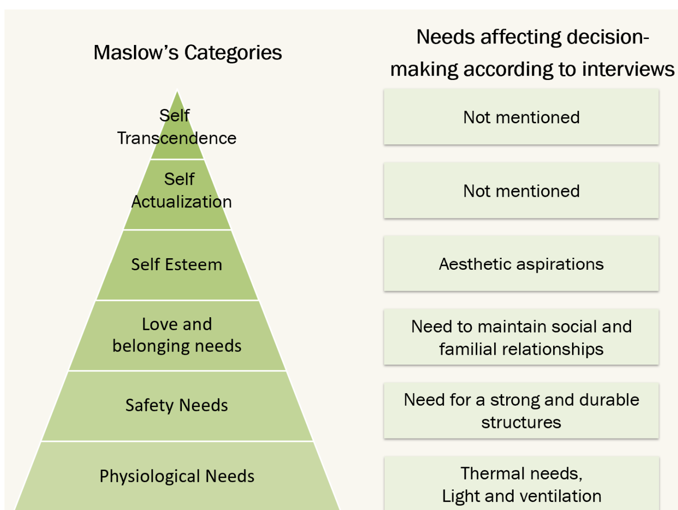

Figure 3.7. Interview-derived need categories mapped onto Maslow's hierarchy of needs. Construction decisions primarily focused on lower-level needs (self-esteem and below), while higher-level needs were not mentioned.

The overlaying of needs identified in the interviews onto Maslow's hierarchy (Fig. 3.7) revealed that owner-builders in Hunza were primarily focused on lower-level needs —physiological, safety, relationship, and self-esteem —when making construction decisions. In contrast, higher-level needs, such as self-actualization and self-transcendence, were not mentioned as factors influencing construction decisions. When specifically prompted to address these needs in their homes, respondents primarily mentioned providing separate spaces for children to study as a benefit of multi-room layouts. However, the main rationale for building such spatial configurations was the separation of activities, rather than engaging in learning activities.

6.2.2. Need prioritization

To systematically analyze the relative importance of various needs using a larger sample, in the surveys, we asked participants directly involved in the construction of their homes to rank the needs they prioritized most during construction. We then analyzed the results using the Wilcoxon signed-rank test for comparing mean rankings. The results revealed a pattern similar to the interviews: relationship needs were ranked as the most important, followed by thermal needs. Strength and durability, aesthetics, and natural light and ventilation received relatively lower rankings. However, these differences were not statistically significant. The only significant difference was a higher prioritization of relationship needs over aesthetic needs (Fig. 3.8). This lack of statistical differences among most needs suggested that various needs coexisted and were negotiated simultaneously rather than being prioritized hierarchically, reflecting a complex decision-making process in which housing attributes must satisfy multiple priorities.

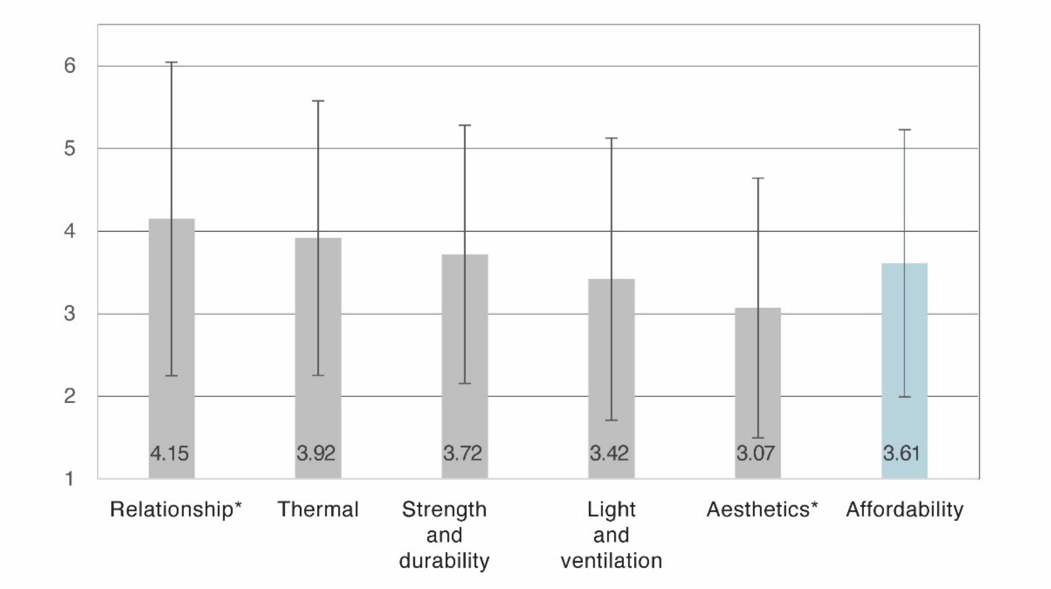

*Figure 3.8. Average ranking of needs based on survey responses. Only the difference between relationship and aesthetic needs approaches significance, n = 41-48 (*p < 0.05, Wilcoxon Signed-Rank test)*

6.3. Influence of needs on housing attribute selection

We next examined whether prioritizing certain needs was associated with the selection of specific housing attributes. Mann-Whitney U and Kruskal-Wallis tests were used to identify statistically significant relationships. The findings were then interpreted alongside interview data, incorporating direct quotes and means-end chain diagrams to illustrate how these preferences are reflected in attribute choices. This approach provided a clear understanding of how specific needs influenced housing decisions, as well as the ways in which housing attributes supported or limited the fulfillment of various needs. In the following sections, we present our findings organized according to Maslow's categories.

6.3.1. Physiological needs – Thermal needs and Light and ventilation needs

Physiological needs included both thermal comfort and the need for light and ventilation (see Section 6.2.1), which were addressed as separate variables in the survey.

Thermal needs: Survey results indicated a near-significant relationship between prioritizing thermal needs and selecting mud-and-stone walls (p = 0.084). Respondents who maintained houses built with these wall types ranked thermal needs higher compared to those living in contemporary CMU- and stone-walled houses (Table 3.6).

Table 3.6. Mean Ranking for Thermal Needs Across Housing Attributes (*n*=48)

Categorization criteria	Mean ranking (SD)			Test type	*p*-value	Test statistics
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	3.69 (1.66)	3.64 (1.781)	5.13 (0.83)	Kruskal-Wallis	**0.08***	5.035
WLR walls	3.86 (1.68)	4.00 (1.57)	3.89 (1.96)	Kruskal-Wallis	0.965	0.071
	RCC or metal sheet		Wooden with mud plaster			
House roof	3.88 (1.54)		3.94 (1.74)	Mann-Whitney U	0.84	0.202
WLR roof	3.73 (1.55)		3.97 (1.70)	Mann-Whitney U	0.606	0.516
	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
WLR layout	3.69 (1.43)	4.07 (1.63)	3.71 (2.05)	Kruskal-Wallis	0.691	0.74

Interviews supported these findings, revealing that most respondents who maintained their traditional *haas* and multi-purpose rooms, built with mud and stone walls, did so primarily for warmth.

> (We did not demolish the haa) because the traditional haa is very warm in the winter. That is why we have still kept it.

Quote 3.10

Retaining mud-and-stone-walled dwellings or spaces, however, was not an option for those who had to build new homes, such as nuclear families separating from a joint family system. Interviews revealed the attributes of contemporary houses people chose to achieve thermal comfort, highlighting additional relationships not captured in the surveys, as illustrated in the corresponding means-end chain diagram (Fig. 3.9).

For example, when affordable, interviewees chose contemporary stone walls because they believed stone walls retained heat better.

> If the peripheral wall is made of stone, it does not let the cold inside.
>
> Quote 3.11

> We get (CMU) blocks in markets these days, and if we use them, the house is cooler. Although the expenditure was a little more, we still used stone in the construction, so that the house was weather-resistant.
>
> Quote 3.12

Furthermore, the use of wooden roofs instead of reinforced concrete or metal sheets, as well as the combination of cooking and living spaces in contemporary construction, resulted from concerns about staying warm during winters.

> Nowadays, people mostly use wood on roofs. They build very little with RCC... If you build RCC, it becomes very cold.
>
> Quote 3.13

> In the kitchen, burning larger logs of wood for cooking keeps it adequately warm inside. It is enough for us until we sleep.
>
> Quote 3.14

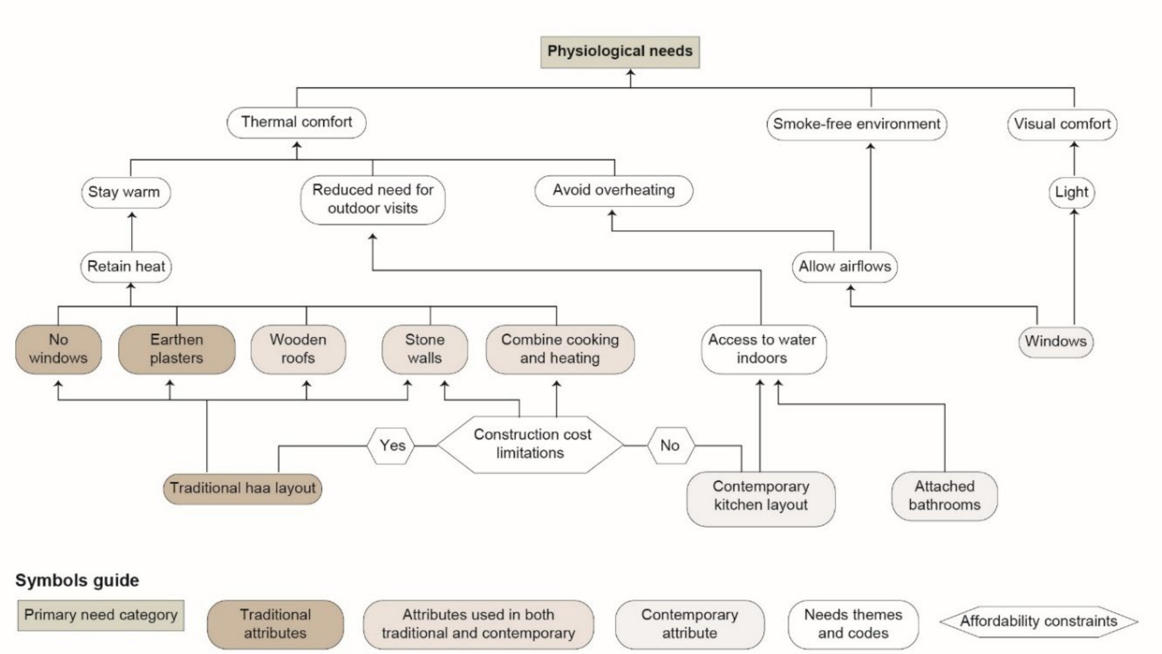

Figure 3.9. Means-end chain diagram illustrating the relationship between housing attributes and physiological needs. The chain begins with the housing attributes at the bottom, linked to the rationales behind their choices as mediating steps, ultimately leading to the basic physiological needs these attributes serve. The diagram also incorporates affordability constraints to show how economic constraints influence whether thermal needs are met through cost-effective or higher-cost attributes.

In contemporary homes, the prioritization of thermal comfort also guided the integration of plumbing into winter living rooms, which required the use of cement plaster in walls. This integration reduced the need for outdoor trips, thereby decreasing exposure to the frigid outdoors and enhancing thermal comfort. Traditional mud plasters, however, could not accommodate plumbing due to the risk of moisture damage. This led some households to retrofit their traditional walls by replacing mud plaster with cement plaster, even though they acknowledge that mud plaster is warmer. Respondents reported that fewer outdoor trips had a greater positive impact on thermal comfort. For example, a resident of one such house mentioned:

> [The retrofitted house] feels warmer because of the facilities… the water comes inside in

the kitchen, everything is here.

Quote 3.15

In addition to these findings, our previous research has highlighted post-construction adaptations made in contemporary houses to achieve thermal comfort [78]. For example, some homeowners lined their kitchen walls with wooden panels, while others took temporary measures, such as covering the lower halves of the walls with polyurethane sheets. Additionally, plastic sheets were installed on windows to reduce air infiltration. During winter, households without contemporary kitchens capable of accommodating wood-burning stoves relocated to smaller storerooms where the stoves were installed. Most of these adaptations were implemented only during the winter months when temperatures were extremely cold, highlighting the ways in which thermal needs became more urgent when people were exposed to greater thermal stress.

Light and ventilation needs: The prioritization of light and ventilation was strongly related to the selection of contemporary housing attributes (Table 3.7). Respondents with CMU-walled houses ranked these needs higher than those with traditional stone and mud-walled houses ($p < 0.01$). Similarly, the selection of contemporary RCC and metal sheet roofs for the WLRs was associated with a higher ranking for light and ventilation ($p < 0.01$). Whole-house roof materials showed a similar but nearly significant association ($p = 0.06$).

Although CMU walls and RCC or metal sheet roofs were not directly accountable for improved light and ventilation, they were features of contemporary houses that typically included larger windows, resulting in brighter and well-ventilated interiors (Fig. 3.9). In contrast, traditional houses often lacked windows or contained smaller ones, which helped retain heat but led to darker and poorly ventilated spaces. A resident of one such house noted:

> There is a lot of darkness in this room, and I think light is important for comfort… That is why I say that the system of natural light should be better.
>
> Quote 3.16

Consequently, households that prioritize light and ventilation were less inclined to continue living in traditional homes built with mud, stone, and wood, as a resident of a contemporary house mentioned:

> Our older house had no windows. In the new one, windows are for light. We can't live in the dark.
>
> Quote 3.17

Table 3.7. Mean ranking for light and ventilation needs across housing attributes (*n*=43)

Categorization criteria	Mean ranking (SD)			Test type	*p*-value	Test statistics
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	3.86 (1.52)	3.77 (1.69)	1.63 (1.06)	Kruskal-Wallis	**0.004*****	11.258
WLR walls	3.94 (1.83)	3.27 (1.43)	2.70 (1.70)	Kruskal-Wallis	0.157	3.698
	RCC or metal sheet		Wooden with mud plaster			
House roof	4.15 (1.95)		3.10 (1.51)	Mann-Whitney U	**0.062****	-1.899
WLR roof	4.89 (1.61)		3.03 (1.52)	Mann-Whitney U	**0.003*****	-2.904
	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
WLR layout	3.40 (1.83)	3.64 (1.65)	2.75 (1.75)	Kruskal-Wallis	0.438	1.652

6.3.2. Love and belonging needs – Relationship needs

Relationship needs, associated with the love and belonging category (Section 6.2.1), were not significantly associated with the selection of any housing attributes (Table 3.8). However, the means-end chain analysis of the interviews (Fig. 3.10), and field observations, provided insight into the reason behind the lack of such evidence.

Table 3.8. Mean ranking for social needs across housing attributes (*n*=47)

Categorization criteria	Mean ranking (SD)			Test type	*p*-value	Test statistics
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	4.04 (2.05)	4.47(1.59)	3.87 (1.35)	Kruskal-Wallis	0.62	0.957
WLR walls	4 (2)	4.63 (1.80)	3.50 (1.84)	Kruskal-Wallis	0.311	2.33
	RCC or metal sheet		Wooden with mud plaster			
House roof	3.63 (2.06)		4.42 (1.78)	Mann-Whitney U	0.226	1.211
WLR roof	3.70 (2.163)		4.27 (1.83)	Mann-Whitney U	0.497	0.735
	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
WLR layout	3.93 (1.94)	4.32 (1.99)	4.00 (1.69)	Kruskal-Wallis	0.81	0.422

Relationship considerations necessitated multi-room layouts with common spaces for family interactions, designated areas for hosting guests, and private rooms for individuals or couples in joint families (Section 6.2.1). Housing layouts were not asked about in the surveys; however, field observations showed that they were present in almost all houses. New constructions incorporated multi-roomed layouts from the start, whereas in traditional dwellings, these were added later as extensions with bedrooms, verandas, and bathrooms. Deviations from this pattern were rare, observed only in two cases in traditional clustered settlements where limited land prevented expansion, although other households in the same settlements had extended their homes by demolishing adjacent structures or building vertically. A respondent in one such house explained:

We had the haa only, at first. Then we added these two rooms for my brother-in-law's wedding… we had to extend the house.

Quote 3.18

This uniformity in housing layouts led to a lack of a distinguishable association between the higher prioritization of relationship needs and the selection of multi-room layouts. Nonetheless, the widespread presence of multi-roomed layouts across all housing types indicated the importance of relationship needs, as all households actively designed and modified their dwellings to ensure these needs were met.

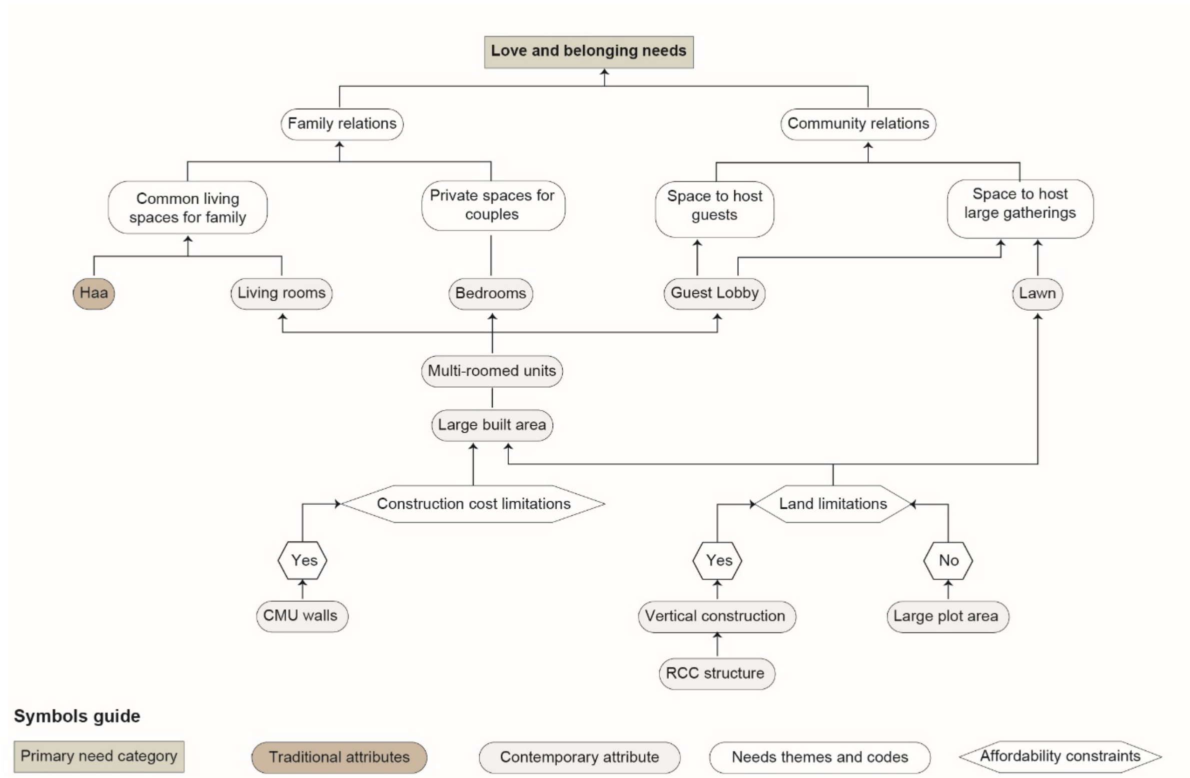

Figure 3.10. Means-end chain diagram illustrating the links between relationship needs and housing attributes. The chain begins with the housing attributes at the bottom, linked to the rationales behind their choices as mediating steps, ultimately leading to the love and belonging needs these attributes serve. The diagram also incorporates affordability constraints to show how economic constraints influence whether relationship needs are met through cost-effective or higher-cost attributes.

6.3.3. Safety needs – Strength and durability needs

Strength and durability, linked to safety needs (Section 6.2.1), did not show any significant association with housing attributes selection in the surveys (Table 3.9). The interviews, however, provided several insights into how these factors relate to construction choices (Fig. 3.11).

Interviews revealed that contemporary houses were built with cement-plastered walls because they were more durable than traditional mud-plastered walls at resisting damage from rain and water, thereby enhancing dwellings' structural integrity.

> If it rains a lot outside, the mud plaster gets damaged. That is why people don't use mud plasters…

Quote 3.19

Table 3.9. Mean ranking for strength and durability needs across housing attributes (*n*=43)

Categorization criteria	Mean ranking (SD)			Test type	*p*-value	Test statistics
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	3.36 (1.761)	4.08 (1.320)	4.13 (1.246)	Kruskal-Wallis	0.365	2.018
WLR walls	3.71 (1.44)	3.82 (1.55)	3.56 (1.94)	Kruskal-Wallis	0.93	0.144
	RCC or metal sheet		Wooden with mud plaster			
House roof	3.25 (1.65)		3.90 (1.51)	Mann-Whitney U	0.23	0.215
WLR roof	3.00 (1.51)		3.89 (1.54)	Mann-Whitney U	0.149	1.491
	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
WLR layout	3.80 (1.47)	3.81 (1.47)	3.29 (2.13)	Kruskal-Wallis	0.781	0.495

Additionally, these cement walls improved safety by preventing pest infestations and providing washable surfaces in kitchens and bathrooms, thereby reducing exposure to pathogens. In contrast, traditional houses were originally constructed with minimal attention to safety against pathogens. These homes often lacked bathrooms, and residents relied on nearby animal sheds for their sanitation needs. This practice was obsolete, as many traditional households replaced their animal sheds with cement-plastered bathrooms.

> (Traditional housing) was unhygienic. Because there was no system of bathrooms.
>
> Quote 3.20

> If we install the sink inside, it needs a water connection, and it's easier to clean. Having a bathroom is a necessity, mainly for hygiene.
>
> Quote 3.21

These findings indicated that the demand for durable and moisture-resistant surfaces had become a key factor driving the adoption of cement plasters, particularly since it was essential in bathroom constructions to ensure proper sanitation facilities.

For roof construction, interviewees found contemporary RCC and metal sheet roofs to be safer than wooden roofs. Metal sheet roofs were valued for their resistance to rain and for being less hazardous during earthquakes due to their lightweight nature.

> When there is an earthquake or a natural disaster, houses with a corrugated metal sheet roof are safer. Because the sheet is not that heavy, even if it collapses, it doesn't cause that much damage. And secondly, the sheet is best used in the rain.
>
> Quote 3.22

Reinforced concrete roofs were considered necessary for vertical constructions. In contrast, wooden roofs were considered incapable of supporting the weight of additional stories. These ideas, however, overlooked the traditional double-story houses that were built with wooden roofs. Nonetheless, most observed houses in Hunza were single-story structures where wooden roofs remained the most commonly used roofing material (Section 6.1), despite the perception that other options were more durable.

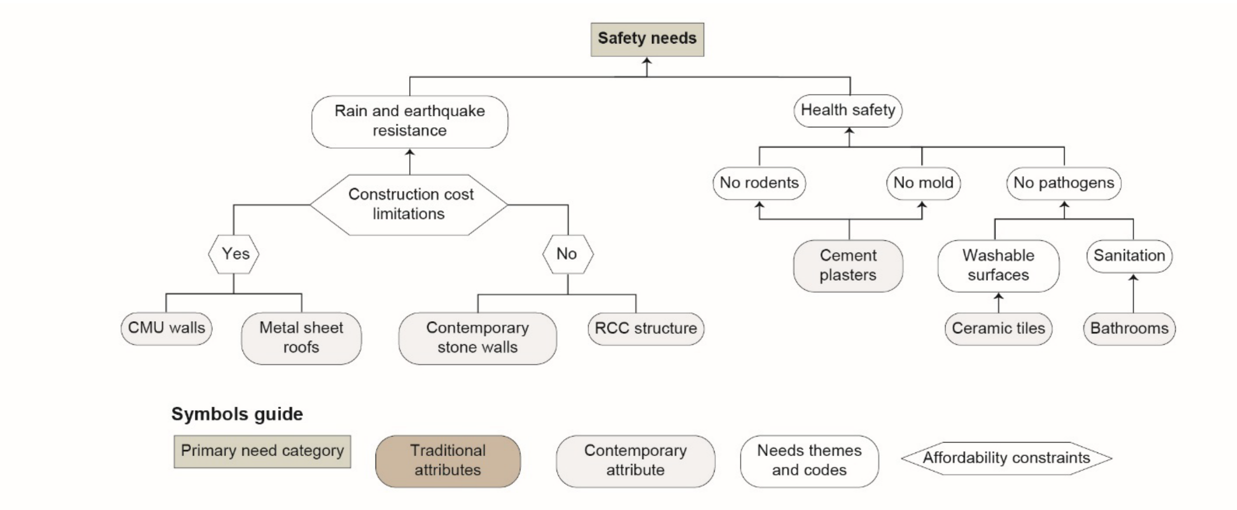

Figure 3.11. Means-end chain diagram illustrating the relationship between strength and durability needs and housing attributes. The chain begins with the housing attributes at the bottom, linked to the rationales behind their choices as mediating steps, ultimately leading to the safety needs these attributes serve. The diagram also incorporates affordability constraints to show how economic constraints influence whether safety needs are met through cost-effective or higher-cost attributes.

6.3.4. Self-esteem needs – Aesthetic needs

The self-esteem needs were closely linked to aesthetic preferences (see Section 6.2.1). The survey results (Table 3.10) indicated that respondents who rated aesthetics highly were more inclined to select contemporary housing features, including CMU walls over traditional stone or mud walls ($p = 0.03$), with similar trends approaching significance for the selection of RCC or metal sheet roofs ($p = 0.08$) and separate living and cooking areas ($p = 0.06$).

Table 3.10. Mean ranking for aesthetic needs across housing attributes (n=43)

Categorization criteria	Mean ranking (SD)			Test type	*p*-value	Test statistics
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	3.59 (1.40)	2.82 (1.72)	2 (1.309)	Kruskal-Wallis	**0.03****	6.498
WLR walls	3.00 (1.36)	3.00 (1.85)	3.33 (1.58)	Kruskal-Wallis	0.8	0.446
	RCC or metal sheet		Wooden with mud plaster			
House roof	3.69 (1.37)		2.79 (1.59)	Mann-Whitney U	**0.085***	-1.76
WLR roof	3.44 (1.50)		2.97 (1.59)	Mann-Whitney U	0.429	-0.818
	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
WLR layout	3.92 (1.67)	2.55 (1.33)	3.29 (1.60)	Kruskal-Wallis	**0.059***	5.673

Interviews supported these survey findings (Fig. 3.12), highlighting that cleanliness and order were central to people's aesthetic aspirations. Respondents valued separate living and cooking areas to maintain cleanliness in the living spaces while avoiding smoke, clutter, and oily residues from cooking. Whereas the traditional system of using a single multi-purpose room for all activities made maintenance burdensome.

> In traditional houses, there is typically one room where eating, drinking, sleeping, and all other activities take place. So, in old houses, that causes a lot of trouble for us. In new homes, rooms need to be cleaned once every two or three days. However, in the traditional house, cleaning up became quite troublesome. We think that if someone visits our home and they see cleanliness, they will also like it.
>
> Quote 3.23

Furthermore, cement-plastered walls made cleaning easier, as they did not chip, harbor mold, or attract pests like traditional walls did.

> [We replaced mud plaster with cement because] there were mice, there was dirt, there was fleece, and the plaster shed off.

