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Emergency Architecture: Application of the Active House Protocol for the Indoor Comfort Prediction in Post-Disaster Shelters

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Abstract: The design of post-emergency shelters is critical for mitigating the impacts of the numerous disasters occurring globally. Unfortunately, these shelters are frequently constructed with insufficient attention to comfort levels and minimum standards for temporary refuge. This study examines wooden post-emergency shelters, which have become increasingly common in various refugee camps and regions worldwide. Using the Active House Protocol, a comprehensive comparative analysis of indoor comfort is conducted to propose innovative approaches to global design challenges, particularly in developing countries. To minimize the negative effects of disasters and increase sustainability, it is essential to explore the feasibility of designing comfortable shelters despite numerous obstacles, such as the limited availability of low-cost materials and the lack of skills of the local workforce. Various shelter configurations are analyzed, revealing that structures made from natural materials and designed with careful consideration of air circulation yielded the highest comfort values. Additionally, the study finds that wooden structures do not always provide the best solution, contrary to common practice. Inadequate comfort standards can lead to distress and psychological stress among occupants, highlighting the necessity to improve design and construction practices to ensure the well-being of disaster-affected populations. Finally, this study provides guidelines on the minimum requirements for the development of post-disaster shelters, advocating for solutions that are both simple and effective in rapidly addressing the critical situations that arise following disasters.

Keywords: emergency architecture; shelter design; Active House protocol; innovative constructive technologies; sustainable materials; design strategies

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1. Introduction

A disaster is a catastrophic event that can have widespread and lasting effects on the affected area. Additionally, disasters can have a ripple effect on communities and local economies, often resulting in long-term impacts, sometimes compromising reconstruction and the return to normal life, including the complete loss of customs and traditions. They thus present a destructive potential that goes beyond a mere territorial devastation. A disaster can occur naturally or be caused by humans; in any case, it often involves loss of human lives, damage to structures and infrastructure, and forced displacement of citizens. In the aftermath of a disaster, it is important to provide immediate relief and assistance to the affected people, as well as to rebuild and recover in a way that makes communities resilient to future catastrophic events [1–3].

The consequent forced displacement of entire communities can be caused by various reasons, two of which are primary: fleeing conflicts and natural disasters [4,5]. In the case of conflicts, in 2020 alone, 9.8 million people were forced to leave their homes due to

violence produced by wars [6]. In the case of natural disasters, in 2019 alone, there were approximately 24.8 million "climate refugees" worldwide who had to leave their homes due to a catastrophic climate event; while in 2020, according to the Internal Displacement Monitoring Center, there were approximately 17.2 million people [7].

According to the Global Shelter Cluster, in 2021 only, the number of people in need of emergency shelter was 47.8 million, with approximately 48% in Africa, 29% in Asia, and the rest in the Americas and the Mediterranean basin. Unfortunately, only 25% of these displaced persons received humanitarian aid. By the end of the same year, that had risen to 82.4 million [8–10]. More than half of these (about 48 million) were internally displaced persons, people who had left their homes but had not been forced to leave their countries [11,12]. The other half, instead, had left their country becoming refugees with the right to international protection precisely because they were fleeing conflicts or persecutions [13]. More recently, throughout 2023, only the United Nations High Commissioner for Refugees (UNHCR) responded to multiple global crises, helping millions of people affected by earthquakes in Syria and Turkey (23.8 million people affected) and in Afghanistan (114,000 people affected and 478,000 forced to return from Pakistan); from a new conflict in Sudan (7.4 million people forced to flee internally or across borders) and from the reignition of old conflicts in Karabakh (100,000 refugees) and in Somalia [14]; and from the worsening crisis in the Democratic Republic of Congo (7 million people affected by the conflict in the eastern part of the country), from unprecedented mixed movements of refugees and migrants in Latin America and the Caribbean, and from floods in Libya (900,000 people in five provinces directly affected by the storm and flash floods) and in the Horn of Africa (over 2 million displaced people) [15,16].

A comprehensive overview of disasters on a global scale, based on frequency and nature, is provided. More particularly, the frequency of disasters in the five continents is shown in Figure 1A; the nature of disasters, arranged in order of Cases per Year (CxY), is presented in Figure 1B. It is important to note that these figures express the number of cases per year and are re-edited from EM-Data data [7]. This introductory report serves to contextualize the magnitude and consequences of disasters, without aiming to present an exhaustive review of the current State of the Art in disaster research; it is meant to highlight the challenges faced by affected populations and the pressing need for efficient disaster response and recovery strategies. This analysis also underscores the disparity in disaster preparedness and response capabilities across different regions, with underdeveloped areas being disproportionately affected due to limited resources and infrastructure [17].