Quote 3.24

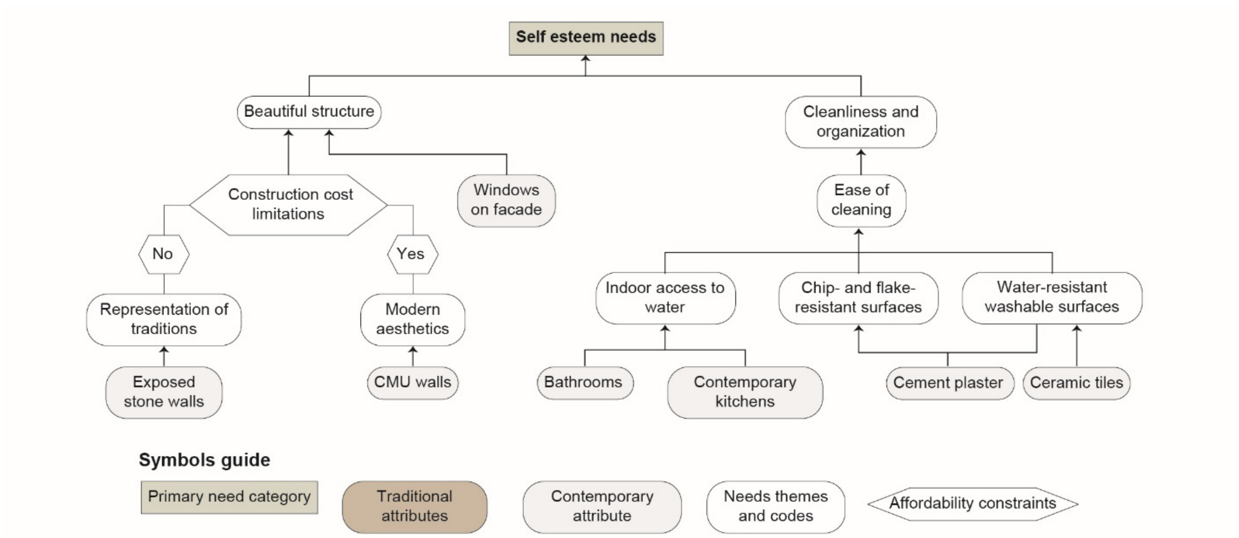

Figure 3.12. Means-end chain diagram illustrating the relationship between aesthetic needs and housing attributes. The chain begins with the housing attributes at the bottom, linked to the rationales behind their choices as mediating steps, ultimately leading to the self-esteem needs these attributes serve. The diagram also incorporates affordability constraints to show how economic constraints influence whether aesthetic needs are met through cost-effective or higher-cost attributes.

Respondents also incorporated cultural and visual elements to enhance aesthetics, which were not captured in the surveys. For house facades, contemporary exposed stone walls were preferred for their visual appeal, but when the costs were prohibitive, contemporary CMU walls were chosen for their clean and sharp finishes.

> Stone houses look beautiful, and if we have the affordability, then we will build a stone house, but if we can't, then we'll build a cement block one.

Quote 3.25

Windows were also considered beautiful, enhancing the house's façade.

> I will demolish this (old) house and build a new home there. I really wish to build a beautiful house with windows, an airy house filled with light.

Quote 3.26

Aesthetics were also expressed through contemporary guest lobbies designed in a traditional haas configuration, consisting of wooden pillars and roof structures, but with contemporary cement-plastered walls. In several cases, decorative elements such as embroidered wall hangings and cushion covers were also used. These design choices reflected both cultural identity and individual tastes, underscoring the role of aesthetics in shaping the selection of housing attributes.

6.3.5. Needs vs choices: The mediating role of affordability

Affordability emerged as a critical external factor shaping the ways in which households balanced competing needs, often limiting the adoption of desired attributes that may have fulfilled multiple needs simultaneously. A prominent trade-off was between relationship needs and thermal comfort, both of which were consistently ranked as high priorities. Relationships required multi-roomed layouts to provide both private and communal spaces, which led to larger dwelling footprints and, consequently, increased construction costs. To keep expenses manageable, most households chose CMU blocks for wall construction, as they were the most affordable option, despite being known to be cold. In contrast, stone walls, which were preferred for their heat retention, were often excluded from new constructions because of their high costs. As one interviewee mentioned:

> (Instead of building one room with stones for thermal comfort) they (people) find it cheaper and quicker to build with CMU blocks. And they find it more useful to have multiple rooms.

Quote 3.27

At the same time, strategies that were thermally beneficial, cost-effective, and compatible with multi-room layouts gained widespread adoption. For example, in houses where stone and mud-walled structures were still present, these were used as the winter living rooms as they could retain warmth. Whereas new CMU-walled bedrooms, bathrooms, and verandas were added as private spaces for the household members. This configuration allowed them to meet both relationship and thermal needs simultaneously in an affordable way. The survey results aligned with this pattern (Table 3.11), showing a significant association between affordability concerns and the continued use of traditional haas ($p = 0.04$). However, in cases where entirely new houses had to be built, affordability concerns led households to almost always return to CMU-walled constructions, thereby compromising thermal comfort.

In contemporary houses, an example of an affordable strategy that met multiple needs was to combine cooking and living spaces, allowing cooking fires to provide space heating and thus reduce overall heating costs. At the same time, bedrooms in these houses offered residents private spaces when needed. Another example was the wooden roofs, which were the most common choice as they were affordable to build over large areas and could retain indoor warmth.

Further findings indicated that less prioritized needs were often met only when they aligned with high-priority objectives. For instance, even though RCC and metal roofs were considered more durable than wooden roofs, they were rarely adopted because they performed poorly in retaining heat. Similarly, while contemporary stone walls were considered both durable and aesthetically pleasing, their expenses made them unsuitable for multi-roomed constructions. In contrast, CMU walls with cement plaster offered durability and protection against moisture and pests, as well as clean finishes that were considered aesthetically acceptable, while also allowing affordable multi-room construction and facilitating indoor plumbing, which reduced outdoor trips for fetching water in the frigid winter. This simultaneous fulfillment of multiple needs made cement-plastered CMU walls the most widely adopted contemporary construction method.

These findings indicated that affordability played a crucial role in balancing multiple needs. Although thermal needs were highly prioritized, they were oftentimes compromised to fulfill relationship needs in a financially manageable way. On the other hand, even low-ranked needs were fulfilled when the relevant housing attributes aligned with relationship needs and remained affordable. These findings, therefore, highlight that any strategy aimed at improving thermal comfort must be financially feasible and compatible with other needs, particularly those related to relationships.

Table 3.11. Mean Ranking for Affordability Needs Across Housing attributes (*n*=44)

Categorization criteria	**Mean ranking (SD)**			**Test type**	***p*-value**	**Test statistics**
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	3.48 (1.78)	3.45 (1.29)	4.25 (1.48)	Kruskal-Wallis	0.507	1.36
WLR walls	3.33 (1.87)	3.41 (1.41)	4.56 (1.13)	Kruskal-Wallis	0.137	3.977
	RCC or metal sheet		Wooden with mud plaster			
House roof	3.31 (1.54)		3.74 (1.65)	Mann-Whitney U	0.372	0.892
WLR roof	2.89 (1.53)		3.80 (1.60)	Mann-Whitney U	0.125	1.588
WLR layout	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
	2.75 (1.60)	3.76 (1.61)	4.57 (0.97)	Kruskal-Wallis	**0.04****	6.195

6.4. Influence of housing attributes on thermal comfort

Next, we analyzed the impact of housing attributes on thermal comfort using mean comfort scores derived from a four-item scale (Cronbach's $\alpha = 0.7$). The Kruskal-Wallis tests revealed a significant effect of winter living rooms on mean thermal comfort, showing that those living in traditional *haas* were more thermally comfortable than those residing in kitchens and living rooms ($p<0.01$; Table 3.12).

The interview data strongly supported the survey findings. Participants consistently mentioned that traditional haas were warmer than contemporary living rooms and kitchens. One interviewee expressed it as:

> The RCC houses, no matter how much fire you burn inside… it heats up and then cools down quickly. However, the houses, traditionally made of stone, for example, have a wooden roof, like the houses we built in our local style, which are very nice for Hunza.
>
> Quote 3.28

As the quote above reflects, in addition to the haa layout itself, interviewees also associated the use of stone walls and wooden roofs with thermal comfort; yet these effects did not translate into measurable differences in thermal experience in the surveys. This discrepancy may be due to variations in how stone walls and wooden roofs have been used across different constructions. For example, multi-room dwellings built between the 1950s and 1980s contained stone walls with mud plaster and wooden roofs. Yet, these also had windows leading to higher heat losses through air infiltration [78]. Similarly, contemporary wooden roofs with thin layers of mud plaster did not retain heat as efficiently as the traditional ones. Therefore, these findings ultimately suggest that the presence of haa was the most important determinant of thermal comfort, as it integrated traditional materials with spatial compositions absent in newer constructions, even when those newer constructions used traditional materials.

Table 3.12. Housing attributes vs mean thermal comfort (*n*=109)

Categorization criteria	Mean ranking (SD)			Test type	*p*-value	Test statistics
	Modern	Hybrid	Traditional			
	CMU with cement plaster	Stone with cement plaster	Stone with mud plaster			
House walls	2.49 (0.99)	2.27 (0.95)	2.72 (1.15)	Kruskal-Wallis	0.305	2.377
WLR walls	2.24 (0.87)	2.51 (1.04)	2.78 (1.11)	Kruskal-Wallis	0.136	3.996
	RCC or metal sheet		Wooden with mud plaster			
House roof	2.56 (1.08)		2.41 (0.96)	Mann-Whitney U	0.585	1307
WLR roof	2.29 (0.84)		2.52 (1.05)	Mann-Whitney U	0.403	1134
	Separated cooking and living space	Kitchen with combined cooking and living	Traditional haa with combined cooking and living			
WLR layout	2.45 (1.03)	2.24 (0.93)	3.08 (0.97)	Kruskal-Wallis	**0.007*****	9.985

6.5. Influence of thermal stress on future construction priorities

To analyze whether lived thermal experiences, as indicated by the mean thermal comfort score (Section 5.3), influenced the prioritization of needs, the survey asked all participants which needs they would prioritize if they were to construct new homes in the future. The analysis of the mean rankings for each need category revealed that thermal comfort ranked highest, followed by strength and durability, and social needs (Fig. 3.13). In contrast, affordability, aesthetics, and light and ventilation were ranked significantly lower. A Wilcoxon signed-rank comparison showed that survey respondents ranked thermal comfort significantly higher than light, ventilation, aesthetics, and affordability. Additionally, strength and durability were ranked significantly higher than light, ventilation, and affordability. Social needs were only significantly ranked higher than light and ventilation needs.

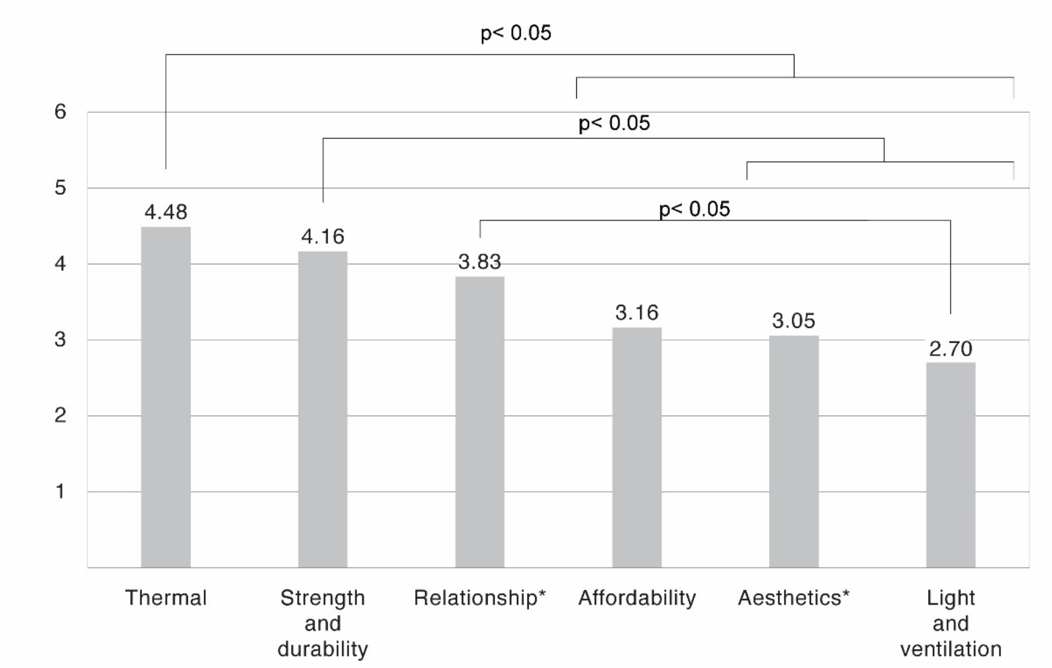

Figure 3.13. Mean rankings comparison for future housing priorities.

Interviews also indicated that people want to prioritize thermal comfort in future constructions, consistent with the survey findings. The interviewees said:

> I prefer that there should be old houses, so that we can stay warm easily.
>
> Quote 3.29

> In new houses, we must have a provision for burning wood. However, we don't keep that to keep our house beautifully decorated. While we strive for our home to be beautiful, we don't think about the risks to our health and life. So, we should use traditional layouts, which include wood burning on the sides.
>
> Quote 3.30

To examine the effects of thermal deprivation on the prioritization of needs, the survey respondents were first divided into two groups: those whose thermal comfort levels were above the overall mean and those whose levels were below the whole sample mean (Mean = 2.46). Next, the difference in the mean rankings of various needs between the two groups was analyzed using the Mann-Whitney U test (Table 3.13). The results revealed a statistically significant difference in the prioritization of thermal needs (p = 0.04) and relationship concerns (p = 0.02) among the two groups. Respondents with below-average thermal comfort ranked thermal needs higher than those with above-average thermal comfort. Contrarily, respondents with below-average thermal comfort ranked relationship needs lower. Interestingly, people with below-average thermal comfort ranked their aesthetic needs higher compared to those with above-average thermal comfort (p = 0.07). This trend is counterintuitive, and further investigation is necessary to understand the underlying cause.

Table 3.13. Comparison of mean ranking for various neat categories among people reporting above- and below-average thermal comfort

Need Categories	Mean Ranking (Standard Deviation)			
	Thermal comfort is below average	Thermal comfort is above average	Z-statistics	*p*-value
Social needs (*n*=86)	3.43 (1.766)	4.29(1.68)	2.23	**0.026****
Thermal needs (*n*=87)	4.82 (1.37)	4.19 (1.51)	-2.051	**0.04****
Affordability needs (*n*=80)	3.25 (1.71)	2.97 (1.54)	-0.703	0.482
Strength and durability needs (*n*=85)	4.06 (1.59)	4.42 (1.36)	0.0982	0.353
Aesthetic needs (*n*=78)	3.34 (1.72)	2.65 (1.60)	-1.789	**0.074***
Light and ventilation needs (*n*=81)	2.64 (1.38)	2.68 (1.49)	0.039	0.969

7. Discussion and conclusion

This study used Maslow’s Hierarchy of Needs as a theoretical framework to examine the motivations of owner-builders in choosing modern dwellings despite the cold stress they face in such housing. In urban housing developed by private actors or government-led social schemes, Maslow’s theory has been widely applied to guide designs and policies that align with residents’ needs, improve their well-being, and promote higher living standards [20–27]. This framework, however, has not been applied in rural areas of developing countries, where most housing is built by owner-builders with little technical support and limited policy guidance. The present study, therefore, aims to identify the ways in which Maslow's framework can meaningfully capture the motivations influencing housing choices in Hunza and, accordingly, guide policies and design strategies to improve construction practices. Understanding this potential is particularly important because owner-built housing constructions are rapidly expanding in developing regions globally [35]. If left unguided, they risk locking in poor construction standards and environmentally unsustainable design choices into the long-term built fabric [73].

7.1. Applicability of Maslow's theory in Hunza

Our findings indicated both alignments and divergences with Maslow's theorization. The alignment lies in Maslow's conceptualization of lower-level needs (physiological, safety, belonging, and self-esteem) as deficiency-driven needs, which must be fulfilled before people aspire to higher-level ones [19]. In Hunza, owner builders' concerns for thermal comfort, adequate light and ventilation, durability, spatial configurations that separate family, private, and guest areas, and aesthetic aspirations all reflect a focus on these basic needs. In contrast, limited attention to higher-level needs such as self-actualization and self-transcendence, which Maslow describes as growth-oriented needs, suggests that preoccupation with meeting basic needs constrains consideration for these higher-level aspirations. These patterns resonate with earlier research in developing contexts, such as in India, where mid- to low-income housing choices and investments similarly center on enhancing comfort, safety, and social relationships [83,84]. Therefore, development in these areas emphasizes fulfilling basic needs as a foundation for improving the quality of life and enabling the pursuit of higher-level goals [84,85]. In the same way, strategies for improving thermal performance and housing in Hunza should address existing deficiencies first, ensuring that interventions respond to residents' most immediate and pressing needs.

While this focus on lower-level needs aligned with Maslow's framework, there were significant discrepancies in the relative prioritization of these basic needs. First, in contrast to Maslow's proposal, where physiological needs are expected to dominate, love and belonging needs were prioritized the most in Hunza. This is consistent with the findings from other non-Western cultures, where maintaining social relations is necessary for survival [23,86]. In Hunza, this dynamic was reflected in the widespread adoption of multi-room houses with separated private and social spaces, even though such configurations increased the overall construction costs, necessitating the selection of low-cost CMU blocks known to exacerbate thermal stress. At the same time, reliance on social relationships also supported coping strategies, as seen in how low-income households depended on relatives for firewood during the winter months [78]. These findings thus suggest that in Hunza, belonging and relationship needs are not secondary to physiological needs; instead, they are integral to basic survival. Thus, any interventions aimed at improving housing quality and thermal performance must be sensitive to these relationship needs by allowing spatial configurations that support both private, familial, and community interactions while remaining affordable for local builders.

Second, consistent with research emerging from urban developing regions [22,72], our findings suggested that need preoccupancy may be simultaneous, rather than strictly hierarchical as suggested by Maslow. This interpretation is supported by the absence of statistically significant differences in how participants ranked various types of needs. This simultaneous prioritization was also evident in the widespread use of housing features that fulfilled more than one need. For example, wooden roofs with mud plaster were prevalent because they retained warmth and were inexpensive, and thus suitable for use over larger areas. Similarly, retaining traditional haas and rooms built with mud-and-stone walls for thermal comfort for winter living while adding contemporary bedrooms and guest lobbies reflected strategies aimed at fulfilling thermal and relationship needs simultaneously. The patterns, therefore, indicate that future interventions that respond to multiple needs at once would be more likely to be acceptable to households as well.

Our findings also aligned with the emerging research from developing regions, indicating that housing motivations are more fluid, i.e., shifting with lived experiences of deprivations, than strictly hierarchical. In Hunza, this fluidity was apparent in post-construction thermal adaptations. For example, people relocating their daily activities, including sleeping in some cases, to cooking areas despite the loss of privacy, illustrated how thermal comfort became an overriding concern as cold stress intensified. Similarly, the willingness to compromise on light and ventilation by sealing windows or by moving into traditional windowless rooms during winters reflected how experiences of thermal stress could temporarily reconfigure priorities amongst different needs. At the same time, the survey suggested a long-term reordering of these priorities, as thermal comfort was ranked significantly higher, especially by those exposed to thermal stress in their current housing, showing a strong influence of lived experiences on people's priorities. This higher prioritization of thermal comfort in future constructions highlights an emerging willingness among owner-builders to take proactive measures to reduce thermal stress in their housing, which presents an opportunity for housing policies and support programs to promote energy-efficient constructions.

Finally, for this willingness to translate into meaningful change, policies must focus on addressing existing limitations. Our findings reveal that a lack of affordable construction methods, which can fulfill various needs simultaneously, is the primary constraint in Hunza. While traditional stone and mud houses (haas) would provide effective heat retention, they are largely incompatible with contemporary preferences for safety, light, ventilation, aesthetics, and multi-room layouts. Contemporary alternatives, such as stone walls with cement plaster, are perceived to balance thermal performance with other functional requirements, but their high cost makes them inaccessible to most households. Addressing these limitations through policies and interventions that provide cost-effective, climate-responsive materials and techniques is essential to enable households to realize their thermal comfort goals while fulfilling their other housing needs.

Building on these insights, the study proposes a dynamic model of need-driven housing decision-making that captures the cyclic relationship between motivations, construction choices, and lived experiences (Fig. 3.14). In this model, the prioritization of needs evolves continuously as residents respond to their lived experiences, such as thermal discomfort. At any given point, the selection of housing attributes reflects the simultaneous pursuits of multiple needs, constrained by the available resources, materials, and competencies. These constraints force owner-builders to make compromises, resulting in suboptimal constructions as seen in the adoption of CMU walls in Hunza. However, lived experiences in these houses prompt a reassessment of what matters most, leading to modifications to their homes and a reorganization of needs prioritizations for future constructions. In this entire process, policies and design strategies must aim to align owner-builders' motivations with housing outcomes. This can be achieved by addressing the constraints that force trade-offs on fundamental needs, rather than imposing externally conceived technical solutions or policies that overlook the owner-builders' reasoning and lived experiences.

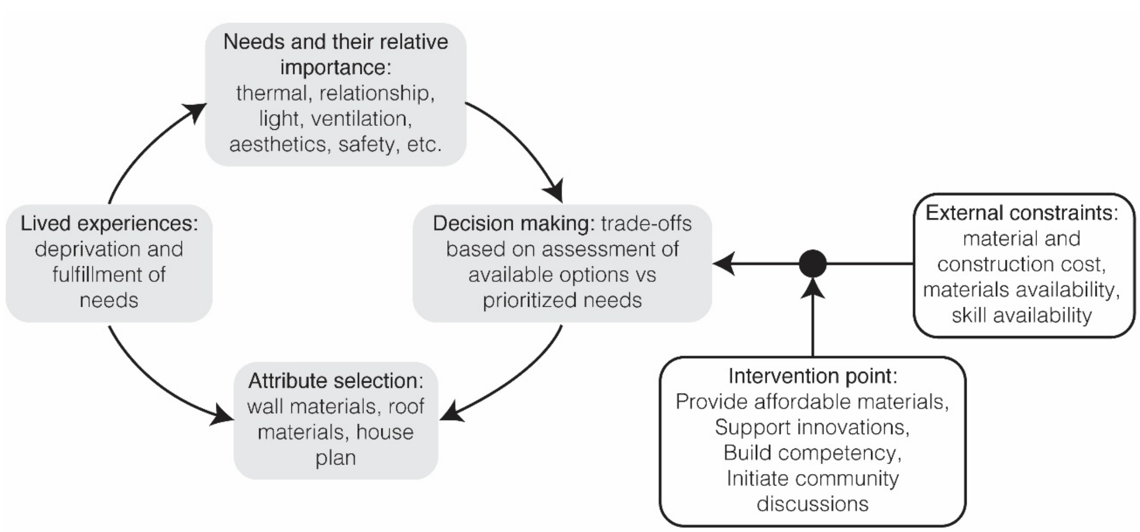

Figure 3.14. Illustration of the dynamic decision-making model, showing the cyclical natures of lived experiences, motivations, and construction choices, dictated by external constraints. Interventions must address constraints to better align owner-builders' needs with housing outcomes (attributes) through existing newly enabled resources and opportunities.

7.2. Policy and design interventions

The findings from this research provided a foundation for considering how future housing policies and design interventions could align with owner-builders' motivations and address the material, financial, and technical barriers faced by households in Hunza. Building on these understandings and drawing on insight from existing literature and real-world applications aimed at improving the thermal performance of buildings, the following section outlines potential policy and design approaches that could help address the problem of thermal stress.

Building competencies and providing affordable technical resources: Since relationship needs have emerged as the most important concern, any proposed designs or policy interventions must prioritize meeting these needs alongside thermal comfort. To do so, construction methods need to remain affordable, allowing households to continue building multi-room layouts that can facilitate social interactions while improving indoor thermal performance. Findings from this study, as well as our previous research [78], indicate that residents are already experimenting with materials and techniques they perceive as enhancing warmth while remaining cost-effective. These locally driven adaptations can provide a valuable foundation for further investigation and refinement [87]. By scientifically assessing the thermal performance of these existing practices and addressing their limitations, targeted interventions can be developed that improve the adaptations people are already using [78]. This approach can ensure that the solutions remain economically viable, socially acceptable, and technically feasible, thereby increasing the likelihood of their successful adoption in the community. Furthermore, the adoption of these policies or proposals will be even more effective if the solutions also meet durability requirements, provide adequate light and ventilation, and align with the aesthetic aspirations of the people.

A possible intervention could be improving contemporary stonewall constructions to improve affordability, as our research showed they were warm but could not be widely adopted due to their high cost. This expense largely stems from the expectations for exposed stone finishes, which require a uniformly shaped and colored stone to be extracted from local quarries [78]. Construction costs can be substantially curtailed if, as in traditional construction, the practice of using irregular stones plastered on both sides is reintroduced. However, to achieve this, it is essential to address the durability-related limitations of traditional walls, which primarily stem from the use of mud mortars and mud plasters. Studies in various regions have tested a range of stabilizers, including organic materials and cement-based additives selected according to local availability and affordability, and these have been shown to enhance the structural strength and durability of earthen walls without significantly compromising their thermal performance [88,89]. Future research in Hunza can therefore focus on similar solutions from a structural, financial, and thermal perspective to develop adoptable solutions.

In existing houses, thermal retrofits can also build upon adaptations that residents are already using. For instance, our previous study found that many households line the lower halves of interior walls with wooden panels to reduce the sensation of cold when touching the wall surface [78]. While this practice responds effectively to occupants' immediate comfort, it overlooks the significant heat losses occurring through the uninsulated upper portions of the walls. Future research could explore extending this locally familiar strategy by applying wooden cladding across the full wall height and integrating affordable insulation materials, such as polyurethane sheets, which are commonly used in the region as carpet underlay. Because this approach draws on existing materials, knowledge, and building techniques, it offers a socially and economically feasible pathway for improving thermal performance. However, a detailed scientific evaluation is required to quantify the potential thermal benefits and determine its overall effectiveness as a retrofit solution.

Similarly, many residents are aware of thermal concerns when choosing wooden roofs finished with mud plaster. However, contemporary roofs often have thinner layers of mud compared to traditional constructions. This results in higher thermal transmittance and reduced insulation. To improve thermal performance, the thickness of the mud plaster layer could be increased. Mud is a locally available and low-cost material, and local builders are already familiar with this technique. However, the actual thermal benefits of this approach need to be verified through scientific evaluations. If proven effective, these strategies could be easily promoted within the community as practical and affordable solutions for enhancing indoor warmth.

Finally, regarding roof constructions, people often assume that multi-story buildings require reinforced concrete structures, even though there are several examples of traditional houses with multi-story buildings using load-bearing walls and wooden roofs. Multi-story construction can offer the dual benefits of reducing building footprint and minimizing radiant and conductive heat losses through roofs, which account for a significant portion of total building heat losses [90,91]. Addressing such assumptions through scientific education and by providing built examples can offer people alternative solutions that are thermally beneficial and affordable.