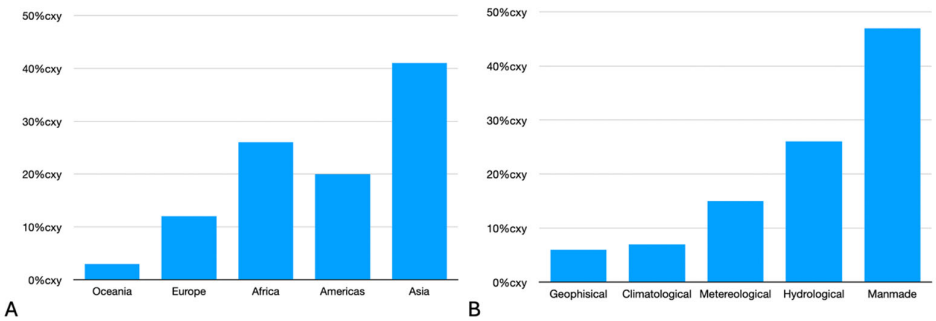

Figure 1. Disasters type: most frequent location by continent (**A**) and nature/origin (**B**).

It resulted that most of the disasters usually happen in Asia, i.e., 40%, immediately followed by Africa—26%. Hence, it is easily understandable that the widespread underdevelopment of many countries in those areas generates extremely huge issues for an immediate and effective intervention [18–20]. From Figure 1B, it is observed that disasters can be essentially divided into two categories: man-made and natural. The former mainly

includes accidents, terrorist attacks, and technological or industrial disasters. The latter includes storms, floods, and earthquakes. In terms of frequency, man-made disasters are more common than natural disasters, resulting in 47% and 45%, respectively. However, it should be emphasized that natural disasters tend to cause more casualties and damage to communities and places [21,22].

With the growing emergencies' occurrence in 2023, expected to persist in 2024, and the number of people forced to flee projected to rise to 130 million by the end of the year, the need for solidarity and support has never been as important as it is nowadays. International humanitarian law imposes that the victims of armed conflict, whether they are forcefully displaced, should be respected as humans, protected from the effects of war, and assisted in an impartial manner [23]. Since many refugees find themselves involved in international or internal armed conflicts, refugee law is often closely related to humanitarian law. The Fourth Geneva Convention relative to the Protection of Civilian Persons in Time of War (1949) [23,24] specifically deals with refugees and displaced persons (Article 44); Additional Protocol I (1977) stipulates that refugees and stateless persons must be protected under the clauses of Parts I and III of that Convention [25]. The part related to displaced people's protection began with the declaration of the UN Human Rights [1] envisaging the application of the principle of non-refoulement when climate change could endanger their lives, thus enabling the development, for States Parties, of appropriate protection laws and measures [23].

The combination of timely interventions to effectively respond to the contingencies and demands of the affected populations should be classified according to different aspects, including the social and cultural instances of the affected ethnic groups, the economic possibilities of the affected states, and the technological and constructive expertise of the local workforce. Moreover, an inevitable aspect is the respect, as far as possible, of the principles of environmental sustainability and circular economy to reconstitute the social cohesion that turns out to be among the most evident losses of communities under emergency conditions [26].

Although emergency housing solutions are designed to address the immediate needs of affected populations, they often neglect a critical aspect: indoor comfort [23]. Living in temporary shelters frequently results in conditions of discomfort, where minimum standards may provide physical protection but fail to adequately meet the psychological and well-being needs of the occupants. Despite the existence of minimum standards for emergency housing, further attention must be paid to construction technologies, building envelopes, and the adoption of passive solutions for air exchange and natural lighting [27]. Issues such as the use of low-performance materials, poor ventilation, inadequate natural lighting, and insufficient acoustic insulation contribute to making many of these spaces uninhabitable. This article focuses on indoor comfort as a central parameter, analyzing existing shelters and their construction typologies to evaluate their performance. The aim is to highlight the importance of integrating solutions that enhance the quality of life for occupants, advocating for a design approach that prioritizes not only functionality but also well-being and sustainability.

2. International Methodology

Among the main aspects that should be taken into consideration whilst designing a sustainable post-emergency structure are the rapid construction, the effectiveness of the performance, and the suitability for both the circumstances and the disaster-affected context [9]. Moreover, the choice of the building and constructive materials is also fundamental, as they should meet as many requirements as possible, according to the needs of the place, the market availability, the local workforce expertise, etc. [25,28]. In this context, alternative

or unusual materials and innovative technologies, at least in the context of emergency shelters or first shelter facilities, can offer great opportunities for experimentation and applicability [14]. Often, indeed, as even the history of construction teaches, it is in the aftermath of an emergency/disaster that it is possible to test and/or verify the effectiveness of used technological/material solutions that are frequently still in the experimental phase [29].

With respect to such needs, the United Nation High Commissioner for Refugees (UNHCR) has provided a Contingency Handbook [13] where the complexity of such issues is presented as strictly linked to the contingent case [30], particularly in material procurement [28]. Accordingly, local sourcing must be facilitated by a cost-effective market economy, preferably characterized by low transportation costs, also ensuring delivery speed and flexibility, along with social acceptance [31]. That is a key aspect that also serves as a measure of the intervention success index since a displaced population is, in fact, relocated and, therefore, completely decontextualized from its everyday life and family intimacy [32,33]. For that reason, a social acceptance of the new life in emergency accommodations—which should, in any case, be momentary—is also crucial to psychologically overcome the sudden change and the tragedy [34]. From another point of view, any shelter project faces the challenge of responding as fast as possible to the occurred crisis by using all the resources [35,36]. That, in turn, translates into a choice of materials, products, and technologies that are readily and affordable globally or, if possible and even better, locally. Such a topic is strictly connected to the broader issue of the environmental sustainability (CO_2 emissions, land use, consumption of non-renewable resources, energy consumption, waste production, etc.) [36].

Therefore, shelters are a part of a wider process that ranges from providing immediate (temporary or emergency) refuge in the event of relocation until buildings are rebuilt or a long-term solution is found. Unfortunately, what is often observed worldwide is that temporary post-disaster shelters turn into a permanent solution without the necessary and basic conditions for people to recover [37]. For this reason, it is crucial that the technological, cultural, social, and economic models of the societies affected by a disaster be reflected in the shelter. As a result, the design should be based on a quick and affordable solution that may also be regarded favorably by the population [24,25].

Due to the variety of social, technical, and geographical contexts and the fact that, most often, the situation calls for a combination of different sorts of policy decisions, experience has shown that it is quite impossible to establish a general standard for shelter design [38,39].

To the best of our knowledge, it is observed that most of the State of the Art on temporary settlements is limited to investigating the housing system used during the response and recovery phases, as suggested by UNHCR (Figure 2) [40].

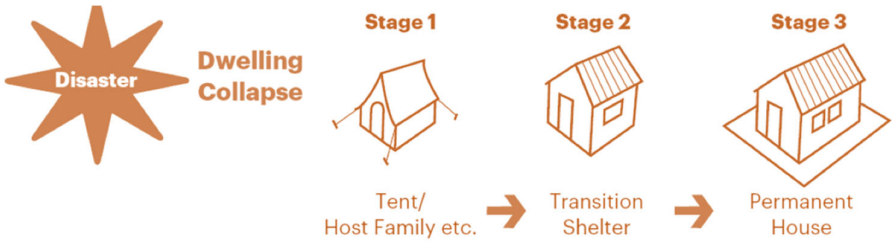

Figure 2. Scheme of the types of shelters, as suggested by UNHCR, re-edited from [41].

The case studies are generally divided, considering the average time of use of the system by type and size. Based on these parameters, shelters can be divided into three main different groups:

(1) Emergency tent: Emergency tents are typically designed for short-term use during the immediate response phase of a disaster. Their primary purpose is to provide quick and basic shelter for evacuees, offering protection from external elements, such as weather conditions, and creating a temporary refuge. However, while intended for temporary use, it has been observed that emergency tents often become a long-term solution in stable refugee camps due to delays in recovery and reconstruction processes. This unintended usage can extend the life of these structures from just a few months to as long as 10 years. Over time, the limitations of emergency tents—such as poor durability, inadequate insulation, and lack of comfort—become significant issues, especially when they are used for prolonged periods (Figure 3A).



Figure 3. Different types of shelter: emergency tent (**A**), transition shelter (**B**), and housing (**C**); re-edited from UNHCR/Paula Bronstein.

(2) Transition shelter: Transition shelters are designed to bridge the gap between the initial response phase and the recovery or reconstruction phase. These structures aim to retain some of the practical advantages of emergency tents, such as being lightweight and easy to assemble, but they are developed to provide a higher level of comfort and functionality for occupants. Transition shelters are often small-scale living solutions with basic amenities to improve habitability. They serve as a temporary home while longer-term housing solutions are planned or constructed. This intermediate solution is critical in ensuring that displaced populations have access to more stable and livable conditions as they move toward recovery (Figure 3B).

(3) Housing: Housing structures are built during the reconstruction phase and are intended to accommodate displaced individuals or families while their permanent homes are being rebuilt. Although still categorized as shelters, housing solutions are significantly larger and more robust compared to emergency tents or transition shelters. These structures are often designed with features that provide greater comfort, privacy, and durability, making them suitable for long-term use. In some cases, housing shelters may even become permanent residences, especially in situations where reconstruction efforts face significant delays. This category represents the final stage of shelter provision, aiming to support a smoother transition back to normalcy for affected populations (Figure 3C).

The proposed research aims at presenting the State of the Art of post-emergency interventions by mainly analyzing the indoor comfort through the study of various types of recovery projects that were already implemented after disasters, as typical and efficacious solution [42]. To the best of our knowledge, in the scientific literature, there are hardly any studies facing the sustainable design applied to emergency shelters. Hence, in the case of a short-term emergency, this study is also intended to offer methodological guidelines intended to help build a reliable place and activate a positive reconstruction process both physically, socially, and culturally. This could also be achieved by evaluating the post-emergency interventions carried out according to the criteria of sustainability, comfort, environmental well-being, and durability [41].