Improving Traditional Houses: The retention and continued use of traditional houses alongside the addition of a multi-room structure was found to be the an effective way of simultaneously fulfilling relationship and thermal needs, yet these *haa*s, in several cases, were being demolished to make space for new constructions or they were being abandoned due to the lack of adequate ventilation, light and safety and aesthetic concerns. Policies and designs encouraging the continued use of traditional houses by enhancing the durability of surface finishes and introducing better light and ventilation conditions can potentially reverse this trend. In Hunza, programs like the Aga Khan Cultural Services Pakistan have sought to encourage the continued use of *haa*s in traditional cluster settlements, while focusing on heritage conservation [92,93]. They preserved these homes in their original forms, modifying entry spaces only by minimally incorporating cement plasters to accommodate plumbing and sanitary systems [92]. Yet the persistent issues of rodents and moisture seepage in the mud plaster of the main living space compromised the residents' safety and aesthetic needs. This issue can be resolved by using alternative plastering materials and methods that offer high heat retention properties comparable to mud plasters, while also providing the strength, durability, and moisture resistance of cement plasters. Additionally, efforts may be made to enhance light and ventilation in traditional houses through low-tech solutions, such as light wells, light-colored interior finishes, and controlled exhaust ventilation systems [94,95]. This will ensure they remain functional and continue to provide thermal benefits without undermining other needs of the residents.

Outreach efforts: Finally, policies need to engage owner-builders while also focusing on training masons and laborers in non-conventional construction techniques. The Aga Khan Planning and Building Services Pakistan has proposed several innovative wall and fenestration constructions for northern Pakistan. However, the lack of outreach to owner-builders and the availability of skilled labor have proved to be significant barriers to their widespread adoption [96]. Hunza has well-organized community networks, established through kinship and village organizations developed under the Aga Khan Development Network [97]. The region also retains a strong culture of resource-sharing [97], which can be leveraged to initiate discussions on the importance of thermally responsive construction methods. Discussions can highlight environmental benefits, thermal advantages for housing inhabitants, and the economic value of these construction methods for owner-builders. By fostering community dialogue and increasing awareness, policies can play a pivotal role in equipping people with the knowledge, skills, and resources needed to implement sustainable and climate-responsive building practices [98].

7.3. Limitations and future research

This study provides important insights into the dynamics of need prioritization and housing-related decision-making in self-built dwellings under resource constraints. Although the remote nature of data collection and a small survey sample posed practical challenges, triangulation across interviews, survey, and observation data enabled an in-depth understanding of decision-making processes. Future work can build on these findings by expanding to larger sample groups and incorporating additional survey variables, such as room count, fenestration presence and sizes, and other architectural features, to identify broader patterns and highlight generalizable trends. Studies in other modernizing rural settings could further expand on these findings as well. Such studies can test and refine the proposed dynamic model of need-driven construction decision-making, exploring whether similar cycles of prioritization constraints and adaptations emerge elsewhere. In addition, longitudinal research in Hunza could provide deeper insight into how repeated construction experiences, along with shifting aspirations, resources, and environmental pressures, may reshape the prioritization of needs and the forms of housing that emerge over time. Such an understanding would be essential for policies aiming at establishing long-term alignment between people's motivations and housing outcomes.

8. Bridge

This chapter showed that, while thermal comfort is important to owner-builders, multiple needs shape residents' choices simultaneously. As a result, residents adopt low-cost contemporary constructions that fulfill their needs for multi-room layouts, offering spaces for familial, communal, and private interactions, durability, and aesthetics, while simultaneously experimenting with adjustments that they see as practical and thermally beneficial. Yet, as Chapter 2 reveals, these adaptations fall short because housing residents cannot directly and precisely identify the heat-loss pathways. The next chapter takes a technical approach to examine heat gain and heat loss pathways across different housing types and, accordingly, proposes improvements to the existing adaptation strategies.

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IV. THERMAL RETROFITS FOR CONTEMPORARY DWELLINGS IN COLD ARID NORTHERN PAKISTAN

1. Introduction

Context and Problem: In the Hunza valley, a cold-desert region in Northern Pakistan, traditional housing construction methods are being abandoned in favor of contemporary ones, resulting in extreme indoor cold stress for the inhabitants [1]. Situated around 2400 m above sea level, the area experiences harsh winters, with the heating season extending from October through May (Fig. 2.2). In addition, the valley receives very little rainfall, resulting in sparse natural vegetation and a scarcity of fuel wood [2,3]. Traditional houses in Hunza were therefore designed to retain indoor warmth with limited indoor heating by using locally available stone, mud, and wood in thick walls and roof configurations [4–6]. Additionally, these houses were built in tight clusters, with spatial configurations that ensured the winter living room walls and roofs were sheltered from the outdoors by adjacent spaces within each house itself or by neighboring structures [1,3,4], further reducing the possibilities of heat loss.

Traditional building practices are now being abandoned, however, as people increasingly desire detached multi-room houses that provide more space and privacy [7,8]. These modern homes are constructed using materials such as concrete, glass, and steel, which are considered more durable, cost-effective, and less labor-intensive to build, while also being aesthetically pleasing [9]. However, in these homes, building envelopes are directly exposed to the cold outdoors, and the walls and roofs are highly thermally transmissive, resulting in greater heat loss and, consequently, colder indoor environments than found in their traditional counterparts [1]. At the same time, people in Hunza face an acute energy shortage, leaving them unable to support mechanical heating in these frigid indoor environments [10,11]. Consequently, improving the thermal performance of buildings themselves is critical for addressing the problem of thermal stress in this region.

Analogous thermal stress has resulted from the replacement of vernacular building materials and methods with concrete, glass, and steel constructions in numerous other areas. For example, in hot-humid regions of Bangladesh and Indonesia, new rural homes with metal sheet roofs are reported to be ~5 °C warmer than traditional stilt houses with thatched roofs, planked floors, and bamboo walls during summer days [12–14]. In traditional Iranian houses in Yazd, basements used for summer living were reported to be up to 20 °C cooler than the hot outdoor temperatures, whereas this feature is often absent in contemporary houses [15]. Research in the cold regions of Nepal, Eastern Turkey, and China has also shown that contemporary houses are colder and less thermally comfortable in winter than traditional homes [16–18].

Existing solutions: Research and policies to address thermal stress in housing in such developing regions have focused primarily on technical solutions. Some have advocated for the adoption of modern measures such as improved insulation systems and double-glazed windows [19–21]. However, these solutions are not widely adopted because they are costly and often require technical skills that many local builders lack [22]. Others have emphasized the need to reintroduce traditional passive heating and cooling techniques, including improved ventilation, solar heating, and the use of thick earthen walls [23–25]. Yet these methods are viewed as outdated, less durable, aesthetically unattractive, and incompatible with modern configurations that separate spaces by activity [26,27]. In response, several studies have advocated for policy interventions, such as standardized building codes and economic incentives to support their adoption. However, in rural developing regions, most houses are owner-built without government oversight, complicating the implementation of such policies [28–30].

In Pakistan, the Energy Conservation Building Code (IBCC) regulates envelope insulation and air-sealing standards to promote energy conservation in high-end residential and commercial buildings [31]; however, it is not implemented in remote areas, such as Hunza [28]. In rural areas, NGOs such as the Building and Construction Improvement Program (BACIP) have proposed alternative construction methods, including the reintroduction of traditional building materials such as mud and stone, as well as the use of modern insulation materials such as EPS and XPS foam [32]. However, locals do not adopt these solutions because stone construction is expensive and labor-intensive; mud plaster degrades easily and is aesthetically unpleasing; and modern insulation products are costly and unfamiliar to local masons [32].

Our recent research in Hunza has highlighted that owner-builders often choose wooden roofs, install wooden panels on wall interiors, and combine cooking and living spaces to cope with thermal stress. However, these measures are only partly effective because occupants don't fully understand the key mechanisms of heat loss and therefore miss chances to improve these adaptations [1,9]. Building on these locally established methods with scientific knowledge could present a promising pathway forward, as studies show that builders and occupants are more likely to adopt familiar construction techniques that align with existing skills, entail lower perceived risks, and integrate easily into established building systems [33–36]. Yet in Hunza, so far, there have been no efforts to quantitatively assess the thermal performance of these commonly used adaptations, or to improve them.

Research approach: To address these limitations, the pathways of heat loss and opportunities for heat gains and retention in existing traditional and contemporary dwellings in northern Pakistan are investigated. Accordingly, improvement strategies are proposed and tested that build on insights from previous studies on residents' lived experiences and thermal adaptation strategies [1], and the decision-making processes guiding owner-builders' construction choices [9].

The study analyzes four houses that represent a spectrum of transitions from traditional to contemporary housing types, using building energy simulations. Although traditional houses are no longer built in Hunza, many still exist and are occupied. These were included in our sample to assess the effectiveness of traditional design strategies, the disadvantages of abandoning them, and the possibilities of using these strategies in modern constructions. The building materials, plans, interior furnishings, indoor air temperatures, heating practices, and daily activities of the housing inhabitants were recorded in each sampled house. This data was used to build and validate EnergyPlus models. The validated models were then used to evaluate the dominant heat-loss pathways and potential heat-gain opportunities in these houses. This insight, alongside findings from our previous studies[1,9], was then used to propose four interventions: using wooden panels for wall insulation, increasing the thickness of roof mud plasters, installing dampers in smoke exhaust pipes to reduce unwanted infiltration, and optimizing skylight placement to increase solar gains.

Implications: The results showed that traditional houses outperformed contemporary ones in thermal performance. However, improvements through low-cost, familiar building technologies can greatly reduce the heat losses and thermal stress in contemporary construction as well. The findings, therefore, suggest that research in developing regions may benefit from understanding local building methods, their thermal advantages and limitations, and occupants' thermal adaptations to develop affordable, familiar building improvement strategies. Such efforts are necessary to achieve the Sustainable Development Goals for sustainable cities and communities (SDG 11) and climate action (SDG 13) by reducing thermal discomfort and improving energy efficiency of housing and resource-constrained developing countries.

2. Methods

2.1. Field data collection

2.1.1. Housing types

The housing transitions in Hunza have been detailed in our previous research [1]. From that dataset, four houses were selected to represent key transitional stages between traditional and contemporary constructions in terms of materials, spatial configurations, and building methods.

The first of these was a traditional two-story house (T2S; coded as 1600-T in previous research [1]), which was built over 400 years ago in a cluster settlement. This dwelling, preserved in its original form by the NGO Aga Khan Cultural Services Pakistan (AKCSP), exemplified the oldest construction type. The second, a traditional one-story dwelling (T1S; 1900-T-c3 in [1]), built around 100 years ago, showed early features of housing transitions with a single-story plan and a semi-detached configuration that resulted after the demolition of some adjoining structures. The third dwelling was a contemporary stone-walled house with a wooden roof (CSW; 2015-C in [1]). This house, built in 2015, represented the integration of traditional materials into contemporary constructions. The fourth was a contemporary CMU-walled house (CCW; 1800-t-C in [1]), built as an addition to a traditional house in 2004. This dwelling represents the most common contemporary construction style with concrete block walls and a wooden roof.

2.1.2. Housing characteristics

In the sampled dwellings, the plans and dimensions of rooms, as well as the construction materials for walls, roofs, floors, and windows, were documented. Information about hidden elements, such as wall cores and floor layers, was gathered by consulting housing residents and local builders regarding the typical construction methods used in the observed structures. Interior furnishings, including carpets, floor coverings, furniture, and storage units, were also documented, as these items can retain heat and slow down heat transfer. Dimensions of possible airflow pathways, including doors, windows, skylights, smoke vent pipes, and visible gaps and cracks around these components, were measured to inform infiltration estimates. Furthermore, exterior features, such as adjacent buildings or nearby trees, that may influence solar and wind exposure were also recorded.

Information on heat-generating sources in houses, including the times and durations of wood burning for cooking and heating, the amounts and types of fuel used for cooking and heating, and the times when family members occupied various parts of the house and their activities, was collected through interviews. The number and wattage of appliances and lighting fixtures in the living rooms were recorded, and the frequency of their use was inquired about in interviews.

2.1.3. Monitoring

Indoor air temperatures were monitored at hourly intervals using Onset HOBO UA data loggers in the winter living rooms of T1S and CCW during the 2020-2021 winter. T2S and CSW were recruited into the study the following year, and their temperatures were monitored during the winter of 2021-2022. To avoid the influence of surface temperatures while minimizing disturbance to occupants, the loggers were suspended 0.5 m below each ceiling and 2 m away from all walls in T1S, T2S, and CCW. In CSW, however, one logger was placed on a wooden shelf 2 m above floor level and 0.5 m away from the wall surface due to residents' preferences.

2.2. Climate and weather files

EnergyPlus weather files were created for the periods of 2020-2021 and 2021-2022 by combining data from the Pakistan Meteorological Department (PMD) and Typical Meteorological Year (TMYx) files retrieved from the Climate.OneBuilding.org repository. The PMD data included air temperature, humidity, dew point, wind speed, wind direction, and cloud cover at 3h intervals from 5 AM to 5 PM from October 2020 to October 2023. These data were interpolated to obtain hourly values, which were then integrated into the TMYx file to represent actual weather conditions during the monitoring period.

2.3. EnergyPlus modeling

All houses were modeled in EnergyPlus v9.8. Building geometries and adjacent features casting shadows on the dwellings were created using the Euclid V.0.9.4.4 plug-in in Google SketchUp Make 2017. Glazing assembly properties were calculated using LBNL WINDOW 8.0 and were imported into EnergyPlus. Because the roof assemblies included large beams spaced ~0.5 m apart, roof thermal transmittance values were calculated in THERM v7.8, and their density and specific heat were determined based on volumetric ratios of individual components to preserve the thermal mass effect [12]. In EnergyPlus, these assemblies were represented as single materials, 0.1m thick, with the corresponding thermal and physical properties. Floors were modeled as multi-layered material assemblies in EnergyPlus, with materials defined according to the documented construction practices. The boundary condition under the floor was set to reference ground temperatures calculated by the slab preprocessor object to ensure realistic heat transfers between the building and the underlying soil. Other constructions, including walls, doors, and internal mass, were modeled directly in Energy Plus IDF Editor. Since most of the materials used in these constructions were locally sourced or manufactured, their thermal and physical properties were adopted from literature reporting materials with comparable composition and sourcing (see Supplementary Information).

Heating Inputs: Heating inputs from the wood-burning stoves, along with internal heat gains, were modeled using People, Lights, and OtherEquipmet objects in Energyplus. Schedules for wood burning were created based on household interviews and observed temperature spikes in the monitored data. Heat outputs were estimated by considering the energy density and quantities of wood used, as recorded on-site. The heat lost through the smoke exhaust pipe, as well as the portion of heat released indoors through radiation, convection, and latent heat, was estimated using values from relevant literature on similar stoves [37,38]. To model the slow cooling of the stove after burning wood, which occurs due to the presence of embers, the heating schedules were adjusted accordingly. Heat gains from people, lighting, and appliances were based on standard heat energy generation values reported by ASHRAE [39] for the observed equipment. Lighting, equipment, occupancy, and activity schedules were determined based on interview reports.

Airflows: Airflows were modeled with ZoneInfiltration:EffectiveLeakageArea, ZoneInfiltration:ZoneCrossMixing, and ZoneInfiltration:DesignFlowRate objects. Effective leakage areas and zone cross-mixing rates were estimated based on the sizes of openings, including doors, windows, skylights, smoke exhaust pipes, and visible cracks in and around these components. Design flow rates were applied to model infiltration in zones with high airflow, such as verandas with metal mesh screens. Additionally, this object was used to simulate stack airflow through the smoke exhaust vent, driven by the higher air temperatures inside the stove during woodburning. These flow rates were calculated based on the smoke exhaust pipe height, its cross-sectional area, and the temperature difference between the hot interior of the stove and the cold outdoor air (see Supplementary information).

Model validation and analysis: EnergyPlus models were first validated by comparing measured indoor temperatures with simulated indoor temperatures during the coldest winter weeks of each monitoring period, and adjusting certain model input values to improve alignment. Specifically, cooking schedules were adjusted to align with observed indoor air temperature peaks, and effective leakage area values were adjusted to reproduce measured fluctuations in indoor air temperatures that aligned with (and presumably resulted from) outdoor air variations. The resulting models met the criteria of ASHRAE Guide 14, which stipulates thresholds of CVRMSE (<30%) and NMBE (<10%) for discrepancies between measured and simulated temperatures in valid models [40]. The thermal behaviors of the validated models, along with proposed improvements, were then tested under identical weather conditions to allow comparison in the thermal performance of various building methods.

3. Results and discussion

3.1. Field measurements and observations

3.1.1. Housing characteristics

In previous research, the broad characteristics of traditional, hybrid, and contemporary houses have been documented [1]. Here, we further define the specific characteristics of the four houses chosen to represent these categories.

Traditional two-story (T2S): The traditional two-story house (Fig. 4.1a) was the oldest house in our study. It was located in a clustered settlement, surrounded by houses on all sides except the entry (Fig 3.1a). The ground floor consisted of an entry room and a bathroom, which were constructed in place of a demolished cattle shed. The entry room led to the winter living room, the *haa*, with a hearth in the center with a metallic wood-burning stove. The smoke exhaust pipe extended vertically through a 10 cm-diameter opening in the *haa* roof, passing through the summer living room, *baldi*, on the upper floor, and exiting above the roof (Fig. 2.5; Fig. 3.1b). Raised platforms for seating and sleeping were located on both sides of the hearth. A traditional storage room was located opposite the entry. The upper floor consisted of a summer living room and a storage room following the footprint of the *haa* and storage room on the ground floor (Fig. 4.1a).

Walls were about 55 cm thick, built of stone with mud mortar, and finished with mud plaster (Fig. 4.2a). The roof rested on peripheral walls and two main beams, supported by interior wooden pillars. It consisted of 10 × 15 cm wooden rafters, supporting 4 cm-thick planks, covered with birch bark for waterproofing, and about 15 cm of mud on top (Fig. 4.3a). The floor was raised about 1 m, filled with stone and gravel, plastered with mud, and covered with woolen rugs and floor cushions (Table 4.1). There were no windows; the skylight, 50 × 50 cm, was the only source of light and ventilation in the *haa*. A small cube-shaped single-glazed box topped the skylight. The summer room contained a large prism-shaped wire mesh skylight, about 1 × 1.5 m, covered with a polyethylene sheet. Doors were small, approximately 1 × 1.5 m (Table 4.1).

The ground floor held a substantial amount of thermal mass, which, in addition to the wall and roof structures, consisted of a large boulder built into the entry lobby wall, another shaped into a raised platform in the *haa,* and the inner partition walls in the *haa*.

Traditional one-story (T1S): The traditional one-story (T1S) house (Fig. 4.1b) was also located in a cluster settlement. However, it adjoined only one neighboring house; the others had been demolished. The household had since expanded its home by constructing contemporary additions, including two bedrooms with attached bathrooms, a kitchen, and a verandah in the space where those structures once stood (Fig. 4.1b).

The traditional structure consisted of a *haa* and a storage room. Similar to T2S, the T1S *haa* had a centrally located hearth with a 0.5 × 0.5 m skylight and a 10 cm diameter opening for a smoke exhaust pipe above and raised platforms for seating and sleeping on either side. The skylight, however, was unglazed: it was usually partially covered with a polyethylene sheet to allow light and ventilation, and the sheet was pulled over completely only during rain to prevent water from entering. The wall and roof materials were similar to those of T2S. However, the walls were thinner, measuring 45 cm in thickness (Fig. 4.2b). Additionally, the exterior mud plaster was replaced with cement plaster during the construction of contemporary additions. The roof had the same structure, but due to erosion and lack of proper maintenance, the thickness of the mud plaster had reduced to approximately 10 cm (Fig. 4.3b). The floor was slightly below the ground level, consisting of a thin gravel infill layer covered with mud plaster. Woolen rugs and floor cushions were laid over the floor. The original small door to the *haa* was replaced with a contemporary 0.9 × 2 m door. Thermal mass in the house only consisted of the *haa* structure itself and interior stone partition walls.

The contemporary additions were constructed with 20 cm-thick CMU walls and wooden roofs with 10 ×15 cm rafters, 2.5 cm wooden planks, polyethylene sheet as a water barrier, and 10 cm-thick mud plaster. These rooms held large single-glazed windows and contemporary-sized doors. The floors were raised 0.3 meters above ground level, with gravel and sand infill, finished with plain cement concrete (PCC). Floor coverings included polyurethane sheet underlay, carpet, rugs, and floor cushions.

Contemporary stone-walled house (CSW): The contemporary stone-walled (CSW) house was a fully detached unit. The plan consisted of three bedrooms and bathrooms, a living room, a guest lobby, a kitchen, a storeroom, and a verandah (Fig. 4.1c). The kitchen was designed to accommodate winter living alongside cooking. It held a wood-burning stove in the center, with a smoke exhaust pipe passing through a 10cm diameter opening in the roof, a raised seating platform on one side, and a contemporary kitchen counter with a sink and a gas stove top on the other.

The exterior walls of the house were 45 cm thick, constructed with stone masonry and bound with cement mortar. The exterior surface consisted of exposed stone, and the interior surfaces were plastered with cement (Fig. 4.2c). The interior walls were constructed of 20 cm CMU blocks, plastered with cement on both sides. The roof structure was the same as traditional ones, except the wooden planks were thinner (2.5 cm), a polyethylene sheet replaced birch bark, and the mud plaster was 10 cm thick (Fig. 4.3c). The floor was raised more than 1 meter above ground level, and it consisted of stone, gravel, and sand infill, topped by concrete slab. Polyurethane underlay, carpet, rugs, and floor cushions covered the floors.

The kitchen contained a single-glazed window with wooden frames, which was covered with a polyethylene sheet from the exterior during the winter. Doors were contemporary-sized (Table 4.1). The concrete countertops contributed to the kitchen's thermal mass, along with the building structure.

Figure 4.1. Floor plans of the sampled houses : (a) traditional two-story house, ca. 1600s; (b) traditional one-story house, ca. 1900s with subsequent contemporary additions in 2005 and 2010; (c) contemporary one-story stone-walled house, ca 2015; and (d) contemporary one-story CMU-walled house, ca. 2004, built as an addition to a traditional two-story structure ca. 1800s, which is no longer used for living (adapted from [1])

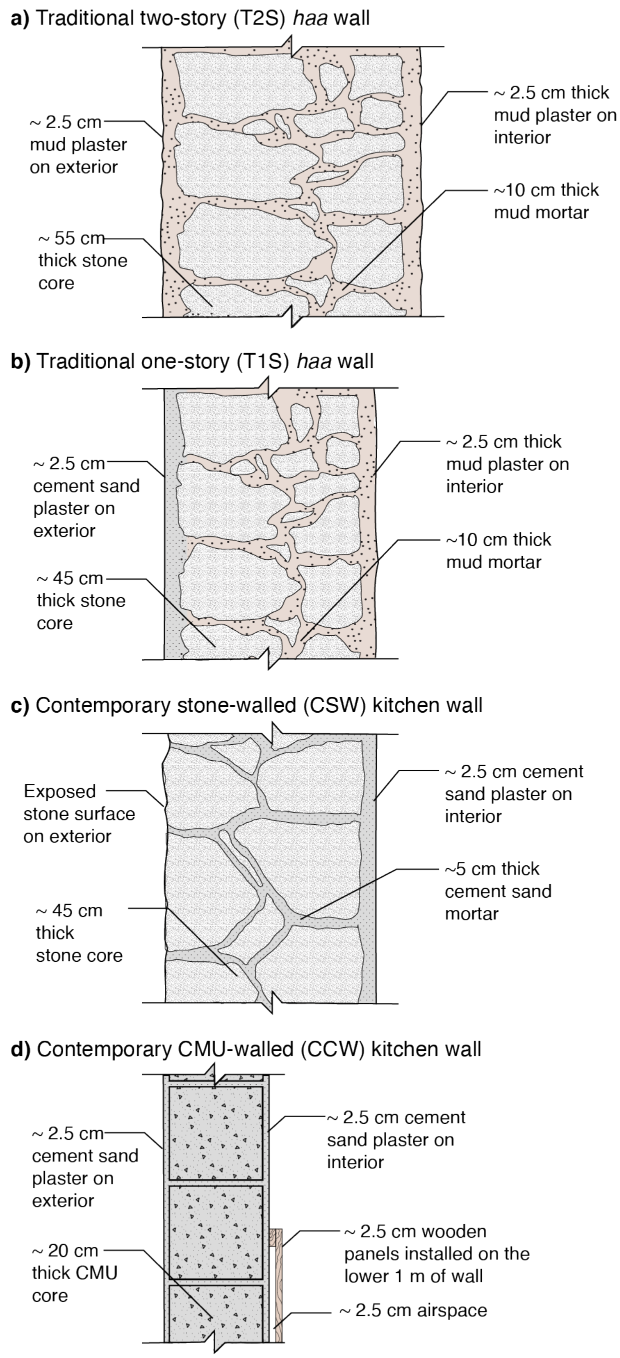


Figure 4.2. Wall constructions in the winter living areas of sampled houses : (a) Traditional two-story (T2S) haa wall with 55 cm thick traditional stone masonry; (b) Traditional one-story (T1S) haa wall with 45 cm thick retrofitted traditional stone masonry; (c) Contemporary stone wall (CSW) kitchen walls with 45 cm thick contemporary stone masonry; (d) Contemporary CMU-walled (CCW) kitchen walls with 20 cm-thick CMU block masonry with wooden panels up to 1 m above floor level.

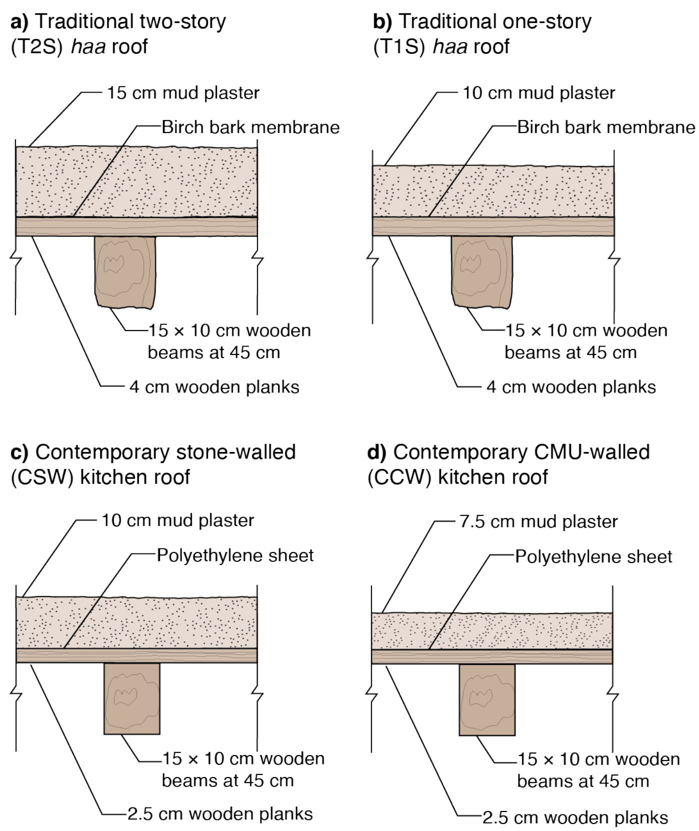


Figure 4.3. Roof constructions in the sampled houses: a) T2S haa, b) T1S haa, c) CSW kitchen, d) CCW kitchen. All roofs consist of wooden beams and planks with waterproofing membranes and mud plaster layers, with variations in material thickness. Traditional houses used birch bark as the waterproofing membrane, whereas contemporary kitchens used polyethylene sheets.