3. Methodology

This study adopted a systematic mixed-methods approach to investigate the architectural design of emergency shelters, focusing specifically on the materials and systems employed to achieve adequate indoor comfort. The methodology was structured to integrate quantitative and qualitative components, enabling a comprehensive evaluation of the selected case studies. The process began with the identification and selection of relevant case studies. From an initial pool of over 50 emergency shelters constructed in various contexts, 12 were selected based on specific criteria. These criteria included the use of wooden structural systems; similar overall dimensions; and their geographical location within two key climatic zones, as defined by the Köppen climate classification, tropical rainy climates (Group A) and arid climates (Group B). This targeted selection ensured that the analysis was grounded in a diverse yet coherent sample, representative of differing environmental conditions and construction practices. The quantitative component of the study was conducted using the Active House Protocol, which provided a robust framework for assessing key performance indicators related to indoor environmental quality. These indicators included air quality, natural lighting, and acoustic comfort, all of which were measured and systematically correlated with the materials used and the specific climatic conditions of the shelters. In addition, field measurements and on-site observations, where feasible, were carried out to further validate the performance metrics and provide empirical grounding to the data collected. The qualitative aspect of the methodology complemented the quantitative analysis by offering insights into the broader contextual factors influencing the design and construction of emergency shelters. This component involved the review of relevant documentation, including reports from the UNHCR shelter design catalog, as well as semi-structured interviews and consultations with professionals in the field. These qualitative methods enabled a deeper exploration of the challenges associated with the selection of materials, the constraints imposed by specific project contexts, and the decision-making processes underpinning the design and implementation of these shelters. By combining quantitative data on performance with qualitative insights into the practical and contextual dimensions of shelter design, the study provided a holistic evaluation of emergency shelters. This integrated approach highlighted the dynamic interplay between materials, construction systems, and climatic conditions, emphasizing their collective role in shaping indoor comfort.

The analysis applied the Active House Protocol, selected for its holistic approach to evaluating indoor comfort, energy efficiency, and environmental impact—key factors when addressing the challenges of temporary emergency shelters. Unlike other established frameworks, such as LEED or BREEAM [43], which are primarily designed for stable contexts and require significant financial and temporal resources, the Active House Protocol stands out for its flexibility and its ability to adapt to extreme and unpredictable conditions typical of post-disaster scenarios. The choice of this protocol is particularly justified by its focus on human well-being, a critical consideration in emergency shelters where indoor environmental quality directly affects the health, safety, and recovery of occupants. Active House enables the assessment of essential parameters such as air quality, natural lighting, and acoustic performance, all of which play a pivotal role in ensuring basic comfort levels under challenging circumstances. Additionally, the methodology facilitates a direct correlation between these parameters, the climatic conditions, and the materials used in each shelter, providing a comprehensive understanding of their performance. Compared to more rigid and technically complex frameworks, the Active House Protocol offers a balanced approach that prioritizes comfort, adaptability, and sustainability, while remaining feasible for the rapid construction of temporary shelters. This choice aims to bridge the gap between technical feasibility and the pressing need to improve living conditions in

emergency shelters, presenting a solution that places the well-being of affected individuals at the center of design considerations.

3.1. Analysis Protocol Choices

To identify the most suitable solutions intended for a sustainable building design, various international protocols have been evaluated. Hence, the analyses were mainly conducted on energy performance, building and construction materials, and inner comfort. That could help in designing a high-performing building, without giving up the instances of emergency, fast execution, and people's general safety.

Among the protocols, LEED, BREEAM, Passivhaus, and NZEB were carefully considered to assess points in favor and any possible weaknesses related to the above-mentioned analyses. Each considered protocol offers different approaches to sustainability, energy efficiency, and effectiveness. Evaluated criteria include energy savings, resource efficiency, reduction of CO_2 emission, and the management of building materials.

Table 1 reports the key focus, indicators, and results/impacts associated with each protocol.

Table 1. Protocol analysis in function to sustainability (indicator: energy).

Protocol	Key Focus	Indicators	Results/Impact
LEED	Energy efficiency, sustainable site development, water savings	Energy use, water efficiency, CO_2 emissions	Recognized globally for encouraging green building practices
BREEAM	Sustainability across energy, health, materials, and pollution	Land use, energy, materials, waste, water	Widely used across Europe, incentivizes sustainable buildings
Passivhaus	Passive heating/cooling, reducing energy demand	Energy consumption for heating, insulation, airtightness	Significant reduction in heating and cooling energy needs
NZEB	Minimizing energy consumption with renewables	Renewable energy share, energy efficiency	Nearly zero energy consumption with high renewables integration
Active House	Balancing energy, comfort, and environmental impact	Comfort (light and air), energy, environment	Improved occupant well-being, applied in emergency shelters

The bibliographic analysis conducted on a dataset of 83 articles aimed to evaluate the thematic distribution and identify key contributions within the field of Active House research. All the reviewed articles focus on Active House principles, either directly applying them or integrating them into broader research contexts. The thematic categorization revealed several key areas of focus, allowing for a deeper understanding of the trends and gaps in the literature.

From the thematic analysis, it was observed that the articles primarily address the following categories:

Design-related aspects: This theme emerged as the most dominant, representing 32.5% of the articles. Examples include studies on the architectural integration of Active House principles in various climates [44] and industrial demonstrations showcasing practical applications.

Energy efficiency and solar energy: Accounting for 29.2% of the articles, this category includes studies focusing on renewable energy integration, power management, and optimizing energy consumption. For instance, "Effect of LCA Data Sources on GBRS

Reference Values" by Palumbo (2021) highlights the role of energy assessment tools in Active House projects.

Sustainability and environmental impact: Approximately 23.5% of the articles explore broader sustainability topics, such as reducing environmental impacts and life-cycle assessment (LCA) methodologies. Notable works include studies that address embedded impacts and their mitigation through Active House principles.

Analytical or computational approaches: Only 10.8% of the articles delve into computational models or analytical methods to evaluate Active House criteria. Examples include the development of simulation tools to assess energy performance and occupant comfort.

Temporary housing and emergency contexts: This theme is notably underrepresented, with only 4% of the articles addressing temporary or emergency constructions. One significant contribution is "Small is More: Wooden Pavilion as a Path of Resilient Design" [45], which aligns with Active House principles such as adaptability, energy efficiency, and minimal environmental impact.

Despite the diverse thematic coverage, a significant gap exists in the application of Active House principles to emergency shelters. None of the reviewed articles explicitly address the unique challenges of post-disaster housing, such as rapid deployment, resource limitations, and ensuring occupant well-being. This highlights a critical area for future research.

The current study bridges this gap by systematically investigating how Active House principles can be adapted to temporary wooden emergency shelters. By balancing functionality, sustainability, and comfort, the research introduces an innovative perspective to the field, offering practical insights into improving the living conditions of displaced populations in post-disaster scenarios. Only one article explores temporary constructions, specifically small pavilions, aligning with Active House principles such as adaptability, energy efficiency, and minimal environmental impact. However, this article does not address emergency contexts or temporary housing related to disasters.

From the thematic categorization of the 83 articles, 66.3% focused on design-related aspects, while 63.9% addressed energy efficiency, solar energy, or power management. Approximately 47.0% of the articles discussed broader sustainability topics, such as reducing environmental impacts or applying life-cycle assessment (LCA) methodologies. Only 31.3% examined analytical or computational approaches to evaluate Active House criteria, and a small subset, 13.3%, explored miscellaneous topics.

In the context of post-emergency shelter design, the Active House Protocol has emerged as one of the most appropriate frameworks. Distinguished by its holistic approach, it prioritizes occupant well-being through a focus on three key aspects: indoor comfort, energy efficiency, and environmental impact. Unlike protocols that concentrate solely on energy performance, Active House integrates parameters such as indoor air quality, natural light, and acoustic comfort, which are particularly crucial in the design of temporary shelters for vulnerable populations [46]. The Active House Protocol has been widely applied in various contexts to assess and improve building performance. For example, studies such as those conducted on the RhOME prototype—winner of the Solar Decathlon competition—demonstrated the protocol's capacity to optimize comfort in diverse climatic conditions [47]. By evaluating daylight penetration, thermal comfort, and air quality, the Active House framework allowed for a comprehensive performance analysis and design adjustment to improve energy efficiency while maintaining comfort standards. Similarly, the Ape Tau kindergarten in L'Aquila applied the Active House Protocol to verify the building's performance following a reverse engineering approach [48,49]. This study highlighted how the protocol can identify criticalities and opportunities in design choices, emphasizing the importance of comfort and sustainability even in post-disaster contexts.

Using tools such as dynamic simulations and the Active House Radar, the study quantified performance across parameters like daylight availability, CO_2 concentration, and operative temperature [50]. From these examples, it is evident that the Active House methodology offers a quantifiable and adaptable approach to assessing building performance, making it especially relevant in post-emergency shelter design. In this study, the Active House framework was implemented to integrate critical input data, including the following:

- Building materials and envelope properties, analyzed for their impact on thermal stability and energy performance.
- Geographical and climatic data, categorized according to Köppen classification to account for specific environmental challenges.
- Indoor comfort metrics, such as daylight levels (measured through the Daylight Factor), air quality (via CO_2 concentration), and thermal comfort (using dynamic thermal simulations).

Through this methodology, the protocol not only supports informed decision-making for material selection and passive design strategies but also provides a replicable framework for balancing technical feasibility with occupant comfort and sustainability.