Table 4.1. Material composition and thermal properties of building components of the winter living rooms.

	Traditional two-story (T1S) *haa*	**Traditional one-story (T2S) *haa***	**Contemporary stone-walled (CSW) kitchen**	**Contemporary CMU-walled (CCW) kitchen**
Wall type	55 cm stone masonry core in 5 cm mud mortar, with 2.5 cm mud plaster on both interior and exterior surfaces	45 cm stone masonry core in 5 cm mud mortar, with 2.5 cm mud plaster on interior and 12 mm cement plaster on exterior	*Stone:* 45 cm stone masonry core in 2.5 cm cement mortar, with 12 mm cement plaster on the interior surface *CMU:* 20 cm CMU block with cement mortar and 12 mm cement plaster on both interior and exterior surfaces	*Uninsulated:* 20 cm CMU block with cement mortar and 12 mm cement plaster on both interior and exterior surfaces *Insulated:* same as above, with 0.25 cm air space, and 2.5 cm wooden panels on the interior

Table 4.1 Continued

	Traditional two-story (T1S) *haa*	Traditional one-story (T2S) *haa*	Contemporary stone-walled (CSW) kitchen	Contemporary CMU-walled (CCW) kitchen
Area	56 m^2	48 m^2	*Stone:* 17 m^2 *CMU:* 19 m^2	*Uninsulated:* 39 m^2 *Insulated:* 7.5 m^2
U-Values	1.062 W/m^2K	1.285 W/m^2K	*Stone:* 2.036 W/m^2K *CMU:* 2.77 W/m^2K	*Uninsulated:* 2.77 W/m^2K *Insulated:* 1.68 W/m^2K
Roof type	15 cm thick mud plaster o/ 4 cm thick wooden planks, over 10 ´15 cm thick wooden rafters	10 cm thick mud plaster o/ 4 cm thick wooden planks, over 10 ´15 cm thick wooden rafters	10 cm thick mud plaster o/ 2.5 cm thick wooden planks, over 10 ´15 cm thick wooden rafters	7 cm thick mud plaster o/ 2.5 cm thick wooden planks, over 10 ´15 cm thick wooden rafters
Area	32 m^2	24 m^2	12 m^2	18 m^2
U-Values	0.788 W/m^2K	1.195 W/m^2K	1.325W/m^2K	1.462 W/m^2K
Floors	Rugs & woolen carpets o/ 10 cm mud plaster o/ 90 cm gravel fill o/ compacted earth	Rugs & woolen carpets o/ 10 cm mud plaster o/ 12 cm gravel fill o/ compacted earth	Rugs and carpets over carpet underlay o/ 1-2 cm cement–sand plaster / 10 cm PCC slab o/ 10 cm sand o/ 90 cm gravel fill 0/ compacted earth.	Rugs and carpets over carpet underlay o/ 1 cm cement–sand plaster / 10 cm PCC slab o/ 10 cm sand o/ 10 cm gravel fill 0/ compacted earth.
Area	32.3 m^2	24.3 m^2	12 m^2	19 m^2
U-Values	0.198 W/m^2K	0.499 W/m^2K	0.301 W/m^2K	0.717 W/m^2K
Windows/ skylight	No Windows 0.5 × 0.5 × 0.5 m cube wood-framed skylight with 7 mm clear glass	No Windows 0.5 × 0.5 m open skylight	1.1 × 1.7 m window with 7 mm clear glass set in 4 cm thick wooden casement panels, and a 4 cm thick wood frame; clear polyethylene sheet on exterior	1.1 × 1.7 m window with 7 mm clear glass set in 4 cm thick wooden casement panels, and a 4 cm thick wood frame 0.5 × 0.5 × 0.5 m cube wood-framed skylight with 7 mm clear glass
U-Values	4.97 w/m^2K	-	3.77 W/m^2K	4.78 W/m^2K
Doors	1 × 1.5 m poplar wood panel, 6 cm thick; 4 cm thick door frame	1.0 × 2 m poplar wood panel, 6 cm thick; 4 cm thick door frame 1.0 × 1.5 m poplar wood panel, 6 cm thick; 4 cm thick door frame	1.0 × 2 m poplar wood panel, 6 cm thick; 4 cm thick door frame	1.0 × 2 m poplar wood panel, 6 cm thick; 4 cm thick door frame
U-Values	1.88 W/m^2K	1.88 W/m^2K	1.88 W/m^2K	1.88 W/m^2K

Contemporary CMU-walled house (CCW): The contemporary CMU-walled house (CCW) was a detached unit as well. The plan consisted of three bedrooms and bathrooms, a guest lobby, a kitchen designed for both cooking and living, a storeroom, and a verandah (Fig. 4.1d). Similar to CSW, the kitchen contained a wood-burning stove in the center, with a smoke exhaust pipe exiting through the roof, a seating space on one side, and a contemporary kitchen counter with a sink and a gas stovetop on the other. The walls were constructed with 20 cm CMU blocks, bound with cement mortar, and finished with cement plaster on both the interior and exterior. In the kitchen, the lower 1 m of the walls were lined with 2.5 cm wooden panels, with a 2.5 cm airspace behind them (Fig. 4.2d). The roof structure was similar to CSW, however, with a thinner (7 cm) mud plaster layer. This roof was the thinnest of any house (Fig. 4.3d). The floors were raised 20 cm above ground level using gravel and sand infill, with a concrete slab. Polyurethane foam underlay carpets, rugs, and cushions covered the floors. The kitchen contained a single-glazed, wood-framed window and three contemporary-sized doors (Table 4.1), one of which opened outdoors (Fig. 4.1d). The kitchen also included a small cube-shaped glazed skylight positioned directly above the stove.

3.1.2. Indoor temperatures

To understand the thermal behavior of the houses in detail, indoor air temperatures were monitored in the winter living rooms of the four houses (Section 2.1.3). T1S *haa* and the CCW kitchen were observed during the winter of 2020-2021. The T1S *haa* and the CSW kitchen were monitored during the winter of 2021-2022. For detailed analysis, we focused on periods when the minimum daily temperatures were the lowest each season: January 9-13, 2021, and December 28, 2021, to January 1, 2022. The concurrent analysis of one traditional and one contemporary house during each winter allowed a direct comparison of actual indoor temperatures between each pair under the same outdoor weather conditions.

a. *Traditional one-story house vs Contemporary CMU-walled house (observed 2020-2021)*

During the study period, January 9th to 13th, the T1S *haa* remained warmer (7 °C to 22 °C) than the CCW kitchen (3 °C to 20 °C; Fig.4.4). On average, the CCW kitchen was about 2 °C colder than the T1S, and around 4 °C colder during the early morning hours. Throughout the day, indoor heating maintained higher interior temperatures in both cases; therefore, the overnight temperature drops in the houses served as a better indicator of their thermal performance. In the CCW kitchen, temperature drops were greater (~11-17 °C) than in T1S *haa* (~9-13 °C).

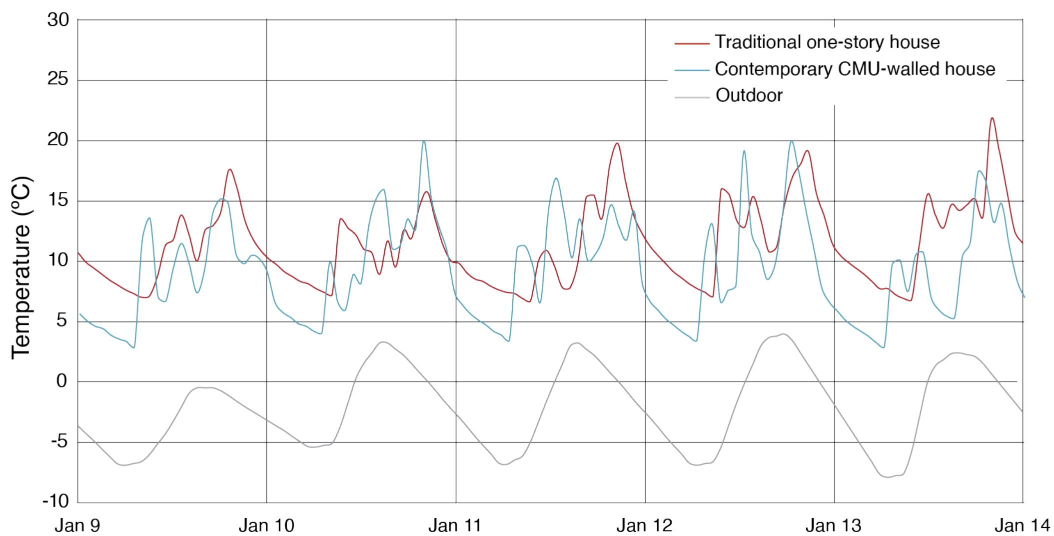


Figure 4.4. Measured indoor temperatures in the traditional one-story house (ca. 1900) and the contemporary CMU-walled house (ca. 2004), and outdoor temperatures as reported by PMD during January 9th to 13th, 202

These temperature differences must be understood in the context of two important factors. First, the skylight in the T1S *haa* remained open, thereby increasing airflows. Secondly, the first temperature rise in both houses every morning corresponded to the first fire lit, rather than being driven by natural daytime temperature rise. The temperature data, as well as the interviews, indicated that the first fires were lit one to two hours earlier in CCW than in T1S. This early heating, therefore, raised the indoor temperature of the contemporary kitchen in the mornings and obscured the full extent of overnight cooling that may have occurred if the fires had been lit later. Despite these factors, the warmer indoor temperatures in the traditional house revealed greater heat retention in theT1S *haa* than in the CCW kitchen.

b. Traditional two-story house vs contemporary stone-walled house (observed 2021-2022)

Next, we compared the indoor temperatures of the T2S *haa* and the CSW kitchen from December 28th, 2021, to January 1st, 2022. During this period, the T2S *haa* temperatures remained, on average, 3 °C warmer than those in the CSW kitchen, and the minimum *haa* temperature remained up to 6 °C warmer. Additionally, the CSW kitchen experienced a much larger temperature range (6 °C to 22 °C; Fig. 4.5) than the *haa* (13 °C to 19 °C; Fig. 4.5). Accordingly, the maximum diurnal temperature drop in the traditional house was 5 °C, whereas that of the traditional kitchen was 14 °C.

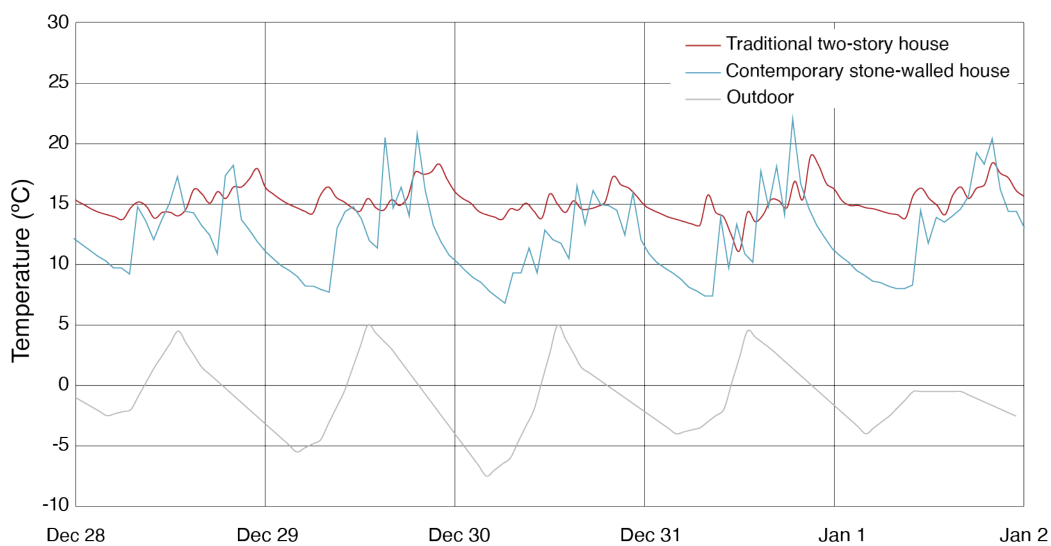


Figure 4.5. Measured indoor temperatures in the traditional two-story house (ca. 1600) and the contemporary stone-walled house (ca. 2015), and outdoor temperatures as reported by PMD during December 28th, 2021, to January 1st, 2022

3.2. Model Validation

Using the housing documentation data, which included information on construction materials, plans, surrounding trees and structures casting shadows on the house, and methods for assembling these materials, as well as common daily family activities and heating patterns (Section 2.1.2), EnergyPlus models for the four houses were created (Section 2.3). To validate these models, simulations were first conducted under actual weather conditions in the Hunza Valley during the corresponding study periods (Section 2.1.3). The simulated temperatures were then compared with the observed winter living room temperatures for each house, both graphically and statistically.

The results for model calibration are shown in Fig. 4.6 and Fig. 4.7. Achieving an exact match between the observed and simulated temperatures was practically impossible, as all the observed rooms were heated throughout the day using wood-burning stoves. In most cases, the embers continued to dissipate heat even after the fires were extinguished at night. In addition, occupant behavior, including the frequency of opening and closing doors and windows, as well as the number of heating hours per day, was expected to vary significantly from day to day, making it difficult to account for these factors precisely. Nevertheless, all four models fulfilled the ASHRAE recommended criteria for model calibration: The Normalized Mean Bias Error (NMBE) values for all models were within ±10% and the Coefficient of Variation of Root Mean Square Error (CV RMSE) were below 30%.

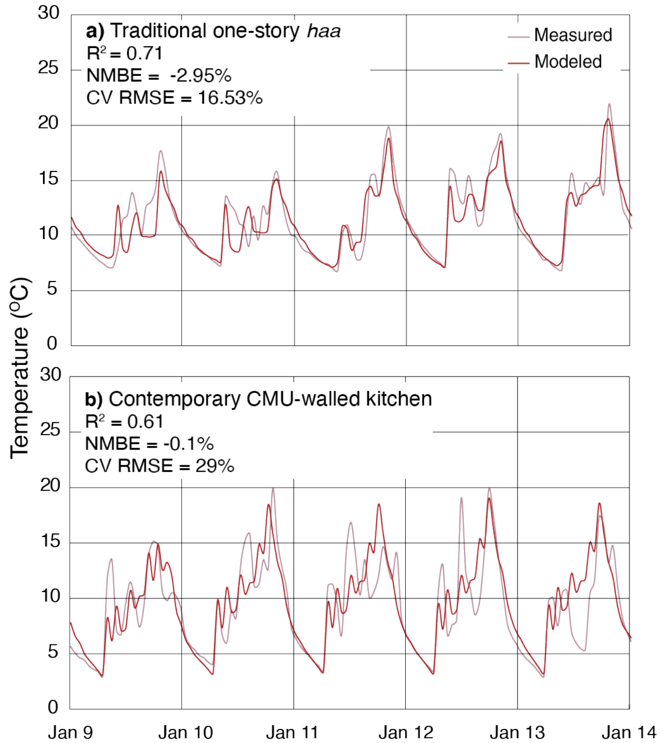


Figure 4.6. Modeled and observed temperatures in a traditional one-story house and a contemporary CMU-walled house, as observed between January 9th and 13th.

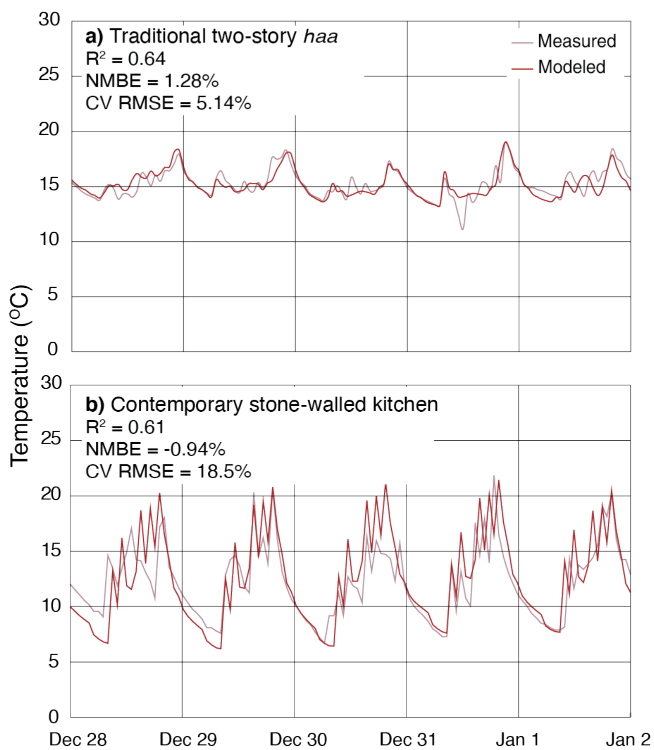


Figure 4.7. Modeled and observed temperatures in a traditional two-story house and a contemporary stone-walled house, as observed between December 28th and January 1st.

3.3. Thermal performance comparison of the four houses

Next, to understand the thermal effects of the stepwise shift from fully traditional to fully contemporary houses, simulated indoor operative temperatures across four houses were compared under the weather conditions of the first week of January, 2021. Observations had shown that cooking was the main source of heating, yet its schedules and frequencies varied greatly across households and even within households from day to day. Because assessing the thermal performance of the different construction types was the main concern, standard cooking schedule based on typical cooking patterns were used in all EnergyPlus models. This standardization ensured a consistent comparison of the thermal influences of envelope constructions and dwelling configurations, revealing heat gain, loss, and retention pathways in each case.

3.3.1. Modeled indoor temperatures

The comparative analysis of the four houses revealed that the T2S haa was the warmest, with indoor temperatures consistently remaining above 16 °C (Fig. 4.8). The highest temperatures, ranging from 20 to 21 °C, were reached in the evenings, when cooking and household activities peaked during dinner preparation. Overall, the temperatures remained closer to the widely accepted thermal comfort temperatures of 18 °C [41] and were well above the suggested comfort temperature of 13-15 °C, as indicated by studies in the Himalayan regions in Nepal and India [42,43], which share a similar weather and geographic profile to Hunza.

While the observations in T2S aligned with studies from other high-altitude regions, indicating that traditional houses remained warmer than contemporary ones [16–18,44,45], interestingly, the T1S *haa* was not significantly warmer than the contemporary CSW kitchen (Fig. 4.8). During dinner preparation, peak temperatures in the CSW kitchen were about 3 °C higher than in T1S, mainly due to the kitchen's smaller volume. Since both spaces received the same cooking heat inputs, the smaller kitchen warmed up more quickly than the larger T1S volume. Additionally, a considerable amount of cooling in T1S resulted from continuous airflow through the open skylight, which further reduced the effectiveness of indoor heating (Section 3.1.2). By morning, temperatures in both spaces dropped to ~8 °C, with a larger decrease overnight in the CSW kitchen (Fig. 4.8). The smaller daily temperature fluctuations in T1S reflected the characteristics of high-thermal-mass constructions, which heat up slowly and retain that heat, slowing its dissipation to the outdoors overnight [46].

The CCW kitchen exhibited the lowest indoor temperatures, remaining below 15 °C (Fig. 4.8). As in other cases, the highest temperatures were reached around the time of dinner preparation. However, the temperature dropped by 10 °C overnight, with early morning temperatures often dropping below 5 °C (Fig. 4.8). Although similar to the CSW kitchen, the CCW kitchen volume was small as well, the highly thermally transmissive envelope limited temperature rises during heating and led to greater overnight cooling.

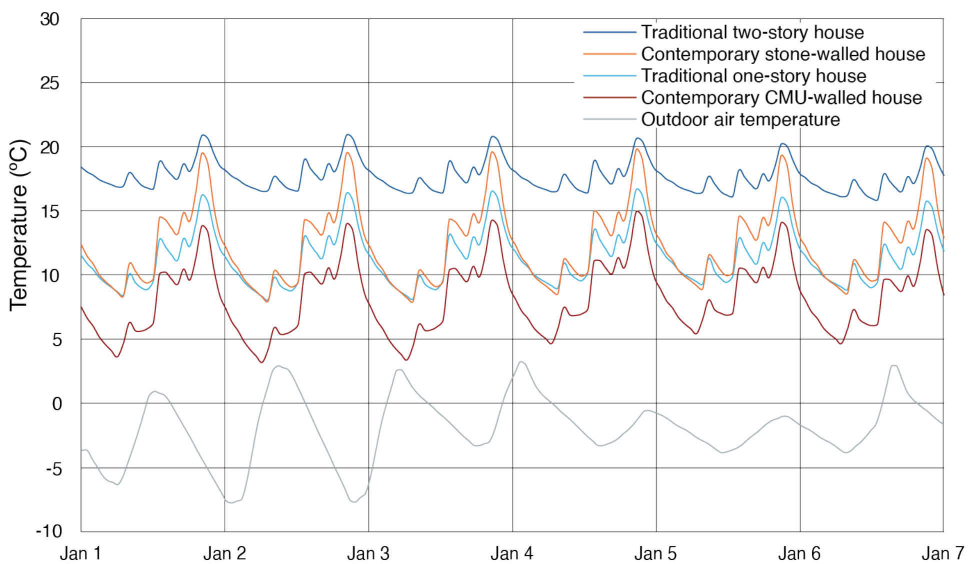


Figure 4.8. Comparison of indoor operative temperatures and outdoor air temperatures across the four sampled houses simulated under the weather conditions of January 1 to 6, 2021. Indoor heating is driven solely by internal heat gains, primarily from cooking, using identical cooking schedules across all models.

3.3.2. Heat flows

Next, we analyze the heat flows in the four houses using EnergyPlus models to highlight the dominant pathways of heat loss and opportunities to enhance heat gain, which then provided the basis for developing strategies aimed at maintaining warmer indoor temperatures during winters.

a. Internal heat gains

To identify appliances and activities contributing passively to indoor heating, the thermal energy gains from cooking, electrical appliances, and the presence of people were analyzed. Cooking was the greatest contributor to indoor heat across all four houses (Fig. 4.9; Table 4.2). Here, a standard cooking schedule was used (Section 3.2). Internal gains from electrical devices were minimal because electricity was only available for two to four hours each day (Table 4.2). As a result, family size and hours of occupancy exerted the greatest influences on the variations in internal heat gains among the four houses.

Table 4.2. Internal heat gains originating from various sources in the winter living rooms

	Traditional two-story *haa*		Traditional one-story *haa*		Contemporary stone-walled kitchen		Contemporary CMU-walled kitchen	
	Source	Energy (MJ)	Source	Energy (MJ)	Source	Energy (MJ)	Source	Energy (MJ)
People	Family of 4	27	Family of 5	36	Family of 5	17	Family of 7	39
Occupancy hours	21.5 h/d each		21.25 h/d each		9.3 h/d each		14.25 h/d each	
Lighting	4 × 16 W LED bulbs; 2 × 25 W fluorescent tube lights	1.6	2 × 16 W LED bulbs	0.46	2 × 16 W LED bulbs	0.46	2 × 16 W LED bulbs	0.46
Electrical equipment	None	0	None	0	55 cm LED TV	0.18	55 cm LED TV	0.18
Cooking	Wood-burning stove	101	Wood-burning stove	101	Wood-burning stove	101	Wood-burning stove	101

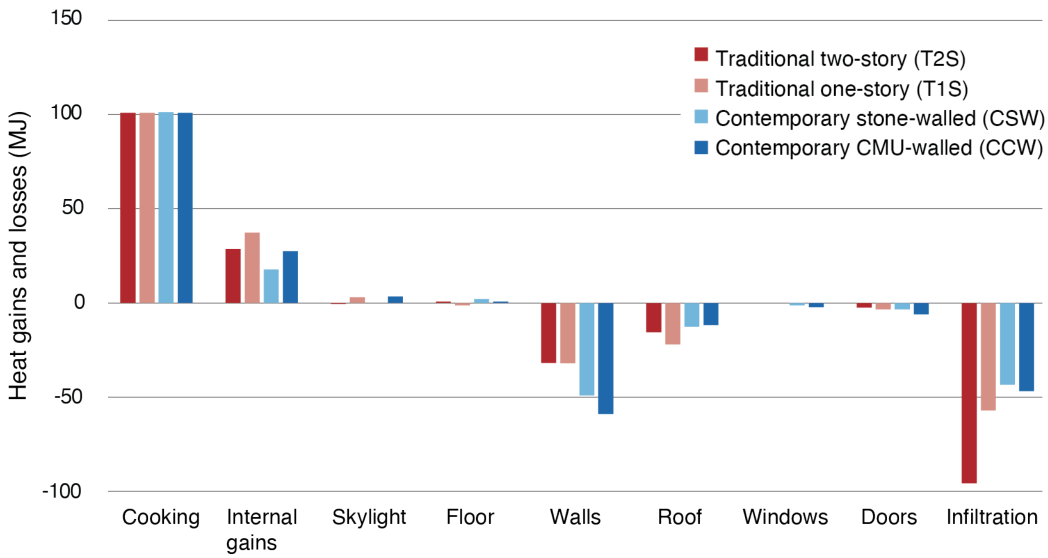


Figure 4.9. Comparison of thermal energy gain and loss pathways in the four sampled winter living rooms: Traditional two-story (T2S) haa, traditional one-story (T1S) haa, contemporary stone-walled (CSW) kitchen, and contemporary CMU-walled (CCW) kitchen, respectively. Internal gains include those from people, lights, and electrical equipment, excluding cooking. Positive values represent thermal energy gains, whereas negative values represent losses.

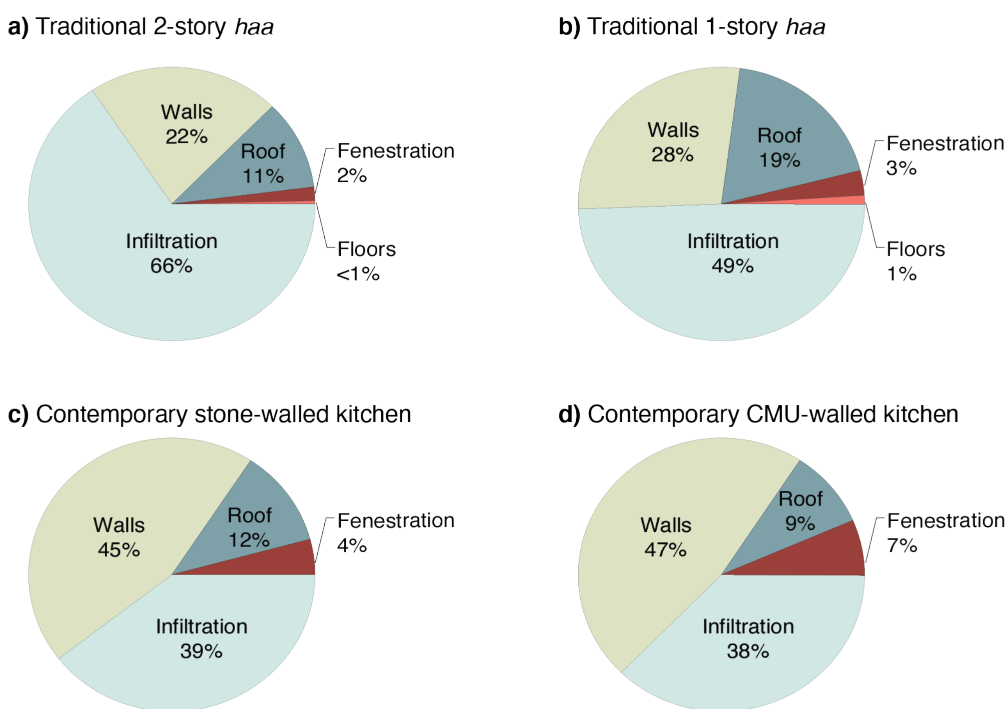


Figure 4.10. Relative contributions of the primary heat loss pathways in a) traditional two-story haa, b) traditional one-story haa, c) contemporary stone-walled kitchen, and d) contemporary CMU-walled kitchen.

b. Walls

Next, heat transfers across the building envelopes were investigated. During the first week of January, all winter living rooms experienced net daily heat losses through their walls (Fig. 4.9). However, the magnitudes of these losses varied with the enclosure of adjoining spaces and the walls' thermal transmittance properties. Previous studies have shown that buildings with lower surface-to-volume ratios, such as multi-unit housing, retain greater proportions of internal heat gains than detached houses [47,48]. Here, likewise, the two traditional houses benefited from adjoining spaces that provided shelter with warmer temperatures than outdoors for the *haa* walls (Fig. 4.11; Fig. 4.12), resulting in the lowest wall-related heat losses in these cases. The low wall U-values further contributed to these reduced losses. T2S *haa* walls exhibited the lowest thermal transmittance (Table 4.1), while T1S walls were slightly more thermally transmissive than T2S due to their thinner constructions and exterior cement plaster (Table 4.1), but the two dwellings' wall-related heat losses were comparable (Fig. 4.9). In these houses, walls accounted for approximately 20-30% of total heat loss (Fig. 4.10).

Walls were the greatest contributors to the heat losses in contemporary kitchens, accounting for almost half of the total (Fig. 4.10). They lost substantially greater magnitudes of thermal energy than the walls of the traditional *haa*s (Fig. 4.9): in CSW, for example, cement mortar and plasters increased the thermal transmittance of the stone walls, despite maintaining the thickness of the T1S walls (Fig. 4.3b and 4.3c; Table 4.1). CSW's interior CMU block walls were even more thermally transmissive due to their materials and thinness (Fig. 4.3d; Table 4.1). CCW, in turn, experienced the greatest total wall-related heat losses because all walls were built with CMU blocks (Fig. 4.9). To reduce the thermal discomfort resulting from cold wall surfaces, CCW residents had lined the lower seating area walls to a height of 1m with wooden panels. Although these panels reduced the thermal transmittance of the walls noticeably (Fig. 4.3d; Table 4.1), they diminished total wall heat loss very little because they covered less than one-third of the wall area.

Next, the surface temperatures and heat fluxes across walls between the winter living rooms and the coldest adjacent spaces (Fig. 4.11) were examined to understand whether massive stone in CMU walls of the winter living rooms absorbed in released thermal energy from interiors in daily patterns as commonly believed [17,49]. The studied wall of T2S separated the *haa* from the fully enclosed entry lobby (Fig. 4.11a), which remained substantially warmer than the outdoors (Fig. 4.12a), while the T1S wall of interest separated the *haa* from a semi-enclosed verandah, which remained slightly warmer than the outdoors (Fig. 4.11b). In contrast, the walls of interest in the kitchens of CSW and CCW were directly exposed to the outdoors (Fig. 4.11c and d).

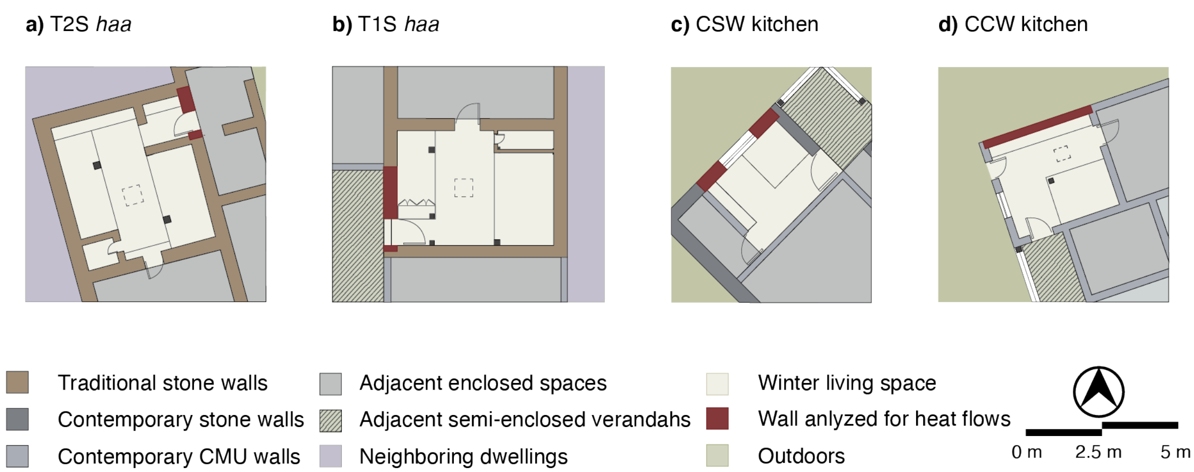
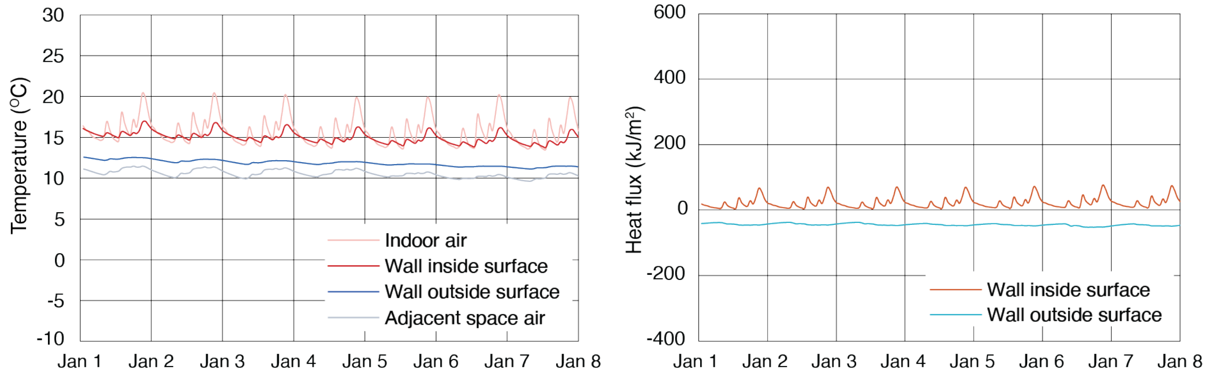
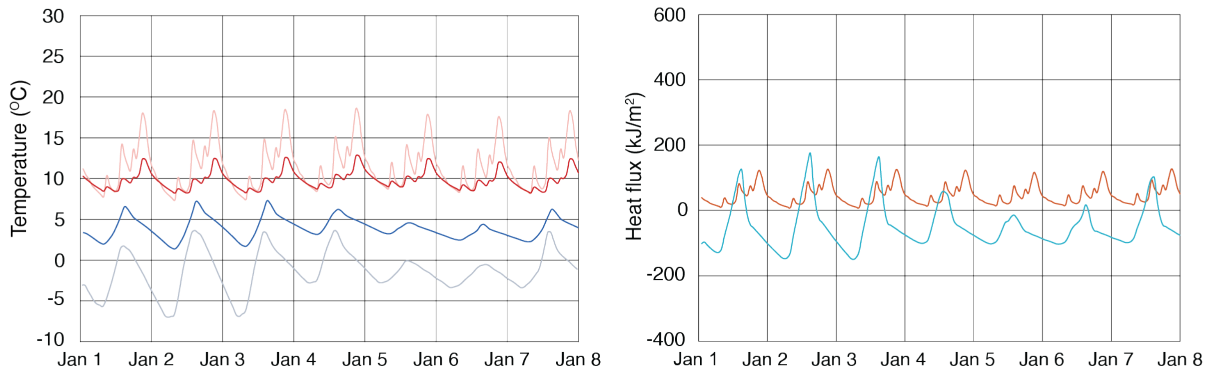


Figure 4.11. Boundary conditions of winter living rooms in the sampled houses: (a) Traditional two-story (T2S) haa, enclosed on all four sides by sheltered spaces; (b) Traditional one-story (T1S) haa, enclosed on three sides with a semi-covered verandah on the fourth; (c) Contemporary stone-walled (CSW) kitchen with two sides adjoining sheltered spaces, one side a semi-covered verandah, and one side exposed to the outdoors; (d) Contemporary CMU-walled (CCW) kitchen with two sides directly exposed to the outdoors. In each plan, the wall analyzed in detail is highlighted.

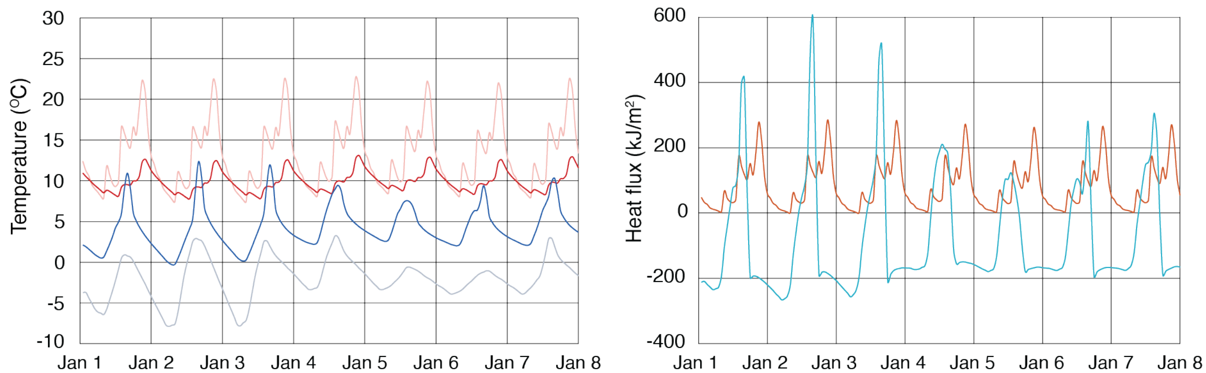
a) Traditional two-story (T2S) *haa* - 55 cm stone and mud wall



b) Traditional one-story (T1S) *haa* - 45 cm stone and mud wall



c) Contemporary stone-walled (CSW) kitchen - 45 cm stone and cement wall



d) Contemporary CMU-walled (CCW) kitchen - 20 cm CMU and cement wall

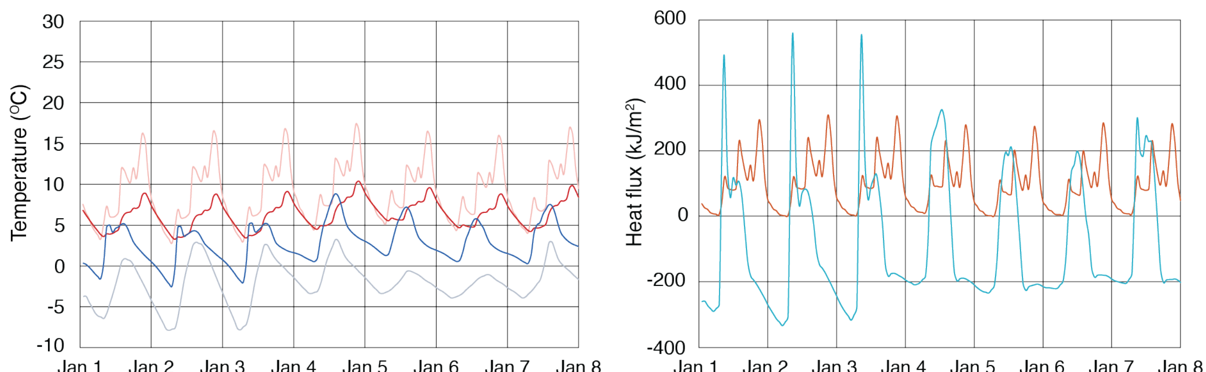


Figure 4.12. Indoor air temperatures, inside and outside surface temperatures, and hourly heat fluxes for four representative walls (see Fig. 4.11) simulated in EnergyPlus: a) 55-cm-thick stone wall between the traditional two-story (T2S) haa and the entry lobby, b) 45-cm-thick stone wall between the traditional one-story (T1S) haa and the verandah, c) 45-cm-thick exterior stone wall of the contemporary stone-walled (CSW) kitchen, and d) the 20-cm-thick exterior CMU wall of the contemporary CMU-walled (CSW) kitchen. Positive heat flux values indicate heat flows into the walls.

All walls continuously absorbed heat from the winter living rooms since their inner surfaces were colder than the indoor air. Absorption rates were highest in the evening, when indoor air temperatures peaked due to cooking, lights, electronics use, and people themselves. Overnight, however, air temperatures dropped as the air lost energy to the walls; wall and interior air temperatures typically converged in the early morning (Fig. 4.12). External wall surfaces remained warmer than the adjacent spaces throughout these hours, however, resulting in continuous heat loss from the walls to the adjacent spaces. The only exceptions to this pattern occurred during sunny days when the exterior surfaces of T1S, CSW, and CCW absorbed solar radiation.

The T2S wall absorbed the least amount of heat from the *haa* and released it at a low but steady rate to the entry lobby (Fig. 4.12a). The T1S wall, in contrast, experienced greater heat fluxes from both the interior and exterior surfaces (Fig. 4.12b). The T1S wall captured solar energy through the verandah during the day as well, which was initially stored in the wall along with the heat gained from the indoors. This heat was gradually released to the verandah later, starting in the early evening and peaking during the cold early morning hours (Fig. 4.12b).

The analysis of these traditional walls contrasts with findings from other regions with similar cold-dry climates and construction typologies [49–51]. Without quantitative analysis, these studies reported that thermal mass provided by thick stone and mud walls stabilized indoor temperatures by absorbing daytime heat from solar exposure as well as from indoor cooking, heating, and metabolic activities, and gradually releasing it back to the indoors at night. In the cases we studied, however, the heat absorbed by the wall of each *haa* or kitchen was ultimately lost to the surrounding spaces; it was not delivered to the *haa* or kitchen. Instead, the traditional walls exerted their thermal effects primarily through their lower thermal transmittances, rather than the release of stored heat energy to the interior. The thermal mass did, however, delay heat flows to the exterior by storing the heat and gradually releasing it, representing a typical characteristic of high thermal mass materials [46,52]. These observations occurred during the coldest month of winter, so the possibility remains that these walls could release stored energy to the interior during warmer months. Still, these findings indicate that the importance of thermal transmittance in traditional walls may have been overlooked previously.

Heat fluxes across exterior walls in both contemporary kitchens were much higher than in the traditional *haa*s (Fig. 4.12c and 4.12d). The CSW wall's interior surface absorbed heat at a rate twice as high as that of the T1S wall. In addition, the exterior surface absorbed solar radiation during the afternoon. This absorbed heat was released to the outdoors overnight, with the fluxes beginning and peaking in the evening and remaining high through the night (Fig. 4.12c). The wall in the CCW kitchen showed similar traits. Its interior surface gained heat energy at high rates, while the exterior also absorbed solar radiation in the mornings. This heat was then released to the outdoors at a rapid rate as soon as solar radiation diminished, and these losses continued until the next morning. Overall, the CMU wall showed the highest heat losses among all cases (Fig. 4.12d).

c. Roofs

Next, heat flows through the roofs were examined. All roofs were built using the same materials, including wooden planks and rafters over beams, with mud plaster on top (Fig. 4.3). Yet their designs differed in three aspects: the overall roof area, the degree of exposure to the outdoors, and the thickness of the roofing materials.

Traditional *haas* experienced greater magnitudes of heat losses through the roofs (Fig. 4.9), primarily due to their larger roof areas than contemporary kitchens (Table 4.1). The relative contribution of roof-related heat losses was greater in T1S compared to T2S (Fig. 4.10). This was due to the thin mud-plaster layer on the roof, resulting from the erosion of the original thick plaster and a lack of maintenance, which reduced the roof's U-value by almost 50% compared to the thick T2S roof (Table 4.1). In addition, in T1S, direct exposure to the cold outdoors increased the temperature gradient across the roof, leading to greater heat losses.

Contemporary kitchen roofs led to relatively lower heat losses (Fig. 4.9), mainly because their areas were smaller. Otherwise, their thermal transmittance values were higher than those of traditional roofs. CCW exhibited the most thermally transmissive roof with the lowest mud plaster thickness and the thin wood planks (Fig. 4.3d; Table 4.1). CSW roof had a higher thermal transmittance because the mud plaster was relatively thicker (Fig. 4.3c; Table 4.1). Nonetheless, the magnitude of heat losses through both roofs was similar, and both contributed to almost 10% of the total heat losses (Fig. 4.10).

d. Infiltration

We then analyzed heat losses from air infiltration. All winter living rooms experienced an average infiltration rate of 1.4-1.5 air changes per hour (Section 2.3). However, the same infiltration rates led to greater volumes of airflow, and consequently greater infiltration-related heat losses in traditional *haa*s, because these were larger in volume than contemporary kitchens. T2S *haa* lost the most heat through infiltration, accounting for ~65% of the total heat losses (Fig. 4.10). This *haa* contained no windows, its small doors opened into enclosed spaces, and a glazed skylight opened into the *baldi* above, thus creating a configuration that would generally limit airflows. Therefore, in this case, heat losses primarily resulted from airflows through the smoke exhaust pipe attached to the wood-burning stove, which created a strong stack effect driven by the heat generated from fire during wood burning and embers afterwards. In addition, because

T2S *haa* was the warmest, the indoor-outdoor temperature difference was the greatest in this case (Fig. 4.8), which further increased the amount of heat lost per unit volume of infiltrating air.

In T1S, infiltration contributed to ~50% of heat losses (Fig. 4.10). This *haa* had no windows as well, and its doors opened into other interior spaces, which limited airflows. However, a substantial amount of cold air entered through its unglazed skylight opening directly to the outdoors. In addition, the smoke exhaust pipe contributed to airflow as well, although the shorter height of the pipe compared to the one in T2S reduced the stack effects and the resultant airflows (see Supplementary information). Furthermore, the indoor-outdoor temperature difference was lower in the T1S *haa* than in the T2S *haa* (Fig. 4.8), which reduced the magnitude of heat loss even with comparable amounts of airflow.

In contemporary kitchens, infiltration contributed to approximately 40% of the total heat losses (Fig. 4.10). In both kitchens, the smoke exhaust pipe remained the primary pathway for airflows (see Supplementary information). Additional infiltration occurred through windows and doors, as well as the small cracks around these openings (Section 2.3). However, the combined volumes of airflows resulting from these pathways were lower than in traditional *haa*s. Furthermore, the lower temperature differences between indoors and outdoors reduced the magnitude of heat lost per unit of infiltrating air (Fig. 4.8).

e. Doors, windows, and skylights

Next, we analyzed conductive heat flows across doors, windows, and skylights, which contributed minimally to the overall heat losses (Fig. 4.9). Together, these sources accounted for less than 10% of the heat losses in all cases (Fig. 4.10). Doors accounted for less than 3% of total heat loss in all houses. Because all the doors shared the same construction and U-value, variations in heat loss were primarily due to differences in door size and quantity (Table 4.1) rather than the materials used. T2S *haa*, with two small traditional doors, experienced the lowest door-related heat losses. Whereas T1S *haa*, with one large contemporary-sized door and one small traditional door, showed a slight increase. CSW kitchen, with two contemporary-sized doors, exhibited moderately higher heat losses. In contrast, the CCW kitchens contained three large contemporary doors, one of which opened directly to the outdoors, resulting in the highest door heat losses in the sample.

Windows and skylights had similarly small effects. The single-pane windows in contemporary kitchens accounted for ~1% of the total heat losses. The traditional *haa*s had no windows, and thus no window-related heat losses. In T2S, however, the skylight opening into the *baldi* led to negligible net daily heat losses (<1%). Interestingly, the skylights in the T1S *haa* and the contemporary CCW kitchen contributed to net daily heat gains (~2% of total heat gains) by receiving solar heat during the day. These net heat gains thus highlight the potential of using skylights for passive heating by increasing their surface area, ensuring maximum solar exposure, and insulating them at night to minimize heat loss [53].

f. Floors

Heat transfers through the floors accounted for less than 1% of the total heat flows. Interestingly, floors led to net heat losses in T1S *haa* and CCW kitchen, whereas they led to almost negligible net heat gains in T2S *haa* and CSW kitchen (Fig. 4.10). These differences corresponded with the floor thickness and U-values (Table 4.1). T2S and CSW were raised more than 1m above ground on gravel infill, increasing the distance between the floors' interior surfaces and the ground and reducing the floors' U-values, thereby reducing heat losses through the floors. In contrast, the CCW floor consisted of approximately 0.3m of gravel in fill above ground, providing a shallower separation from the ground and a higher U-value. The T1S floor was entirely embedded in the soil. The closer thermal contact with the ground and the low U-values in these cases, therefore, allowed heat to flow from the floor into the ground.

g. *Internal thermal mass*

The internal thermal mass of the houses influenced the heat flow patterns as well. The T2S *haa* contained the most thermal mass, consisting of an internal partition wall constructed with stone masonry and an approximately 2 m^3 boulder converted into a raised platform. It also contained wooden elements, including pillars and beams, as well as wooden storage cabinets; however, wooden elements are known to be less thermally massive than stone and mud [54]. All this thermal mass allowed T2S *haa* to absorb internal heat during warmer hours and release it gradually during colder hours, which reduced diurnal temperature fluctuations and, accordingly, dampened heat flows out of the *haa*. The other three winter living rooms contained less internal thermal mass: T1S had an approximately 1 m^3 internal partition wall, along with wooden pillars and storage cabinets, whereas the contemporary kitchens contained concrete slabs and 20-cm-thick CMU blocks used to construct kitchen counters. Accordingly, these houses exhibited much higher diurnal temperature variations and heat loss from the winter living area (Fig. 4.8).

3.4. Thermal improvements testing

Next, four improvement strategies for enhancing indoor warmth were tested in each dwelling. These included increasing wall insulation, increasing roof insulation, reducing infiltration, and increasing solar heat gains. These improvements were tested individually and in combination, under the weather conditions of the first weeks of January and February of 2021. The goal was to evaluate extent to which the tested improvements raised indoor temperatures above the minimum comfort threshold compared to the baseline model (without any improvements).

Thermal comfort thresholds can vary greatly among people, depending on their past experiences as well as the thermal adaptation strategies they use [55]. People in the Himalayan regions of Nepal and China have reported globe temperatures as low as 10 °C to be comfortable in their homes, as they adapt psychologically and behaviorally to these cold climates [42]. In Nepali regions with altitudes similar to Hunza (2400- 2700 m), occupants reported globe temperatures of 13.4 °C, and indoor air temperatures of 13.9 °C to be comfortable [56,57]. Under indoor conditions with low air velocity, the globe temperature can be taken as an approximate measure of operative temperature [58]. An operative temperature of 13.5 °C was therefore selected as a comfort threshold for our analysis.

Under original modeled conditions, the T2S *haa* temperatures remained above 13.5 °C at all times (Fig. 4.13). Improvements were therefore tested only in T1S, CSW, and CCW.

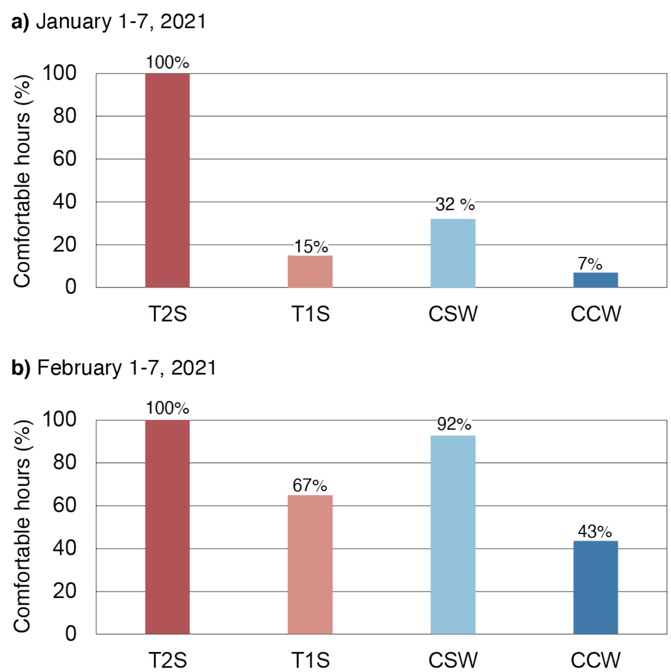


Figure 4.13. The percentage of time that the operative temperature remained above the comfort threshold of 13.5 °C in the modeled traditional two-story (T2S) haa, traditional one-story (T1S) haa, contemporary stone-walled (CSW) kitchen, and contemporary CMU-walled (CCW) kitchen during: a) the first week of January, 2021, and b) the first week of February, 2021.

3.4.1. Wall insulation

Walls were the largest source of heat loss in contemporary homes (Section 3.3.2). Therefore, a wall insulation system built on the local practice of using wooden wall panels was tested. These panels typically have a 2.5 cm air gap behind them and are installed up to 1 m high (Fig. 4.2d). In the improved models, however, the air gap was replaced with polyurethane foam insulation, commonly used as carpet underlay, to enhance the wall U-value. The panels were also extended to full wall height to minimize heat loss through the upper halves of the walls. This insulation system was applied to the interior wall surfaces in both contemporary houses. The interior mud plaster in T1S was replaced with cement-sand plaster as well. This change reflected modifications made to traditional houses by several other households [1], as well as the plans of T1S inhabitants, to address issues of rodent infestations and moisture damage.

The modified walls raised indoor operative temperatures across all housing types (Fig. 4.14). During the first week of January, the proportion of comfortable hours in T1S and CSW doubled, increasing from ~15% to 30% and from ~30% to 60%, respectively. Improvements in CCW were most substantial; the percentage of thermal comfort hours increased from ~10% to 40%. Improvements were observed during February, as well, as outdoor temperatures became milder. In T1S, the proportion of comfortable hours rose from 65% to 80%. The CSW baseline model exhibited a high percentage of comfortable temperatures, at around 90%, but this increased to 97% with the addition of wall insulation. In CCW, comfortable hours rose from almost 45% to 60% (Fig. 4.15).

Operative temperature comparisons demonstrated that wall insulation was most beneficial during the daytime and evening hours when spaces were actively used (Fig. 4.14). This was especially prominent in the contemporary kitchens of CCW and CSW, where temperatures rose by ~5 to 7 °C over baseline models in the evenings (Fig. 4.14b & c). In contrast, the T1S *haa* experienced an increase of only 2 to 3 °C (Fig. 4.14a). Overnight temperatures dropped considerably in all cases, and morning temperatures in the wall-insulated models fell close to those of the baseline models. These nighttime heat losses underscored that other heat-loss mechanisms, such as air infiltration, must be addressed as well to achieve consistently warmer indoor temperatures.