3.2. Evaluation of Climatic Zones and Identification of Case Studies

When selecting the projects case studies, the climatic zone and the type of emergency shelter are the two most important factors to be considered. Depending on the local climate, different types of emergency shelters may or may not be appropriate in terms of indoor comfort [50]. In fact, not all shelters have the chance to take advantage of a variety of building materials; many are constructed using prefabricated systems, often produced by suppliers of PVC sheets and lightweight steel or aluminum frames. These systems, while quick to assemble, frequently lack the insulation and durability needed for long-term comfort. On the other hand, some shelters rely on locally sourced materials, almost always timber, and are covered with simple sheets, bamboo panels, or aluminum roofs. Such designs, though more integrated with the local context, can vary greatly in regard to performance depending on the quality of craftsmanship and material treatment [51]. The construction methods observed in the selected shelters highlight diverse approaches tailored to the resources and skills available in the respective regions. Prefabricated structures typically use modular assembly systems, with components designed for rapid deployment and minimal reliance on local labor. In contrast, shelters made with local materials often employ traditional techniques, such as wattle and daub, bamboo weaving, or timber framing, reflecting the cultural and technological context of the affected area. While these traditional methods offer a degree of environmental integration and cost efficiency, they may also result in inconsistencies in structural stability and indoor comfort if not executed properly. The choice of case studies, aimed at defining the degree of inner comfort, was based on the use of different types of wooden construction, keeping as a constant case the two climatic zones where most climatic disasters usually occur, as shown in Table 2 [44]. In selecting the final set of shelters, over 50 case studies were initially analyzed, focusing on a variety of building materials, climate zones, and shelter configurations. Out of this larger sample, a selection of 12 shelters was made based on the similarity of the materials used (mainly wood), the climatic zone, and the comparable size of the structures. The construction systems included combinations of timber framing with lightweight cladding materials (e.g., bamboo, PVC tarpaulins, or plywood) and occasionally incorporated hybrid methods, such as steel reinforcement in wooden frames. This approach allowed for a more precise and consistent evaluation of the indoor comfort levels across shelters that share these key characteristics.

Table 2. Shelters' cases of study as per climatic zone. A—rainy tropical climates; B—arid climates.

Case Study	Name	Year of Construction	Group Köppen	Location	Dimension (mq)	Ref.
1	Emergency Shelter A	2019	Group A—Tropical climates	Congo	10	[52]
2	Emergency Shelter B	2019		Congo	10	[52]
3	Lombok Shelter	2018		Indonesia	15	[52,53]
4	Kutapalong B	2017		Bangladesh	17.5	[53,54]
5	Wooden Gable Frame Shelter	2013		Sud Sudan	21	[53,55]
6	Steel Frame	2004		Vietnam	20	[52]
7	Compact Bamboo Shelter	2013	Group B—Arid climates	Ethiopia	21	[52]
8	Tuareg Tent	2012		Burkina Faso	49	[52]
9	Timber Frame A IFRC	2017		Perù	12	[52]
10	Timber Frame B IFRC	2017		Perù	12	[52]
11	Dadaab Shelter A	2000		Kenya	19	[52]
12	Dadaab Shelter B	2000		Kenya	19	[52]

The selected case studies were chosen depending on climatic zone, according to the Köppen model [51] (Figure 4, Table 3): Zone A, "rainy tropical climates"; and Zone B, "arid climates". Zone A, known as the "rainy tropical climates", is characterized by consistently high temperatures throughout the year, with monthly averages always above 18 °C. Rainfall is abundant and evenly distributed across the year, although there are variations within this zone, such as the monsoon climate, which features distinct wet and dry seasons. The humidity levels in these regions are generally high due to the significant amount of rainfall. This climate supports dense and lush rainforests with a rich diversity of plant and animal life. Within Zone A, we can identify specific subcategories like the tropical rainforest climate (Af), which experiences heavy rainfall year-round without a dry season; the monsoon climate (Am), with very intense rainfall during the wet season and a brief dry period; and the tropical savanna climate (Aw), characterized by wet summers and dry winters.

Table 3. Climate zones by Köppen.

Cod.	Description	Group	Precipitation Type	Heat Level
Af	Tropical rainforest climate	Tropical	Rainforest	
Am	Tropical monsoon climate	Tropical	Monsoon	
As	Tropical dry savanna climate	Tropical	Savanna, dry	
Aw	Tropical savanna, wet	Tropical	Savanna, wet	
BSh	Hot semi-arid climate	Arid	Steppe	Hot
BSk	Cold semi-arid climate	Arid	Steppe	Cold
BWh	Hot deserts climate	Arid	Desert	Hot
BWk	Cold desert climate	Arid	Desert	Cold

Zone B, referred to as "arid climates", is defined by very low levels of precipitation. In desert areas (BWh), annual rainfall is less than 250 mm, while in steppe areas (BSh), it can be up to 500 mm. Temperatures in these zones can vary greatly; deserts typically have extremely high daytime temperatures and can have very cold nights. Humidity levels are very low, often with evaporation rates exceeding the amount of rainfall. The vegetation in arid climates is sparse and adapted to survive with minimal water, featuring xerophytic plants. Within this zone, we find the desert climate (BW), which is extremely arid with almost no vegetation, and the steppe climate (BS), which has slightly more rainfall than deserts and can support grasslands or steppe.