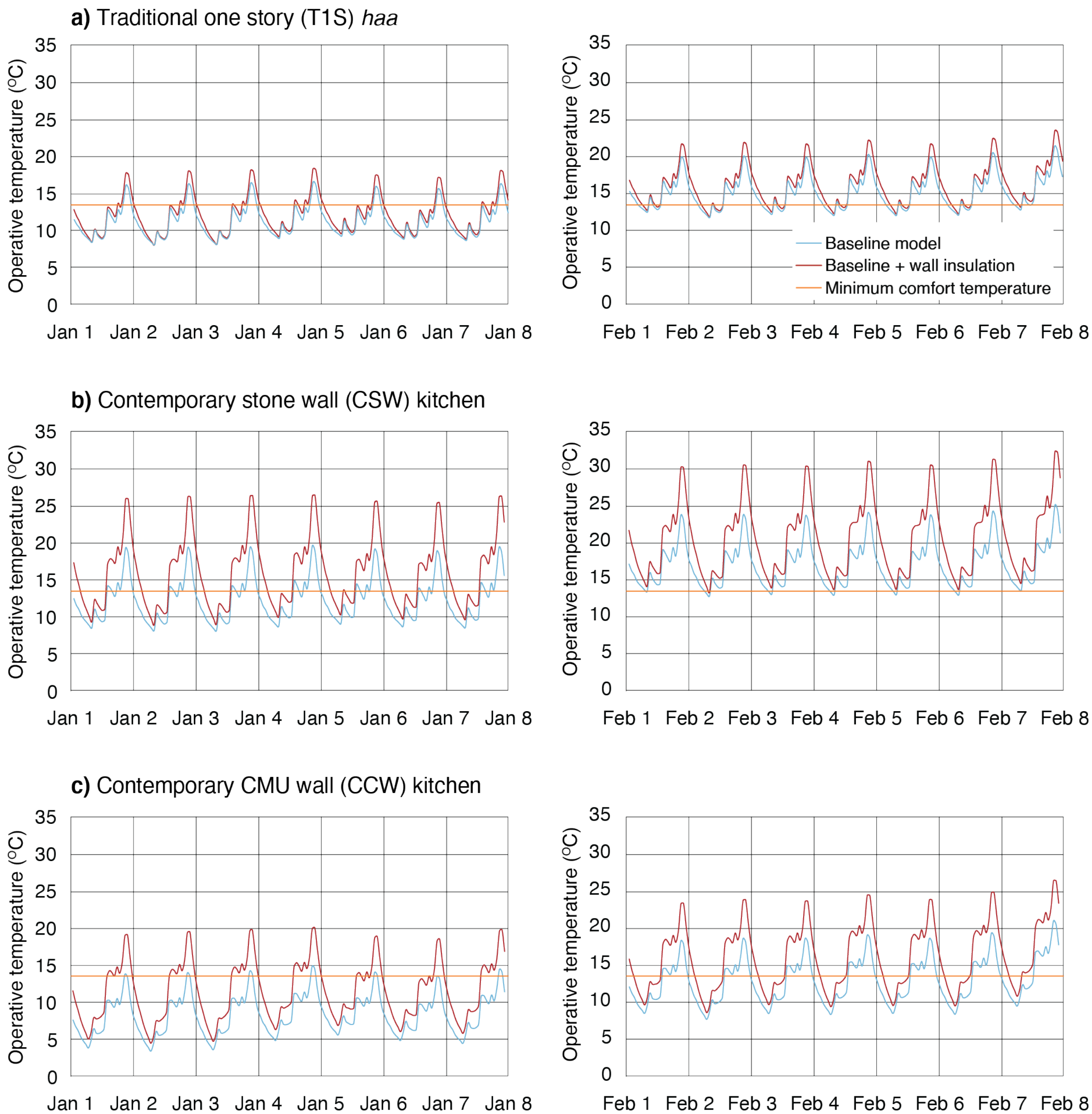


Figure 4.14. Comparison of operative temperatures observed in baseline models and improved models with wall insulation, observed during the first weeks of January and February 2021, in: a) traditional one-story haa, b) contemporary stone-walled kitchen, and c) contemporary CMU-walled kitchen. Using wall insulation increases operative temperatures in all cases.

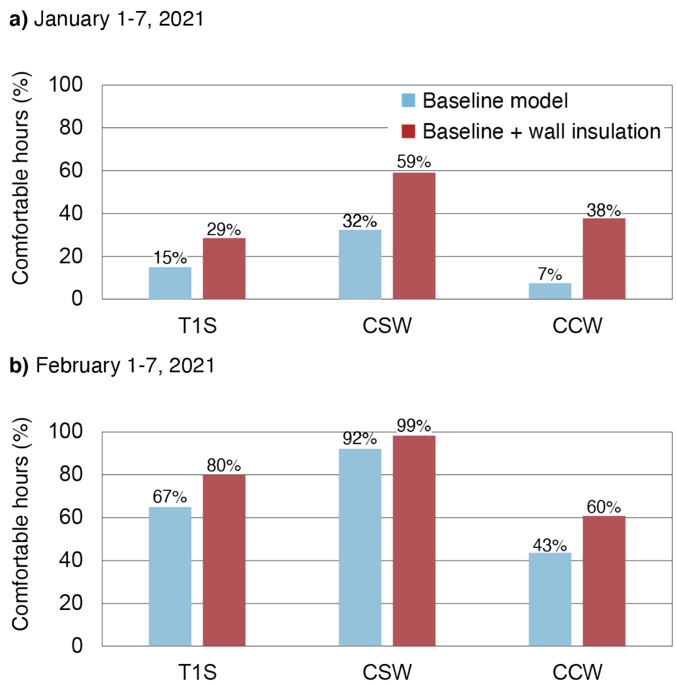


Figure 4.15. The percentage of time that the operative temperature remained above the comfort threshold of 13.5 °C in the baseline vs. improved model with wall insulation during: a) the first week of January, 2021, and b) the first week of February, 2021. In both cases, wall insulation increased the amount of time that indoor conditions remained above this threshold.

3.4.2. Reduced infiltration

Infiltrations through cracks and gaps around windows, skylights, and the smoke exhaust pipes were the greatest heat loss pathway in traditional houses and the second greatest in contemporary ones (Fig. 4.9; Section 3.3.2). Sealing air leaks around fenestration is challenging because local carpenters build these doors and windows without sealants or weatherstripping due to limited experience with these products. Additionally, some airflow is necessary in these winter living areas to prevent particulate matter from wood-burning stoves from reaching levels hazardous to health [59,60]. However, infiltration can be reduced by closing smoke exhaust pipes with dampers or by using a cap plug overnight after fires are quenched. In addition, sealing windows and skylights with polyethylene sheets to reduce infiltration was a common practice in many houses, including CSW; however, it was not used in T1S and CCW. Therefore, these strategies were tested as low-cost solutions by reducing the corresponding infiltration input values in the models (Table4.3: Section 2.3).

Table 4.3. Existing and improved infiltration-reduction features in the houses studied and their corresponding changes in thermal comfort hours during the first weeks of January and February.

House	Existing features for reduced infiltration	Improvements for reduced infiltration
T1S	No windows + polyethylene laid over half of the skylight	Polyethylene sealed skylight + smoke exhaust pipe damper
CSW	Polyethylene sealed window + glazed skylight	Smoke exhaust pipe damper
CCW	Glazed skylight	Polyethylene sealed window and skylight + smoke exhaust pipe damper

Reducing infiltration was most effective in T1S, leading to an increase of approximately 1 to 2 °C during both January and February (Fig. 4.16). Comfortable hours increased as well, from 15 to 35% in January and 65 to 95% in February (Fig. 4.17). The greater improvement in T1S primarily resulted from the covering of the skylight, resulting in substantially lower infiltration. Improvements in CSW and CCW kitchens were relatively modest. In CSW, the percentage of comfortable hours rose from around 35% to 40% in January and from 90% to 95% in February. In CCW, the percentage of comfortable hours increased negligibly, remaining around 10% in January and 45% in February (Fig. 4.17). In terms of operative temperatures, this resulted in an almost 0.5 °C increase throughout the monitoring period (Fig. 4.16).

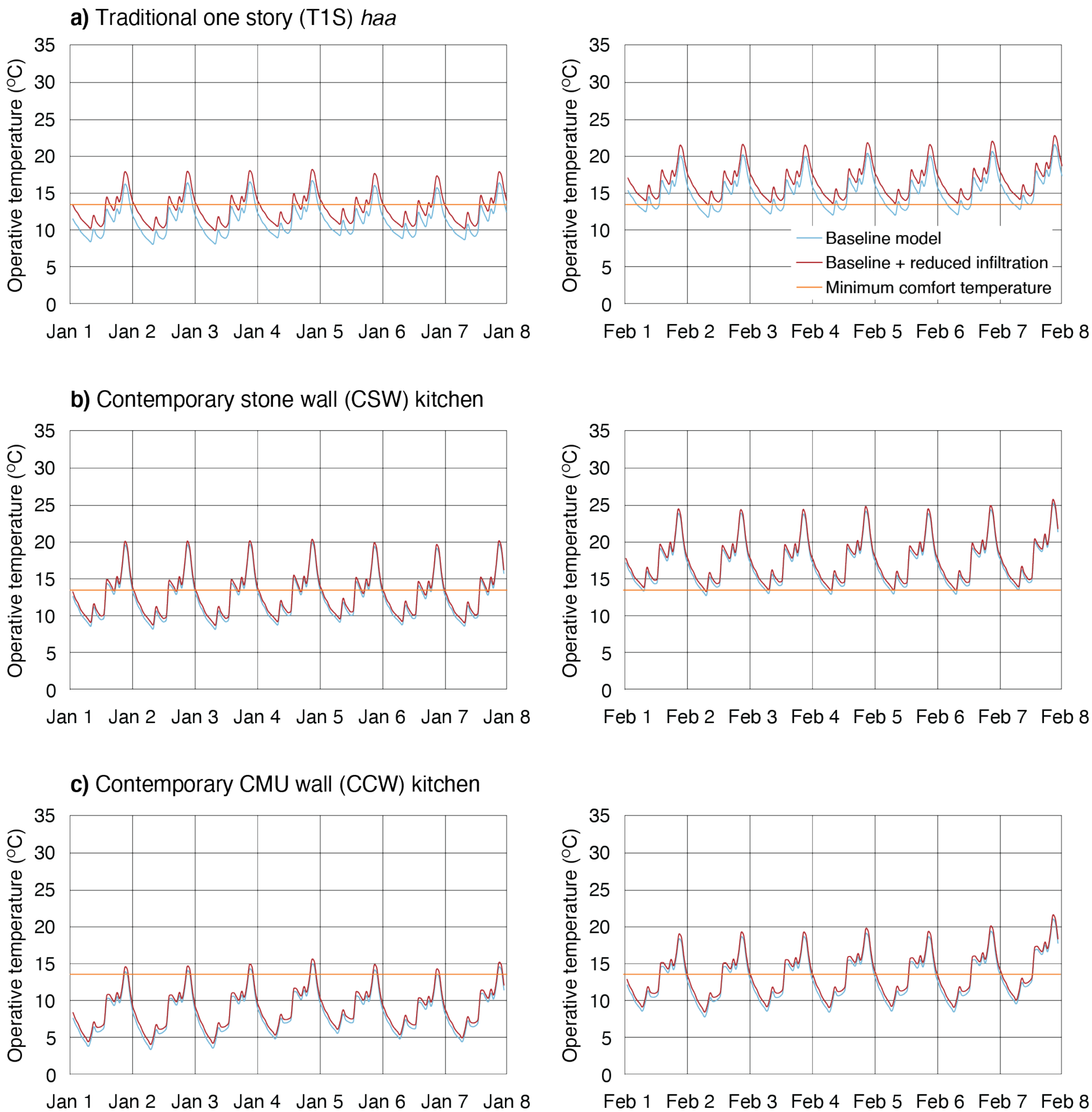


Figure 4.16. Comparison of operative temperatures observed in baseline model and improved model with reduced infiltration, observed during the first weeks of January and February 2021, in: a) traditional one-story haa, b) contemporary stone-walled kitchen, and c) contemporary CMU-walled kitchen. Reducing infiltration increases operative temperatures most prominently in T1S, whereas the increases in CSW and CCW are minimal.

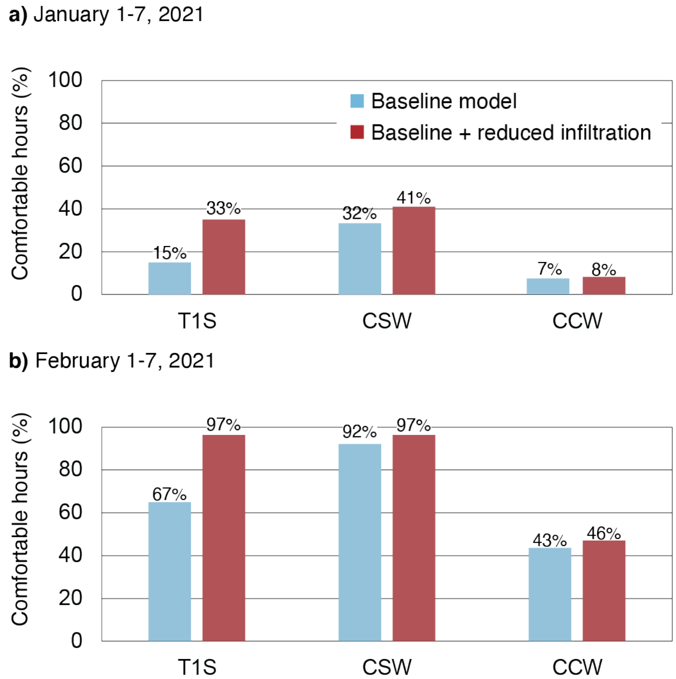


Figure 4.17. The percentage of time that the operative temperature remains above the comfort threshold of 13.5 °C in the baseline vs improved model with reduced infiltration during: a) the first week of January, 2021, and b) the first week of February, 2021. Reducing infiltration was the most effective in T1S, whereas modest improvements were also observed in CSW and CCW.

3.4.3. Replastered roof

The third tested strategy was increasing the thickness of mud plaster on roofs, given the substantial differences in thermal transmittance between traditional and contemporary roof forms (Table 4.1). Most houses in Hunza use roofs made with wooden beams, planks, and a layer of mud plaster [9]. Increasing the thickness of this locally available mud fits well with existing building methods and does not add extra costs or require new skills. These improvements, however, exhibited only a slight increase in comfortable hours (Fig. 4.18) and a minimal effect on indoor thermal conditions in contemporary houses, resulting in only a 0.5 °C increase in early morning temperatures (Fig. 4.19b and 4.19c). In T1S, however, improvements were relatively pronounced. Early morning operative temperatures increased by ~1°C, leading to a slight increase in comfortable hours in January (Fig. 4.19a; Fig. 4.18). In February, there was a more pronounced improvement (from ~65 to 80%) as higher early-morning temperatures lifted just above the comfort threshold (Fig. 4.18b). In all other cases, the morning temperatures were far below the comfort threshold, resulting in a lower effect on overall thermal comfort hours.

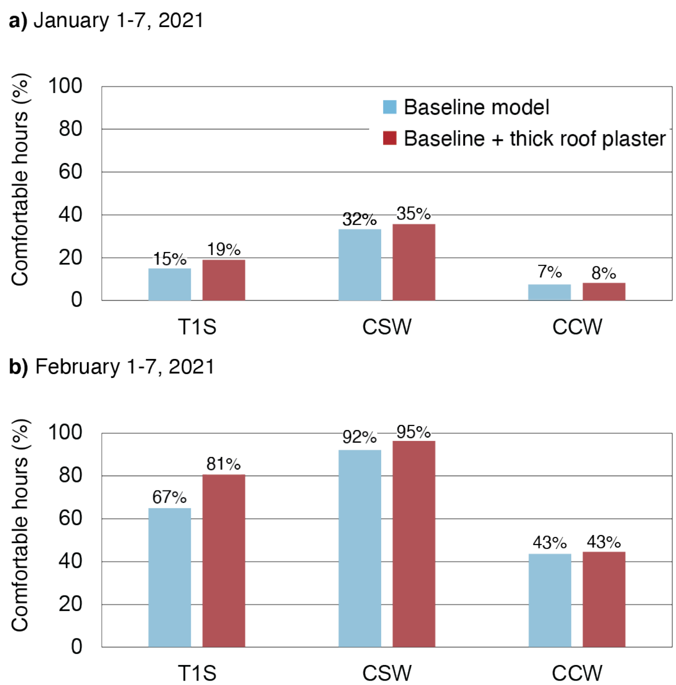


Figure 4.18. The percentage of time that the operative temperature remains above the comfort threshold of 13.5 °C in the baseline vs improved model with 15 cm thick roof plaster during: a) the first week of January, 2021, and b) the first week of February, 2021. Increasing mud plaster thickness on the roofs minimally increases the percentage of comfortable hours in most cases.

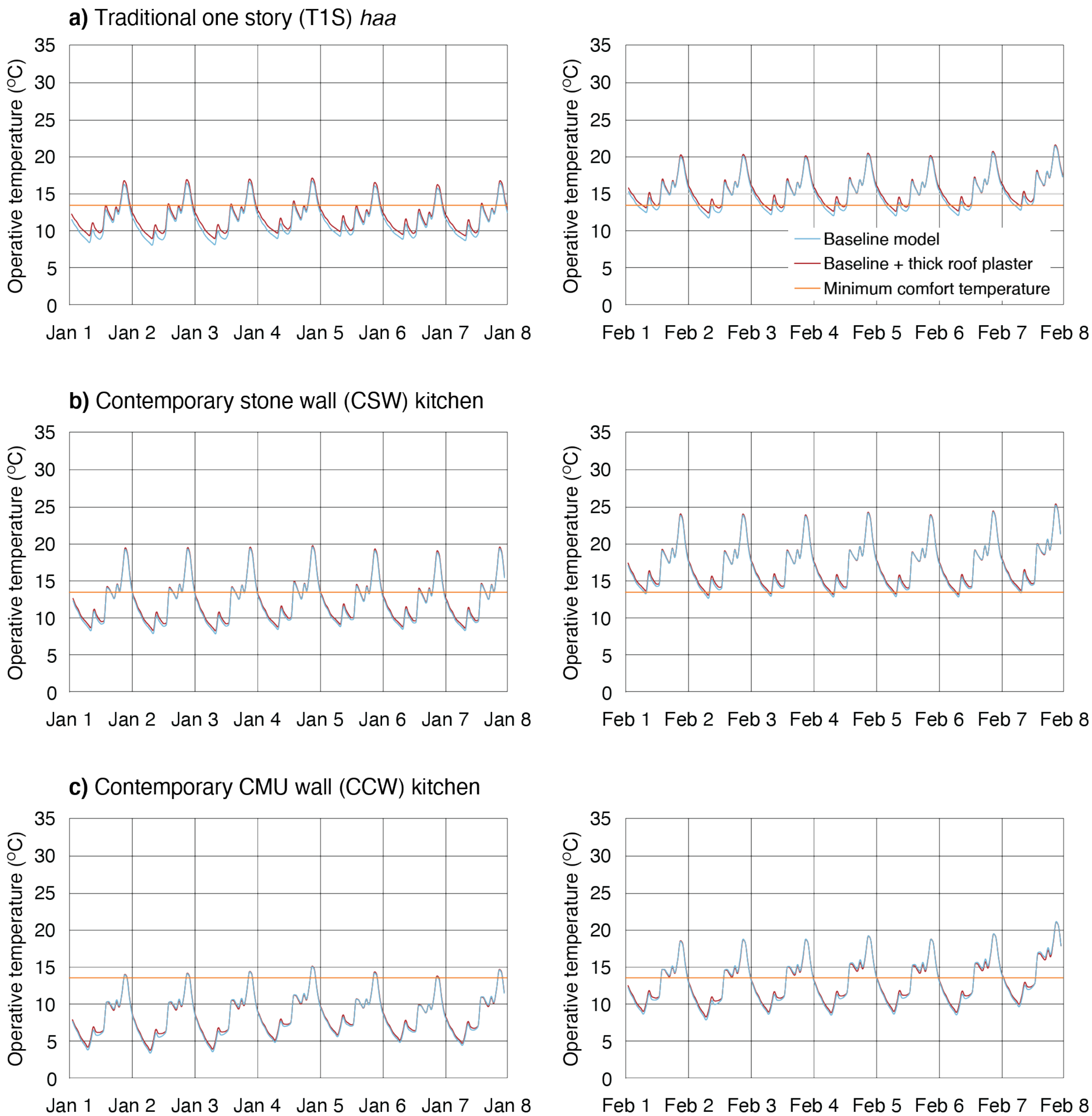


Figure 4.19. Comparison of operative temperatures observed in baseline model and improved model with 15 cm thick roof plaster, observed during the first weeks of January and February 2021, in: a) traditional one-story haa, b) contemporary stone-walled kitchen, and c) contemporary CMU-walled kitchen. Increasing the mud plaster thickness of roofs minimally increases the early morning temperatures in all cases.

3.4.4. Insulated skylight

Finally, the models revealed that even small uninsulated skylights provided net heat gains over the day, highlighting the potential of using passive solar heating. In Hunza, several homeowners have already adopted smaller glazed skylights, introduced by BACIP, an NGO focusing on construction improvements in northern Pakistan, to reduce airflows. Building on this strategy, larger glazed skylights oriented to maximize solar heat collection during the day were tested in both contemporary kitchens. The skylights were tilted at 45° (based on the solar altitude angle during winter), with their orientations determined by the kitchen layout to ensure southern exposure. The skylight areas were approximately 20% of the kitchen floor area. Nighttime insulation covers were added to prevent excessive heat loss. Since the traditional *haa* roof structure did not allow for a larger skylight, in T1S the existing ~2 m^2 skylight was glazed and insulated at night.

The addition of a glazed skylight in T1S improved indoor comfort, raising indoor operative temperatures by 1 °C during the monitoring period (Fig. 4.20), resulting in a small increase in the percentage of comfortable hours in January (from ~15% to 25%) and a more prominent increase in February (from ~60% to 90%; Fig. 4.21). However, these improvements were not solely due to solar gains: they also resulted from reduced air infiltration caused by the installation of skylight glazing.

Significant improvements were also observed in CSW, where temperatures increased roughly by two to 4 °C, with the largest increase occurring in early afternoons (Fig. 4.20). As a result, comfortable hours increased in both January (from ~30 to 50%) and in February (from ~90 to 100%; Fig. 4.21). In CCW, temperature increased by 1-3 °C as well, with higher gains in the late afternoons (Fig. 4.20). Despite these temperature rises, the increase in comfort hours was negligible in January (from ~7% to10%), but relatively noticeable in February (increasing from ~ 40% to 50%; Fig. 4.21).

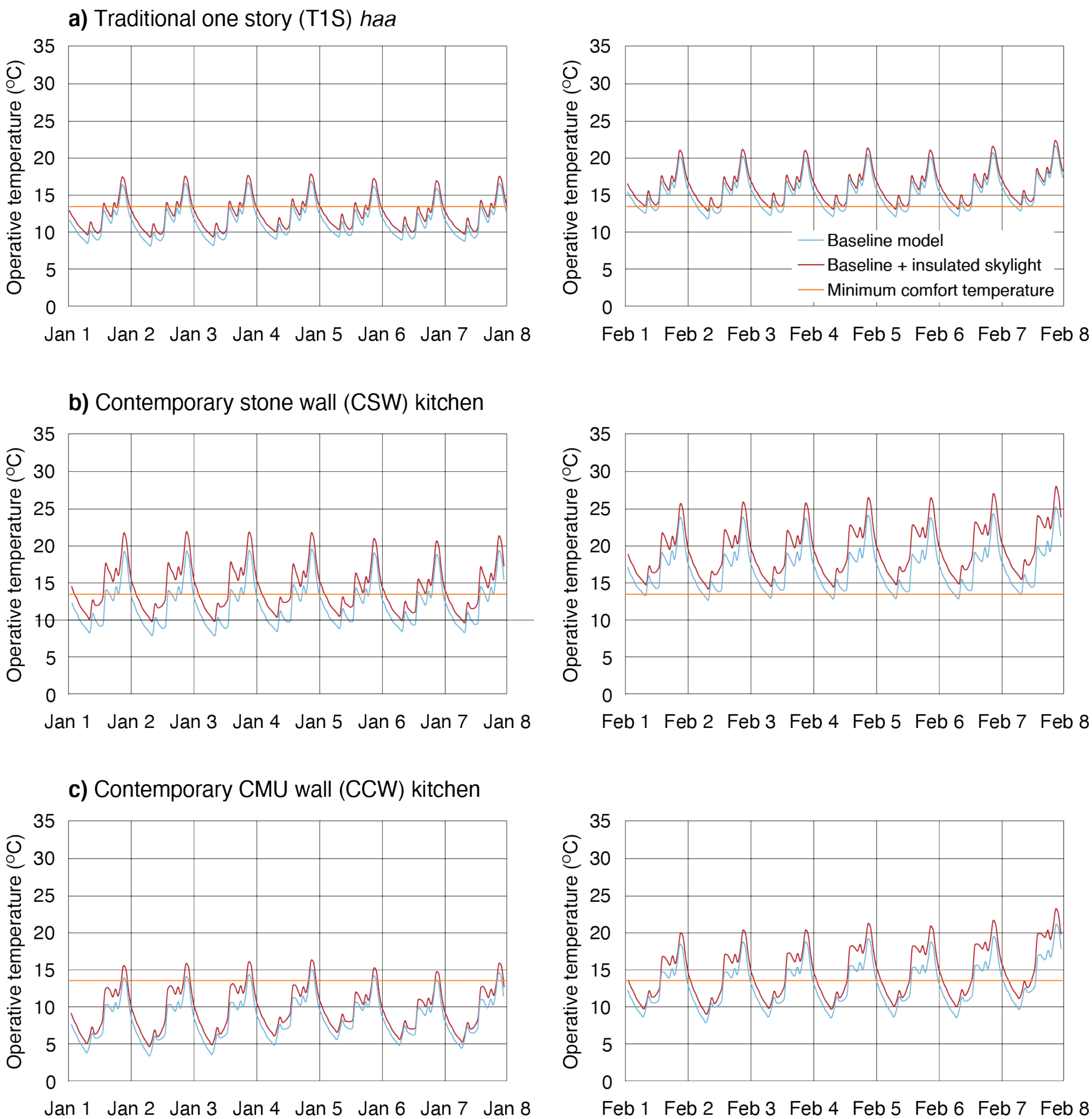


Figure 4.20. Comparison of operative temperatures observed in baseline model and improved model with insulated skylights, observed during the first weeks of January and February 2021, in: a) traditional one-story haa, b) contemporary stone-walled kitchen, and c) contemporary CMU-walled kitchen. Adding skylights with nighttime insulation increases operative temperatures in all cases.

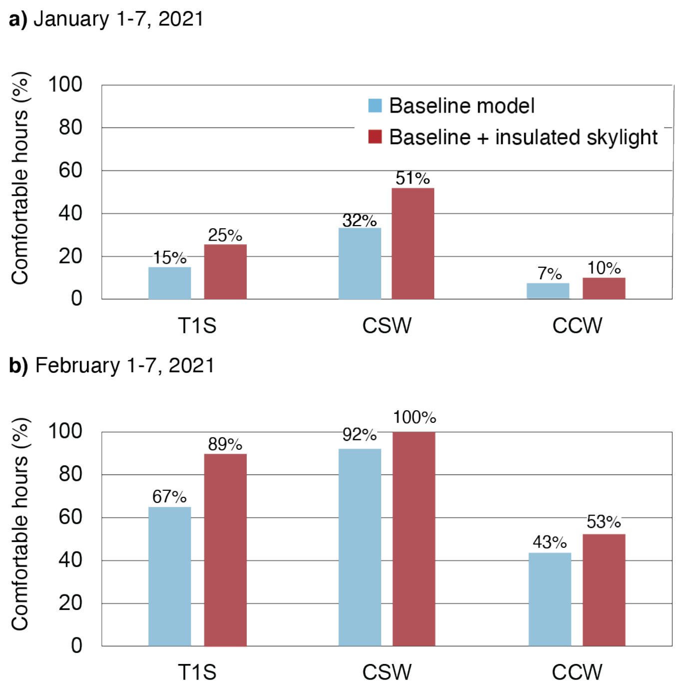


Figure 4.21. The percentage of time that the operative temperature remains above the comfort threshold of 13.5 °C in the baseline vs improved model with insulated skylights during: a) the first week of January, 2021, and b) the first week of February, 2021. Notable improvements are observed in most cases; however, in CCW, the improvements are minimal during January.

3.4.5. Combined strategies

Next, all previously tested strategies were combined to determine the maximum achievable improvement. The combined strategies model showed substantial improvements in comfortable hours across all three houses (Fig. 4.22). In T1S, the improvements resulted in a ~3 °C higher temperature throughout the day and night (Fig. 4.23a), maintaining comfortable temperatures for most of the time in January (~65%) and all of the time in February (Fig. 4.22). In the CSW, early morning temperatures rose by around 6 °C, while daytime peaks exceeded by 10 °C (Fig. 4.23b), and comfort temperatures were achieved throughout the monitoring periods of both January and February (Fig. 4.22). This model exhibited the highest temperature increase, often overheating to 30 °C or more during evening cooking. At the same time, the model also showed greater overnight temperature drops. In such a case, integrating additional thermal mass, as present in T1S *haa*, to absorb extra heat during the day and release it slowly overnight can moderate temperature swings. CCW also experienced an increase of around 5 °C in early morning temperatures and a 5-10 °C increase in daytime and evening temperatures (Fig. 4.23c), resulting in comfortable hours rising to approximately 60% of the time in January and almost all of the time in February (Fig. 4.22).

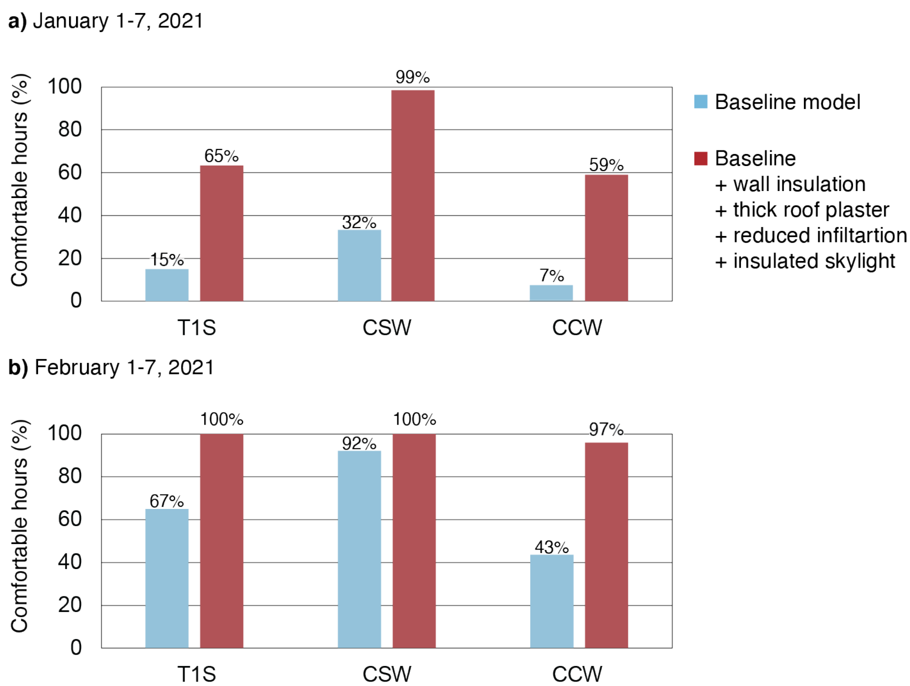


Figure 4.22. The percentage of time that the operative temperature remains above the comfort threshold of 13.5 °C in the baseline vs model combining all improvements including wall insulation, roof plaster, reduced infiltration, and insulated skylight during: a) the first week of January, 2021, and b) the first week of February, 2021. Substantial Increases in comfortable hours are observed across all houses in both January and February.

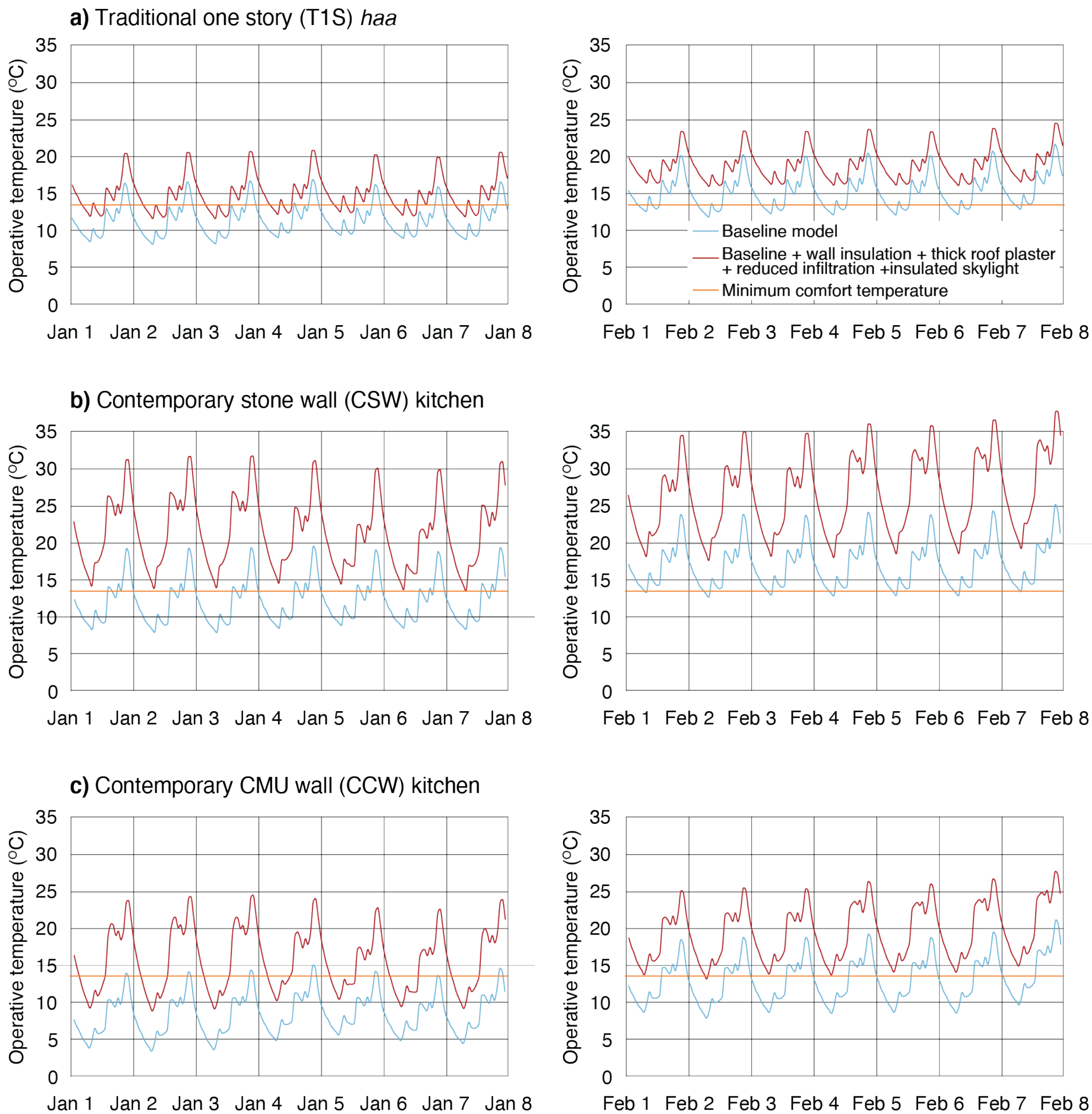


Figure 4.23. Comparison of operative temperatures observed in baseline model and the model combining all improvements, including wall insulation, roof plaster, reduced infiltration, and insulated skylight, during the first weeks of January and February 2021, in: a) traditional one-story haa, b) contemporary stone-walled kitchen, and c) contemporary CMU-walled kitchen. *Substantial increases in indoor temperatures are observed across all houses with the greatest temperature increases observed in CSW and CCW.*

4. Conclusions

This study investigated the thermal behavior of four houses representing the ongoing transition from traditional to contemporary housing construction in Northern Pakistan, using indoor temperature monitoring and building energy modeling. One goal of this work was to understand the thermal processes that have created extensive cold stress in new homes [1]. Specifically, this work sought to reveal the ways in which different construction materials, methods, and configurations affected heat gains and losses. Using this information, the second goal was to identify opportunities for enhancing indoor warmth using construction techniques already commonly used in the valley.

Several key elements provided greater warmth and thermal comfort in the traditional constructions. These included (i) the combination of cooking and living in the same space; (ii) clustered configurations that sheltered winter living spaces from the exterior; (iii) internal thermal mass, particularly in interior partitions, floors, and in-situ boulders integrated into walls and raised platforms, and (iv) the low thermal transmittance of walls and roofs. The benefit of compact space combining cooking and living was also apparent in contemporary kitchens, in which cooking heat warmed the smaller indoor air volumes more rapidly. However, contemporary kitchens lost heat quickly, especially overnight, due to their higher envelope thermal transmittance values, outdoor exposures, and low internal thermal mass. Nonetheless, with improvements, the contemporary kitchens were able to maintain comfortable temperatures for more than 50% of the time, even during the coldest periods, thereby highlighting the benefits of maintaining combined cooking and living as an effective thermal strategy.

This study revealed walls to be the primary source of heat loss in contemporary houses, underscoring the need to reduce their thermal transmittance to retain indoor warmth. Detailed analysis of heat flows showed that the low thermal transmittance of traditional walls played a greater role in retaining indoor warmth than their higher thermal mass. This contrasts with the statements of previous studies of high-altitude regions, which attributed indoor warmth in traditional dwellings to the diurnal absorption and release of heat by thermal mass, without analyzing heat flows in detail [61,62]. Instead, these findings aligned with research showing that improperly placed thermal mass can continuously absorb indoor heat in cold climates, without returning it [63]. These insights therefore suggest that future designs and policies should support low-thermal-transmittance envelopes, rather than the indiscriminate use of thermal mass.

Consistent with these findings, the improvement strategy designed to enhance wall insulation with wooden panels and polyurethane foam was found to be the most effective at improving indoor temperatures across all houses, including T1S. This wall insulation system outperformed traditional mud plaster in terms of thermal performance. At the same time, it can offer additional benefits of durability and resistance to pest infestation and water damage [9], making it potentially a better alternative to both traditional and contemporary CMU wall constructions.

Another key issue identified was infiltration, which accounted for the greatest proportion of heat losses in traditional houses and the second highest in contemporary ones. In both traditional and contemporary houses, low-technology measures such as installing smoke vent dampers and sealing windows and skylights with polyethylene sheets resulted in measurable improvements. More robust strategies, such as low-cost weather-stripping techniques for windows and doors, could further reduce infiltration-related heat losses [64]. However, such reduction would need to be balanced with an appropriate amount of air exchanges to allow smoke and cooking odor removal, and to maintain clean indoor air quality, as each of these houses burned wood for heating and cooking in their winter living rooms [59,65,66].

Furthermore, the lower contribution of the roofs to overall heat losses, particularly when compared with reports from other developing regions where RCC and metal sheet roofs are prevalent [67,68], underscored the effectiveness of traditional roof construction in retaining indoor warmth. These findings highlight the importance of maintaining and encouraging the continued use of wooden roofs in Hunza, especially as transitions towards contemporary roofing materials are accelerating [1,8,9]. An attempt to improve roof thermal performance by increasing the thickness of the mud plaster, in simulations, increased indoor temperatures only modestly. In the future, such modifications could be supplemented with thicker wooden planks or locally available insulation products, such as polyurethane sheets. However, these options should be carefully evaluated for their thermal benefits, cost feasibility, and required construction skills.

These findings further revealed the potential to improve indoor thermal performance through passive solar heating. Adding or enlarging skylights, when paired with appropriate orientation and nighttime insulation, raised indoor temperatures substantially in all simulated dwellings by capturing solar gains during the day. Although solar heating is not common among existing construction methods, precedents do exist for such innovations. Roof hatch windows introduced by BACIP, a local NGO, are widely used in both traditional and contemporary winter living rooms [32,69]. In the future, this potential could be extended further by developing sunspaces to take further advantage of passive solar heating [70]. Our previous research and field observations have also suggested that some residents are already aware of these benefits and are experimenting with such configurations, reporting significant thermal improvements [1]. Furthermore, since windows are desired for their aesthetics and enhanced light and ventilation conditions in contemporary houses [1,8,9], designs and policies should focus on guiding appropriate window orientations and insulation, allowing residents to install windows while maintaining favorable thermal performance in future constructions.

Overall, this study highlights the significant potential of locally used construction materials to improve the thermal performance of contemporary dwellings, as well as the substantial improvements in indoor thermal conditions that are possible from combining retrofit strategies.

These improvements are simple and can be implemented incrementally, offering residents a practical alternative to advanced, expensive, and technically complex systems such as modern insulation, triple-pane and/or Low-E windows, heat-recovery ventilators, heat pumps, and advanced airtightness [22,32,71].

5. Broader applicability, future directions, and limitations

The study contributed to the limited body of research on housing performance in cold, high-altitude regions and highlighted thermal challenges and adaptive strategies observed in traditional and contemporary dwellings. These findings are particularly relevant to other mountain areas, especially in the Himalayan and Karakoram regions, where communities share similar climatic conditions, resource constraints, and trends toward modernization. However, it is important to acknowledge that this study focuses on a small number of case studies in the central Hunza Valley, and the applicability of specific adaptations must be tested in other nearby regions, especially considering the vast difference in weather conditions across smaller distances, primarily due to drastic differences in elevations in mountain regions.

Furthermore, while the interventions proposed in this study are based on assessments of common building practices, housing aspirations, and thermal adaptation methods, a more robust analysis of their acceptability through cost-benefit analysis and feedback from the local community and Hunza's builders is necessary. Furthermore, given that construction practices in Hunza are continuously evolving, any proposed interventions must also remain flexible and open to revision over time. Rather than proposing one-time solutions, such research should be ongoing, and improvement strategies must continue to align with changing local construction methods, the introduction of new technologies, and the emerging availability of construction materials.

More broadly, this study underscored the value, importance, and effectiveness of integrating local construction practices, knowledge, and thermal adaptation practices into building sciences research, which, as an approach, is transferable to both warm and cold developing regions facing thermal stress resulting from a combination of building modernization and energy poverty.

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V. DISSERTATION CONCLUSIONS

Thermal stress, resulting from the transition from traditional climate-responsive building methods to contemporary ones, is widely recognized in both warm and cold developing regions [1–3]. However, the issue remains unresolved as the proposed solutions, primarily technical in nature, are not widely adopted. This is often due to affordability constraints, incompatibility of the proposed solutions with locally available materials and skills, and misalignment with domestic needs for privacy, convenience, and aesthetic preferences [4–6]. Therefore, this research adopted an integrated approach combining social and technical inquiries to develop context-appropriate design and policy guidelines to alleviate thermal stress in the Hunza Valley, northern Pakistan. Furthermore, by examining thermal stress associated with building transitions in high-altitude cold-developing regions, this study fills an important gap left by prior research, which has been predominantly focused on warm climates.

In the first phase of this research, field observations of occupant behavior, interviews, and dwelling documentation were used to i) investigate the evolution of housing typologies over the last 100 years; ii) explore the effects of shifts in contemporary materials and spatial configurations on residents' thermal experiences; and iii) examine the ways in which people cope with thermal stress in various housing types. Consistent with observations from other regions, traditional houses were found to be warmer compared to contemporary homes. However, documentation of 23 dwellings spanning 400 years of construction revealed that contemporary dwellings evolved incrementally, as homeowners selectively adopted newly introduced construction materials and spatial configurations to enhance the privacy, economy, durability, and aesthetics of their homes. In this process, housing occupants assessed the thermal implications of each change and responded by either making adjustments to minimize cold stress or rejecting the new elements in favor of traditional ones. For example, people adopted multi-room dwellings separating living and sleeping spaces for privacy; however, they continued the traditional practice of combining cooking and living in contemporary kitchens to stay warm in winter. Therefore, in contrast to the perception of owner builders as recipients of thermal stress, our research reveals them as active agents, reorganizing their dwellings and behaviors, to achieve warmth based on their sensory experiences. These adaptations, however, were limited because humans cannot fully interpret all modes of heat loss. For example, people lined the lower halves of CMU walls to avoid direct contact of their backs with the cold walls, but they could not perceive the continued heat losses through the upper halves of the walls. Evidence, therefore, suggested that educating homeowners about buildings' thermal performance may provide a promising pathway to improve occupant-devised thermal adaptation strategies.

Since owner builders were identified as central to shaping housing evolution in Hunza [1], their decision-making rationales were examined next using survey and interview data. Maslow's Hierarchy of Needs was used as a framework to understand the motivations of owner-builders for choosing contemporary construction despite experiencing thermal stress in such housing. Maslow's framework has been widely applied in urban contexts to inform housing policy and design [7–14]. Its applicability to rural settings, however, has remained underexplored. This study, therefore, attempted to understand whether Malsow’s theory can help design policies and design strategies for rural areas as well. The findings of this study suggested that owner builders in Hunza are primarily concerned with meeting needs lower in Maslow’s hierarchy, including physiological safety, relationship, and self-esteem needs; however, the relative prioritization of these lower-level needs appears to vary with people’s recent and long-term experiences instead of following a hierarchical pattern in which basic physiological needs must to be fulfilled before pursuing safety or belonging needs. In Hunza, relationship needs were often prioritized over the basic physiological need for thermal comfort. These priorities prompted owner-builders to select multi-room configurations with separate bedrooms, living rooms, and guest lobbies to accommodate private, familial, and communal interactions. Since these multi-room configurations increased construction costs, owner-builders sought cheaper materials, such as

CMU blocks, even though they were popularly known to exacerbate cold stress. Nonetheless, experiences of cold stress during winter forced owner-builders to reassess their priorities: in the short term, by engaging in behavioral adaptations, such as sleeping in the kitchen despite reduced privacy, and in the long term, by reconsidering thermal needs as the most important concern for future constructions. This shift in priorities reflected a growing willingness to invest in climate-responsive solutions, creating an opportunity for policy and design interventions. Such interventions, however, must remain affordable, enabling the construction of multi-room configurations at low cost, to incentivize widespread adoption. Evidence of this relationship is already visible in practice. For example, households widely adopt wooden roofs not only because they retain warmth, but also because they are inexpensive to construct over large spans. This widespread use, therefore, demonstrates that affordability is a critical driver of adoption. In addition, thermal improvement proposals will be even more likely to be adopted if they fulfill people's needs for durability, light, ventilation, and aesthetics, as this study also found that these needs are emerging as integral concerns in contemporary construction alongside thermal comfort and relationship needs.

Finally, the thermal performance of four houses representing the transition from traditional to contemporary housing in Hunza was examined using dwelling documentation, indoor temperature monitoring, and building energy modeling. The purposes of this work were, first, to identify the sources of heat gain, the mechanisms of heat retention, and the dominant pathways of heat loss, and second, to use this understanding to enhance the thermal adaptation strategies that residents use in their homes to mitigate cold stress.

Walls were found to be the greatest contributors to heat loss in contemporary houses. Accordingly, the intervention, which upgraded the existing wall paneling by adding a polyurethane sheet layer behind the wooden panels and extending it to the full height of the wall, substantially improved thermal comfort in all three houses. Other tested improvements, including reducing infiltration by installing dampers on smoke exhaust pipes and sealing windows with plastic sheets, as commonly observed in Hunza, as well as introducing skylights with proper orientation and night insulation, and increasing the thickness of mud plaster on roofs, showed small to moderate improvements in indoor warmth. However, when all of these strategies were combined, they raised indoor temperatures substantially: The improved configurations achieved inward comfort levels using internal heat gains only for more than 50% of the time during the coldest month of January and for nearly 100% of the time during the milder months of February in all three cases.

Limitations and future directions:

This study provided several important insights into the nature of housing transitions and the motivations of owner-builders in abandoning traditional constructions and adopting contemporary ones, and identified potential policy approaches and design retrofits to address the resulting thermal stress in Hunza. These insights are tailored to Hunza's unique combination of social, climatic, and economic factors, which, among others, include exposure to global trends facilitated by widespread access to education and tourism [15,16]; rapid economic growth driven by tourism and an expanding service sector [17]; and strong aspirations to adopt modern technologies and infrastructure [18]. In addition, the types of construction materials, methods, and skills addressed in the study are unique to the Hunza Valley as well. All these factors are crucial for determining the feasibility of new construction and retrofit strategies for alleviating thermal stress. Studies in other regions must therefore contextualize and adapt these insights to their own social, material, and climatic conditions, rather than applying them directly.

Due to limited knowledge in the area of investigation, the study employed a grounded theory approach, gathering data from diverse sources until consistent themes emerged. The patterns identified in this study, such as the thermal adaptations shaped by interactions between people and dwellings, the incremental nature of housing transitions, and opportunities to mitigate thermal stress, establish a foundational understanding for future research to build upon. Within Hunza, further investigation into people's spending capacity, available technical skills, and material availability could provide a clearer picture of the practical feasibility of the proposed solutions. Moreover, future studies incorporating gendered perspectives on construction-related decision-making and cost-benefit analyses of various construction methods could add further nuance to the policy and design interventions. Beyond Hunza, similar research in other climatic and cultural contexts could provide valuable comparative insights into how communities experience and adapt to thermal stress. These comparative studies would help determine whether strengthening these local adaptations with scientific and technical knowledge could be beneficial elsewhere, thereby revealing the potential to generalize these findings across other developing regions.

Finally, since construction practices, as well as the availability of monetary resources, materials, skill sets, and environmental and climatic conditions, are rapidly changing in Hunza, people's experiences of comfort, stress, and adaptation within their homes are likely to be changing as well. These changes highlight the need for continuous research engagement to ensure that scientific support for design strategies and policy interventions remains responsive to housing and thermal comfort conditions. Longitudinal studies could play a particularly valuable role in this regard by capturing the iterative nature of these processes, revealing the ways in which building forms, thermal experiences, and housing choices evolve.

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SUPPLEMENTARY INFORMATION

This document provides a list of topic-initiating questions used in the open-ended, exploratory interviews of 2019, a list of questions for semi-structured interviews used in 2021, and a list of focused questions asked in 2023, In addition, it includes a list of themes, codes, and subcodes generated through open coding of the interview transcripts. Next, it provides the questionnaire for the 2020 survey and it lists thermal properties of buildings materials, based on the available sources of information, used to estimate U-values of selected building components reported in Table 1.7. Finally, it documents the EnergyPlus model input information used in the analyses.

1. List of interview questions

1.1. Summer 2019 - open-ended, exploratory interviews

Topic initiating questions for housing residents

- Tell me about your house. (When was it constructed? How many rooms do you have? What materials are used?)
    - When did you build your house?
    - Who was involved in the construction process?
    - What kind of things are in your house? How are they arranged? e.g., winter vs. summer kitchens.
- What guided the choice of construction materials and methods?
    - Why did you want to build a new house?
    - What are your concerns while constructing the house?
- How comfortable do you feel with the temperature inside your house during winters and summers?

    - How well do you like it? Why?
- What do you do to stay warm during winters?
    - Which room(s) is/are used the most in summer? In winter? Why?
    - How do you heat, cool, and ventilate your house?
- What do you think about different building methods?
    - Do you know about BACIP and AKCSP?
    - What do you think about traditional construction methods?
    - How do you feel about new building types?
    - Why do you think building methods have changed?
- What are some common problems that you experience in your house?
- What do you think about the changes in local climate?

Topic initiating questions for craftsperson and community gatekeepers:

- What types of constructions and housing designs do your clients/people want?
- What types of constructions do you think are feasible in Hunza?
- How possible is it to build traditional-type houses today?
- What are the obstacles in the implementation of traditional and contemporary housing designs?
- How do clients/people respond to the potential of adopting new building methods?

1.2. Summer 2021 - semi-structured interviews

For housing residents

- Tell me about last winter?
    - How was your experience with indoor thermal comfort conditions?
    - How do you compare it to the previous winters?
- What rooms did you use the most during last winter, and for what purposes?

- What fuels did you use for heating during last winter? How long did you burn the fire? How long did the space remain warm after burning a fire?
- How did you prepare for staying warm during the winters? What special things did you do to keep the cold out?
- What worked well for keeping the cold out during the last winter?
- What places were the coldest? Where do you think the heat escaped out of the most?
- What was the most problematic thing in your house during the winter?
- Did you experience any issues regarding space or privacy during the last winter?
- How are you planning to prepare to stay warm during the next winter?

For craftsperson and community gatekeepers:

- What types of constructions and housing designs do your clients/people want?
- What types of constructions do you think are feasible in Hunza?
- How possible is it to build traditional-type houses today?
- What are the obstacles in the implementation of traditional and contemporary housing designs?
- How do clients/people respond to the potential of adopting new building methods?

1.3. Winter 2023 - Focused interviews

- Describe a comfortable house. What physical attributes are needed and wanted for comfort?
- How comfortable do you find your house to be?
    - What attributes create comfort?
    - What attributes create discomfort?
- What is your level of satisfaction with comfort in your house?
- How important is thermal comfort in achieving comfort?
- How comfortable do you feel thermally in your house?

- What are the sources of thermal comfort? and how often do you face them?
- How satisfied are you with the conditions of thermal comfort?
- Why did you use the following specific physical attributes:
    - Building material, e.g., stone, CMU blocks, metal sheet for roof, wood and mud for roof, etc.
    - Building layout, e.g., multiple rooms, bedrooms, kitchen with a living space, *haa*, etc.
    - Components, e.g., larger doors, larger windows, aluminum framed windows, etc.

2. Themes and codes

Table S1. List of cotes, categories, and themes.