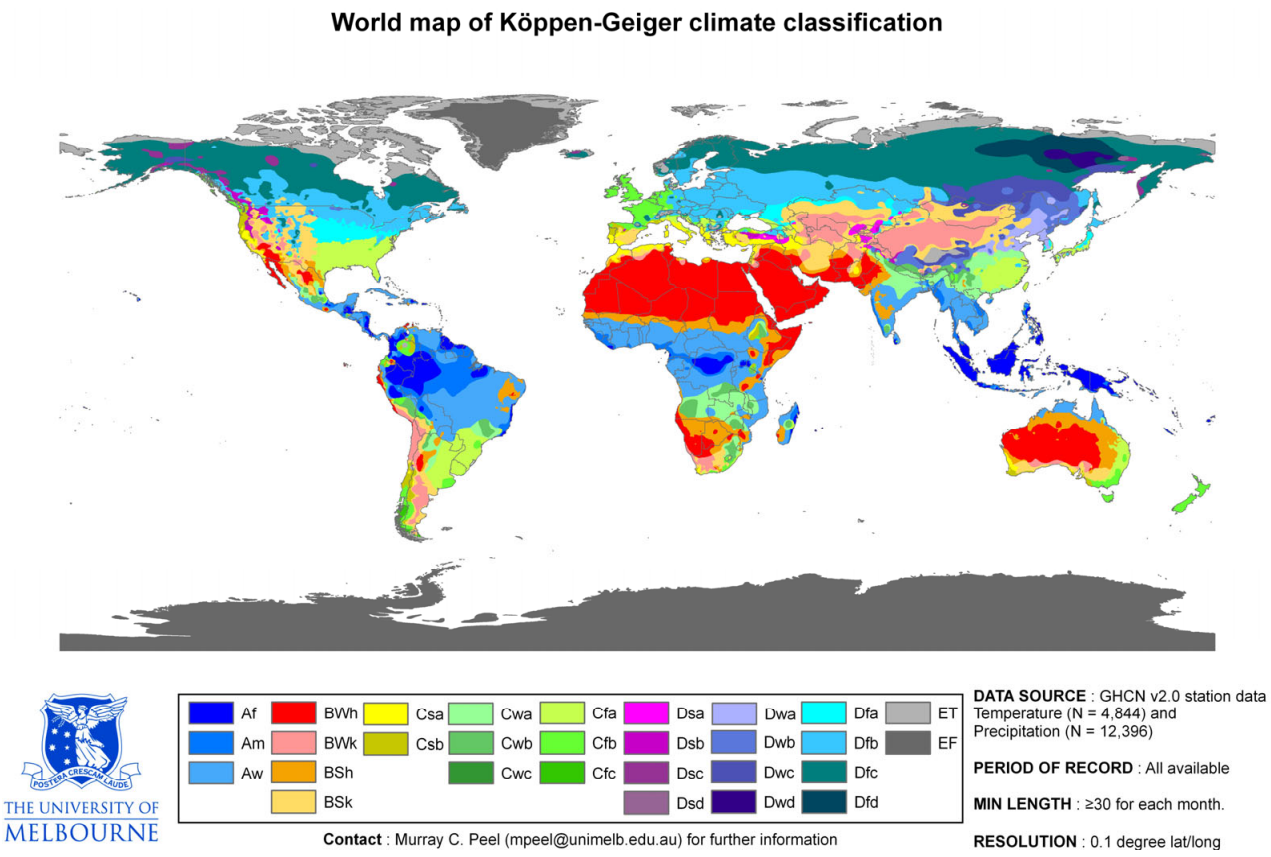

Figure 4. Climate zones by Köppen [51].

Those two zones identify the climatic areas from the equator to the tropics and are characterized by the greatest number of disastrous events linked to the climatic agents [25]. Moreover, they represent climate extremes, returning a variety of options when considering the various types of shelters.

When disasters strike and people are consequently displaced, wooden structures are usually built to provide a fast shelter. In the aftermath of the 2010 Haiti earthquake, for example, many people took shelter in wooden houses that were still standing after the quake. The same occurred after the Hurricane Matthew in 2016 in the same region. In both cases, wooden houses provided a crucial shelter to people who had lost everything.

Indeed, in the aftermath of a disaster, wood can be a vital resource for survival. Moreover, it must be considered that for many people in poor countries, such as the African ones, it represents the only option. In January 2020, UNHCR and the Ethiopian government launched a new initiative to provide compact bamboo shelters to the refugees living in camps [56]. Such action is a response to the growing needs of refugees in Ethiopia, where more than 940,000 people currently live in camps [52,57].

The initiative is providing refugees with more durable and comfortable shelter that can better withstand Ethiopia's extreme weather conditions. In fact, the compact bamboo shelters are designed to be more energy efficient than the traditional tents usually used in refugee camps [53,55].