Themes	**Categories (Descriptions)**	**Codes**
Building descriptions – Descriptions of physical attributes of the buildings and construction process	Number of rooms (Descriptions of number of rooms in the house)	Less than 4 5-7 more than 8
	Number of levels (Descriptions of number of levels/stories in a house)	Single story Double story Triple story
	Materials (Descriptions of the construction materials of houses)	Floors Walls Roof Fenestrations Structure
	Presence of spaces (Descriptions of spaces present in the house)	Traditional 'Haa' Large kitchens Bedrooms Bathrooms Verandah
	Household size (Descriptions of number of people living in housing units)	Less than five More than 6 Varies according to season
	Construction process (Descriptions of who were involved in the construction of houses)	Community help Self-constructed

Themes	**Categories (Descriptions)**	**Codes**
		Masons only Mason's and self Design professionals
Factors affecting building choices	Social needs (Social and societal factors affecting the choice of construction methods and housing types)	Hygiene and health Changing Lifestyle Familial privacy Gender roles in decision-making Aesthetics Social consciousness Spaciousness
	Economic needs (Concerns for economizing the use of available capital and resources)	Availability of land Speed of construction Labor Material availability Construction expenses
	Technological (technical concerns that affect the building choices)	Ideas for alternatives Durability Maintenance Hot water Sanitary and plumbing
	Safety concerns (Concerns for structural and human safety)	Structural concerns Health concerns
	Thermal concerns (Considerations for constructing houses that can stay warm during winters)	
	Lack of options (Mentions of lack of technical, material and intellectual resources for better buildings)	Lack of technology Lack of resources Lack of information
	Long term planning (Concerns about the long-term implications of construction methods and material choices)	
Adaptation during winters	Space use patterns (Duration, intensity and timing of use of different spaces in the house)	Use of traditional Haa Use of kitchens Use of rooms Internal migration
	Active heating (Active heating, duration and timings of burning fires and types of fuels used)	Heating patterns Fuels
	Passive strategies (Use of passive methods	Air sealing

Themes	Categories (Descriptions)	Codes
	heat capture and retention)	Insulation Layout design solutions Solar gains Internal gains
	Personal adaptation (Modification in lifestyles and activities to better adapt to cold winters)	Activities Food Clothing
Observations, concepts and popular beliefs	Temperatures (description of indoor and outdoor temperatures and weather patterns)	Comparative descriptions of weather (Past vs present) Descriptions of weather Temperatures of indoor spaces
	Fuels (Descriptions of financial, sustainability, safety, and availability concerns about different fuels)	Wood Electricity Natural gas Biofuels
	Construction materials (Observations about construction material's physical properties, availability and desirability)	Prices Durability and strength Thermal and hygroscopic performance Availability Social value and aesthetics Labor and expertise requirements
	NGO solutions (Use, knowledge and usability of solutions introduced by NGO's for better buildings)	Social outreach Use of solutions Success of solutions
	Compromise (Expressions of a need to compromise one's needs for the fulfillment of other or for lack of viable alternatives)	Social compromise Health compromise Financial compromise Thermal compromise
	Importance of culture (Comments on the importance of retaining cultural practices)	For representation For living
	Content with present (Expressions of happiness and feeling blessed because of improvements in livelihoods)	
	Perceptions of change (Comments about the cultural, social and environmental change over time)	Desirable changes Undesirable changes Occurrence of change
	Popular issues (Issues of the present day that people perceive as important to	

Themes	Categories (Descriptions)	Codes
	address)	
Problems	Problems in old houses (Problems experienced in traditional houses)	Privacy Pests Spaciousness Ventilation Maintenance needs and moisture damage
	Problems in new houses (problems experienced in newly constructed concrete houses)	Thermal discomfort and adaptation Hot water Storage Condensation
	Elders and infants (Special thermal needs for elders and infants in families)	
	Discomfort (Expressions of discomfort with indoor environment)	

3. Survey questionnaire

Demographic Information

Q - What is your gender?

Q - What is your age?

Q - Where is your house located? (City)

Q - How many people typically live in your house during winters?

a) 4 or less
b) 5-10
c) 11 or more

Q - What is your average household income?

a) Less than Rs. 30,000/month (less than Rs. 360,000/year)

b) Rs. 30,001 - 70,000/month (Rs. 360,001 - 840,000/year)

c) Rs. 70,001 - 100,000/month (Rs. 840,001 - 120,000/ year)

d) Rs. 100,001 - 200,000/month (Rs. 120,001 - 240,000/year)

e) More than Rs. 200,000/month (more than Rs. 240,000/year)

Building information

Q - What is the total covered area of your house?

a) Less than 1000 square feet

b) 1000-2000 square feet

c) More than 2000 square feet

Q - When was your house originally built?

a) 15 years ago or less

b) 15-30 years ago

c) 31-50 years ago

d) 51 years ago or more

Q - Have you made any additions/changes to the original structure? If yes, what changes have you made and how many years has it been since you made these additions/changes.

Q - What is the construction type of your house?

a) Type 1. Stone walls with RCC roof

b) Type 2. Concrete block walls with RCC roof

c) Type 3. Stone walls with traditional roof (wooden roof with mud/cement plaster)

d) Type 4. Concrete block wall with traditional roof (wooden roof with mud/cement plaster)

e) Type 5. Stone walls with GI Sheet roof

f) Type 6. Concrete block walls with GI sheet roof

g) mix of two or more type (write the type number below)

Q - Other than for sleeping at night, does your family stay together in one specific room during winter days and evenings? If yes, which room do you use?

a) Yes-Traditional Haa
b) Yes-Kitchen with seating space
c) Yes-A separate room such as living or TV room, where heating system is installed
d) Yes-others
e) No-we occupy multiple rooms during the day

Q - When was this space, that you use in winters, constructed?

Q - What are the walls of the space, that you use in winters, made of?

a) Stone walls with cement plaster
b) Stone walls with mud plaster
c) Concrete blocks with cement plaster
d) Others (please name the materials)

Q - What is the roof of the space, that you use in winters, made of?

a) RCC (Reinforced cement and concrete)
b) Wooden roof with mud plaster on top
c) Wooden roof with cement plaster on top
d) Metal GI sheet with wood frame
e) Other (please name the materials)

Q - What are the floors of the space, you use in winters, made of?

a) Cement plaster
b) Mud plaster
c) Wooden flooring
d) Other (please name the materials)

Q - Do you have any insulation in the walls, roof, or floor, anywhere in your house?

Q - In which rooms is the insulation installed?

a) Winter living space
b) Bedrooms
c) Entire house
d) Other

Q - Where is the insulation installed? Please name the insulation material for:

a) Wall
b) Roof
c) Floor

Q - Is the insulation effective?

a) Definitely yes
b) Probably yes
c) I am not sure
d) Probably not
e) Definitely not

Comfort questions

Q - How much do you agree with these statements?

- It feels very cold inside the main living area during winter.
- The low indoor temperature in the main living area causes physical discomfort.
- During winters, the cold indoors in the main living area restricts my activities and movements.
- During winters, I would prefer the indoor temperature to be higher than what it usually is, in the main living area.

- During winters, the indoor temperature is comfortable in the main living area.
- During winters, I would prefer the indoor temperature of my house to be higher than what it usually is.
- The low indoor temperature in the house causes physical discomfort.
- During winter, the cold indoors restricts my activities and movements.
- During winters, the indoor temperature is comfortable.
- It feels very cold inside the house during winter.
- Indoor temperature in the main living area is comfortable with heating.

Response scale:

Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

Q - How satisfied do you feel with the following?

- Indoor temperature in the main winter's living space.
- Amount of clothing you have to wear while you are inside your house.
- Indoor temperature of the bedrooms when you go there to sleep at night.
- Effort you put into keeping your house warm.
- Privacy your family gets in your house.
- Conditions of plumbing, sanitation and hygiene in your house.
- Natural light and ventilation in your house.
- Ability of your house to stay warm during winters.
- Strength, durability and the requirement for regular maintenance for your house.

Response Scale

Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied

- **Adaptation Questions**

Q - Considering the cold climate of Gilgit Baltistan, which materials do you think are the most effective for keeping the house warm? Write 1 for the most effective material and 2 for the second most effective one.

Q - What strategies do you and your family use to stay warm during winter? You can choose multiple options.

a) Light up a fire or turn on a heater
b) Wear extra layers of clothes
c) Stay together in one room
d) Cook and live in one room
e) Use a sunny room during daytime
f) Put plastic sheets or curtains on windows
g) Eat warm foods
h) Use insulation in walls, floor or roof
i) Others

Q - Choose the first 3 strategies you and your family use as the temperature starts decreasing.

Q - Choose top 3 strategies that are the most effective during winters.

Q - What fuels do you use for space heating?

a) Wood
b) Gas cylinder
c) Electricity
d) Kerosene (Matti ka tel)

Q - How much money or effort do you spend on collecting the fuel and keeping your house warm?

a) Not at all
b) Not much
c) Neutral Alot
d) A great deal

Q - How much money or effort do you spend on keeping the house warm?

a) Not at all
b) Not much
c) Neutral Alot
d) A great deal

Q - For how many hours do you heat up your home (by burning fire or turning a heater on) during a day?

a) 16 or more hours
b) 10-15 hours
c) 5-9 hours
d) 4 hours or fewer

Q - Does your family go to bedrooms for sleeping during winters?

a) Yes, everyone sleeps in the bedrooms
b) No, some family members sleep in the winter's living area
c) No, everyone sleeps in the winter living area
d) Other, please explain

Q - Do you heat up the bedroom before sleeping?

a) Yes, we always heat it
b) No, we don't heat up the room
c) Depends on availability of fuel/electricity
d) Others, please explain

Building choices

Q - Did you get your house constructed by yourself?

Q - Rank the priorities you had while constructing your house, from 1 (most important) to 6 (least important). Note: Two or more items cannot have the same ranks, e.g. both aesthetics and natural light cannot be ranked as 1, at the same time.

a) Staying warm during winters
b) Aesthetics and appearance
c) Social needs (private spaces for family, large spaces for gatherings etc.)
d) Natural light and ventilation
e) Affordability of construction
f) Strength of the structure (durability, reducing need for maintenance, earthquake resistance etc.)

Q - Are you planning to construct a house in the future?

Q - Rank the priorities you will have while constructing your house in future. 1 is most important

a) Staying warm during winters
b) Aesthetics and appearance
c) Social needs (private spaces for family, large spaces for gatherings etc.)
d) Natural light and ventilation
e) Affordability of construction
f) Strength of the structure (durability, reducing need for maintenance, earthquake resistance etc.)

NGO solutions

Q - Do you know about the construction technologies of AKCSP or/and BACIP?

Q - Have you used them in your house?

Q - What technology have you used?

Q - Are you satisfied with its performance?

Q - Do you think their technologies are feasible for common residential buildings? And why do you think so?

Qualitative questions for generating elicited texts

Q - What is the biggest cause of discomfort for you during winters, at your home.

Q - What alteration to your house building could make your daily life considerably easier during winters?

Q - What alteration to your house building could make your daily life considerably easier during winters?

Q - Do you have any concerns about your current heating system or the fuels you use for heating during winters? If so, please explain briefly.

Q - What helps the most in providing comfort during winters at your house?

Q - In your opinion, what is the biggest drawback of old traditional houses?

Q - In your opinion what is the biggest drawback of the newly built house?

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4. Thermal properties of materials

Table S2 lists material properties used to estimate assembly U values in Chapter II.

Table S2. Thermal properties of materials used to calculate component U-values in Table 2.7

Materials	**Thermal conductivity (*k*) W/m·K**	**Roughness**	**Emissivity (ε)**
Stone: Gneiss and Granodiorite	2.66[a] [1]	Rough	0.93 [2]
Wood: Poplar	0.072[b] [3]	Rough	0.9 [4]
Earthen Plaster with wheat straw fiber	0.32 [5]	Rough	0.91[c] [6]
Cement sand plaster (C/S ratio 1:3)	2.79 [7]	Rough	0.93 [2]

[a] Reported thermal conductivity values for granodiorites and gneisses collected from various Karakoram regions ranges between 2.62 and 2.70 W/m·K [1].

[b] The listed value indicates transverse heat transfers at 20°C [3].

[c] Listed as plaster, rough surface emissivity coefficient on The Engineering ToolBox [6].

Materials	**Thermal conductivity (*k*) W/m·K**	**Roughness**	**Emissivity (ε)**
Stone: Gneiss and Granodiorite	2.66[a] [1]	Rough	0.93 [2]
Cement: sand mortar (C/S ration 1:6)	1.99 [7]	Rough	0.93 [2]
CMU Block 200 mm	1.11 [8]	Rough	0.94 [2]
Fired brick	0.565 [9]	Rough	0.75 [6]
0.07 mm corrugated sheet metal	45.3 [8]	Smooth	0.89 [2]
1 cm polyurethane foam sheet	0.024 [4]	Rough	0.9 [10]
1 cm plywood sheet	0.13 [8]	Smooth	0.9 [4]
Reinforced concrete	1.9 [2]	Rough	0.94 [6]
Plain concrete (floors)	2.25 [11]	Rough	0.85 [6]
Earth: silty loam soil texture	0.7 [12]	-	0.91[d]
Wool carpet	0.2 [13]	-	0.9[e]
Synthetic carpet	0.12 [14]	-	0.9[5]
Cotton wool filled floor cushions	0.029 [15]	-	0.9[5]
0.3 mm clear glass	1 [16]	Smooth	0.84
Thermal resistance of roof spaces	R: 0.08 $m^2 \cdot K \cdot W^{-1}$ [17]		
Thermal resistance of synthetic carpet 6 mm	R: 0.0945 $m^2 \cdot K \cdot W^{-1}$ [14]		
Thermal resistance of synthetic rug 10 mm	R: 0.0133 $m^2 \cdot K \cdot W^{-1}$ [14]		

[d] Listed as clay surface emissivity coefficient on The Engineering ToolBox [6].

[e] Listed as fabric (unspecified) surface emissivity coefficient in CIBSE Guide A [2].

5. EnergyPlus Model inputs

5.1. Material Properties and Construction Assemblies

Thermal and physical properties, including thermal conductivity, density, and specific heat of building materials, were adopted from various literature sources. These are listed below in Table S3.

Table S3. Material properties used for EnergyPlus Models and their sources

Materials	**Roughness**	**Conductivity (W/m-K)**	**Density (Kg/m^3)**	**Specific Heat j/Kg-K**
Wall mortar and mud Plaster	Medium rough	0.215 [1]	1610 [1]	806 [1]
Wall stone (gneiss)	Rough	2.14 [2]	2660 [2]	750 [2]
CMU blocks	Rough	1.13 [1]	2180 [1]	920 [1]
Roof mud plaster	Medium rough	0.215 [1]	1610 [1]	806 [1]
Wood Birch (doors, structural elements, and wall panels)	Medium smooth	0.172 [1]	704 [1]	1630 [1]
Glass	Smooth			
Floor mud plaster	Medium rough	0.35 [1]	1800 [1]	806 [1]
Floor granite slates	Rough	2.14 [2]	2240 [2]	880 [2]
Floor gravel infill	Very rough	0.36 [3]	1840 [3]	840 [3]
Compacted earth	Rough	0.52 [3]	2050 [3]	880 [3]
Floor concrete	Medium rough	1.95 [1]	2240 [1]	900 [1]
Cement screed (walls and floors)	Rough	0.72 [1]	1700 [1]	850 [1]
Woolen carpet (traditional)	Medium rough	0.31 [4]	40 [4]	1450 [4]
Synthetic carpet	Medium rough	0.06 [3]	288 [3]	1380 [3]
Polyethylene sheet	Medium smooth	0.31 [5]	920 [5]	2090 [5]
Polyurethane sheet	Medium smooth	0.025 [1]	24 [1]	1590 [1]

Envelope constructions

Roofs: Roof assemblies are created in THERM 7.8 as equivalent materials using the following inputs

- Outdoor Temp = 0^0 C
- Indoor Temp = 10^0 C
- Outdoor surface film resistance coefficient = 34 W/m^{2}K [5]
- Indoor surface film resistance coefficient = 9.26 W/m^{2}K [5]

Roof constructions and their corresponding thermal properties calculated using Therm 7.8 and calculations (Table S4) are as follows:

Table S4. Thermal properties of roofs calculated using THERM 7.8

	T2S	T1S	CSW	CCW
Construction	15 cm thick mud plaster o/ 4 cm thick wooden planks, over 10 ×15 cm thick wooden rafters	10 cm thick mud plaster o/ 4 cm thick wooden planks, over 10 × 15 cm thick wooden rafters	10 cm thick mud plaster o/ 4 cm thick wooden planks, over 10 ×15 cm thick wooden rafters	7 cm thick mud plaster o/ 2.5 cm thick wooden planks, over 10 ×15 cm thick wooden rafters
U-factor calculated by TTHERM 7.8 (W/m^{2}K)	1.16	1.43	1.602	1.836
Thickness of equivalent material (m)	0.1	0.1	0.1	0.1
Derived thermal conductivity	0.11	0.143	0.162	0.183
Derived heat capacity ((j/Kg.K)	936	1061	1038	1073
Derived density (Kg/m^3)	1418	1321	1370	1297

Heat capacity and density for the roof, equivalent materials are calculated using the following methods:

$$\text{Equivalent density} = \rho_{eq} = \Sigma(Af_i \times \rho_i)$$

Here,

Af_i = Fractional area of the material i

ρ_I = Density of the material i

$$\text{Equivalent heat capacity} = \Sigma(Af_i \times \rho_I \times C_i)/\rho_{eq}$$

Here, C_i = Specific heat of material i

Walls: Wall constructions of the modeled houses are listed in Table S5.

Table S5. Wall construction types in modeled houses

Construction type	Construction detail	Model
55 cm traditional wall	55 cm stone masonry core in 5 cm mud mortar, with 2.5 cm mud plaster on both interior and exterior surfaces.	T2S
45 cm traditional wall	45 cm stone masonry core in 5 cm mud mortar, with 2.5 cm mud plaster on interior and 12 mm cement plaster on exterior	T1S
45 cm contemporary stone wall	45 cm stone masonry core in 2.5 cm cement mortar, with 12 mm cement plaster on the interior surface	CSW
Uninsulated CMU wall	20 cm CMU block with cement mortar and 12 mm cement plaster on both interior and exterior surfaces.	T1S, CSW, and CCW
CMU wall with wooden panels	Same as above with 0.25 cm air space, and 2.5 cm wooden panels on interior	CCW
Wall insulation retrofit	Same assemblies as above, except the interior surface consists of cement plaster, 2.5 cm polyurethane sheet, and 1.25 cm wooden panels.	T1S, CSW, and CCW

Floors: Floor constructions of the modeled houses are listed in Table S6.

Table S6. Floor construction types in modeled houses

T2S	House: Rugs & woolen carpets o/ 10 cm mud plaster o/ 90 cm gravel fill o/ compacted earth Bathroom: Granite slats set in 3 cm cement grout o/ 10 cm plain cement concrete (PCC) o/ 90 cm gravel infil o/ compacted earth
T1S	Haa: Rugs & woolen carpets o/ 10 cm mud plaster o/ 12 cm gravel fill o/ compacted earth Contemporary additions: Rugs and carpets over carpet underlay o/ 1 cm cement–sand plaster o/ 10 cm PCC slab o/ 10 cm sand o/ 10 cm gravel fill 0/ compacted earth Bathrooms: Ceramic tiles o/ 3 cm grout o/ 1 cm cement–sand plaster o/ 10 cm PCC slab o/ 10 cm sand o/ 10 cm gravel fill o/ compacted earth.
CSW	Rugs and carpets over carpet underlay o/ 2.5 cm cement–sand plaster / 10 cm PCC slab o/ 10 cm sand o/ 90 cm gravel fill 0/ compacted earth.

	Bathroom: Ceramic tiles o/ 3 cm grout o/ 1 cm cement–sand plaster o/ 10 cm PCC slab o/ 10 cm sand o/ 90 cm gravel fill o/ compacted earth.
CCW	Rugs and carpets over carpet underlay o/ 1 cm cement–sand plaster / 10 cm PCC slab o/ 10 cm sand o/ 10 cm gravel fill 0/ compacted earth. Bathroom: Ceramic tiles o/ 3 cm grout o/ 1 cm cement–sand plaster o/ 10 cm PCC slab o/ 10 cm sand o/ 10 cm gravel fill o/ compacted earth.

Fenestration: Windows', doors', and skylights' constructions are listed in Table S7.

Table S7. Fenestration constructions in modeled houses

	T2S	T1S	CSW	CCW
Doors	1 × 1.5 m poplar wood panel, 6 cm thick; 4 cm thick door frame	1 × 3 m poplar wood panel, 6 cm thick; 4 cm thick door frame	1 × 3 m poplar wood panel, 6 cm thick; 4 cm thick door frame	1 × 3 m poplar wood panel, 6 cm thick; 4 cm thick door frame
Windows	No Window	No window in haa Rooms: Various sizes, 5 mm clear glass set in 4 cm thick wooden casement panels, and a 4 cm thick wood frame	Various sizes, 5 mm clear glass set in 4 cm thick wooden casement panels, and a 4 cm thick wood frame Kitchen window: 1.1 × 1.7 m	Various sizes, 5 mm clear glass set in 4 cm thick wooden casement panels, and a 4 cm thick wood frame Kitchen window: 1.1 × 1.7 m
Skylight	Haa: wood-framed skylight with 5 mm clear glass Baldi: 1 m×2m opening with a 0.5 m high prism-shaped wire mesh skylight with wooden framing and polyethylene sheet on top	Opening in the roof created using highly transparent glass material	No Skylight	0.5 × 0.5 × 0.5 m cube wood-framed skylight with 5 mm clear glass

Internal Mass: Thermal mass observed in the modeled houses is listed in Table S8.

Table S8. Internal mass constructions in modeled houses

House	Thermal mass objects
T2S	0.3 m thick interior partition walls built with stones, 0.15 m raised floors, 0.6 m 1.5 m 0.6 m stone boulder, and wooden pillars, beams, shelves, and cabinet doors

T1S	0.3 m thick interior partition walls built with stones, 0.15 m raised floors, and wooden pillars, beams, shelves, and cabinet doors
CSW	Concrete cooking counters with 10 cm thick concrete slab and 20 cm CMU wall support. Slab ~ 2 m long. and raised seating area ~ 0.25 × 3 × 1.75 m
CCW	Concrete cooking counters with 10 cm thick concrete slab and 20 cm CMU wall support. Slab ~ 4 m long.

5.2. Internal gains

Table S9 lists the input parameters for internal gain objects used in the EnergyPlus models.

Table S9. Fractional distribution of internal heat gain sources.

Source	Return/lost fraction	Fraction radiant	Fraction Latent	Fraction visible	Fraction convected	Model
Fluorescent tube lights [6]	0	0.27	n/a	0.23	0.5	T2S
LED bulbs [9]	0	0.32	n/a	0.23	0.5	T2S, T1S, CSW, CCW
Cooking	0.4 [11]	0.12 [f]	0.22 [10]	n/a	0.26	T2S, T1S, CSW, CCW
TV [10]	0	43	0.16	n/a	41	CSW, CCW

Cooking heat calculations:

[f] The remaining 38% of the heat will be dissipated as convective and radiative transfers. Kanneesamkandi 2014 [12] studied a similar stove and calculated convection and radiative transfers from each surface of the stove. For each stove, of the heat not lost, approximately 67% is convective and 33% is radiant.

Based on observations made in Hunza, one-time heating uses approximately 2-3 kgs of wood. Using an intermediate value of 1700 MJ/kg, each kg of wood burning will produce 4722 Watts (J/s) of heat.

$$(1700 \times 106 \text{ J/kg})/3600 \text{ s} = 4722.22 \text{ Watts/kg}$$

For 2kg = 9444 Watts and For 2kg = 1416 Watts

Using an intermediate value ~11000

5.3. Air Flows

Design Flow Rates

Design flow rates are calculated to represent the air flow through the smoke exhaust pipe. The design flow rate for the smoke exhaust pipe is divided into two components because the wood-burning stoves generate stack-driven flows even when active heating is not occurring. A small, continuous baseline flow results from the stack effect and leakage, while a much larger flow occurs only during periods of active wood combustion. Splitting the flow into a low, always-on component and a higher heating-only component allowed the model to represent both conditions realistically.

<u>Active burning time airflows:</u>

The design flow rate during active heating is calculated as follows:

Exhaust velocity = V = $\sqrt{2gH\frac{(Ti-To)}{To}}$ …………(1)

Here:

Exhaust pipe diameter = 4 inches or 0.10 m

Area of exhaust pipe = 0.008 m^2

G=gravity =9.81

H = height of exhaust pipe = 4 m in T2S and 3m in T1S, CSW, and CCW

Ti = 300^{0}C (estimated wood temperature [12]) = 573K

To = outdoor temperature = 0^{0}C = 273 K

Using the formula:

Exhaust velocity in T2S = 11.09 m/s

Exhaust velocity in T1S, CSW, and CCW = 9.28 m/s

Next, calculating the exhaust flow rate using the formula:

Exhaust flow rate = Q = Area × Velocity……….(2)

Exhaust flow rate in T2S = 0.088 m^3/s

Exhaust flow rate in T1S, CSW, and CCW = 0.0742 m^3/s

<u>No burning time airflows:</u>

The design flow rate for non-wood burning times is calculated by using equations (1) and (2), except that indoor temperatures are changed to 10 °C, yielding an airflow rate of 0.02 m^3/s

- In T2S, both air flows are input separately using design flow rates, thus
  - Design flow rate with wood burning = 0.08 - 0.02 = 0.06 m^3/s
  - Design flow rate with no wood burning = 0.02 m^3/s
- In T1S, CSW, and CCW,
  - Design flow rate with wood burning = 0.07 – 0.02 = 0.05 m^3/s
  - Design flow rate with no wood burning is replaced with an effective leakage area object of 80 $cm^{2,}$ which is used to imitate air flows under non-wood burning conditions.

Effective leakage area in winter living rooms (cm^2)

Since all crack widths exceed 0.5 mm, the discharge coefficient is set to 1, yielding effective leakage areas equal to the measured areas [13], listed in Table S10.

Table S10. Observed crack areas in the modeled houses

	T2S	T1S	CSW	CCW
Windows	0	0	34	85
Doors	0	0	0	57
Skylight	0	256	0	136
Smoke exhaust pipe	0[g]	80	80	80

Zone cross mixing in Winter living rooms

T1S is a unique case because of the small doors and the cross-mixing through the skylight.

Entry and storeroom

Both the entry and the storeroom have 11 meters by 1.5 meters doors, shared with the *haa.*

Door perimeter = 3.96 m

Crack width = 0.5 mm

Area of openings (A) =19 cm^2

Discharge coefficient for gaps >0.5 mm (C_d)= 1

Estimated pressure difference (ΔP) = 4 Pa[h]

Air density (d) = 1.21

$$\text{Air flow rate} = A \times Cd \times \sqrt{((2/d) \times \Delta P)} = \mathbf{0.005\ m3/s}$$

Haa and summer living room

Skylight perimeter cracks × crack width = 7.8 m × 1 mm = 78 cm^2

Smoke exhaust pipe perimeter crack × crack width = 0.3 m × 1 mm = 3 cm^2

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[g] T2S is fully enclosed on all sides. air flows are thus only occuring as zone cross mixing

[h] 4 Pa is a reasonable, low-pressure differential representing normal door leakage and balancing conditions in HVAC design.

Area of openings = 81 cm^2

Discharge coefficient for gaps >0.5 mm (C_d)= 1

Estimated pressure difference (ΔP) = 4 Pa

Air density (d) = 1.21

Air flow rate = A × Cd × √((2/d) ×ΔP)= **0.02 m3/s**

In T2S, CCW, and CSW, the winter living rooms cross-mix air with the adjacent room through cracks around the doors. These are calculated using the following methods

Door perimeter = 5.7 m

Crack width = 0.5 mm

Area of openings (A) =28 cm^2

Discharge coefficient for gaps >0.5 mm (C_d)= 1

Estimated pressure difference (ΔP) = 4 Pa[i]

Air density (d) = 1.21

Air flow rate = A × Cd × √((2/d) ×ΔP)= **0.007 m^3/s**

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