3.3. The Active House Protocol: Evaluation of the Comfort Level

The case studies were analyzed to evaluate and discuss the comfort levels of the selected post-emergency shelters, with the aim of identifying the best solutions relative to the climatic conditions in which the structures were built. The Active House Protocol was implemented as the central framework for this analysis. Developed by a consortium of

European organizations and companies, the Active House Protocol focuses on balancing comfort, energy efficiency, and environmental impact, making it particularly relevant for this study. Unlike other frameworks, such as LEED or BREEAM, which emphasize energy performance or resource management, Active House prioritizes the well-being of occupants, addressing key factors like indoor air quality, natural lighting, and thermal and acoustic comfort. This focus on human-centered design makes the protocol especially suitable for evaluating temporary emergency shelters, where comfort often plays a secondary role to rapid deployment [48]. The choice of the Active House Protocol was primarily driven by its flexibility and adaptability to post-disaster contexts. While other frameworks are better suited for permanent structures in stable environments, Active House provides a more holistic and scalable approach, capable of addressing the unique challenges of emergency shelters. Its emphasis on indoor environmental quality aligns with the needs of displaced populations, where poor living conditions can exacerbate physical and psychological distress. The protocol's ability to incorporate climatic conditions and local material availability into the assessment process further reinforced its suitability for this study [44,58]. To apply the Active House Protocol, the research methodology integrated quantitative and qualitative data collection. Each case study was georeferenced, and relevant data were gathered on construction materials, the availability of natural light, ventilation systems, and spatial configurations. Structured field observations and interviews with professionals—such as designers, construction specialists, and NGO workers—further enriched the analysis, offering practical insights into how the shelters performed under different climatic conditions. The interviews explored aspects such as occupant satisfaction, the adaptability of the designs, and the challenges of implementing specific materials and systems in emergency contexts. The data collected were systematically analyzed through the Active House framework, which assigns a quality index to each shelter based on parameters like natural light, indoor air quality, and acoustic comfort. These results were visualized using a 9-point radar diagram, where scores ranged from 5 (lowest) to 1 (highest comfort). This approach enabled a comprehensive comparison across shelters, correlating the observed comfort levels with climatic conditions, material choices, and design strategies. The Active House assessment was instrumental in identifying the strengths and limitations of various shelter types, offering a clear understanding of how design and material decisions influenced comfort performance. By integrating the Active House Protocol into every stage of the research—data collection, analysis, and interpretation—this study ensured a structured, evidence-based evaluation of the selected shelters. The protocol provided a consistent framework for measuring comfort while emphasizing the importance of human well-being in emergency situations. Ultimately, its application highlights the need for design solutions that balance practical feasibility with the urgent requirement for improved living conditions in post-disaster scenarios. As part of the methodology we followed, the considered cases of study (cf. Table 4) served as examples to analyze the performance of buildings that could meet the Active House standards. As previously discussed, these case studies represent a variety of shelter types, including single-family houses, apartment buildings, and office buildings [59,60]. Hence, the main result of the Active House application was to understand the degree of satisfaction of people living in shelters with the offered services in comparison to the conditions of their actual conditions. To achieve that, the case structures were georeferenced. Moreover, data on the used materials, eventual presence of natural light, and the use or not of efficient a/c systems had been considered and inputted [47,61].

Table 4. Input parameters for Active House.

Case Study	Shelter	Year If Construction	Köppen Climate Classification	Structure	Envelope	Dimension (mq)
1	Emergency Shelter A	2019	Group A—Tropical climates	Wood frames	PVC tarpaulins	10
2	Emergency Shelter B	2019		Wood frames	Earthen walls	10
3	Lombok Shelter	2018		Wood frames	Bamboo strips	15
4	Kutapalong B	2017		Wood frames	Bamboo strips	17.5
5	Wooden Gable Frame Shelter	2013		Wood frames	Bamboo	21
6	Steel Frame	2004		Wood frames	Plywood	20
7	Compact Bamboo Shelter	2013		Wood frames	Bamboo	21
8	Tuareg Tent	2012		Wood frames	PVC tarpaulins	49
9	Timber Frame A IFRC	2017	Group B Arid climates	Wood frames	Bolayna	12
10	Timber Frame B IFRC	2017		Wood frames	Eucalyptus wood poles	12
11	Dadaab Shelter A	2000		Wood frames	PVC tarpaulins	19
12	Dadaab Shelter B	2000		Wood frames	Wattle and daub with straw reinforced earth	19

3.4. The Protocol Active House: Input Parameters

The Active House program considers a wide range of inputs when evaluating the performance of buildings. The implementation of the Active House protocol in this study required the systematic collection of several key input parameters, essential to evaluate the performance of emergency shelters. A primary focus was on the building and construction materials used in each case study, including timber, bamboo, plywood, and PVC tarpaulins. These were analyzed for their thermal properties, durability, and air and moisture permeability, which are crucial factors in maintaining indoor comfort. The second set of inputs concerned the climatic and geographic conditions of the shelter locations. Each case study was georeferenced, and the relevant Köppen climate classification was identified, in particular, tropical rainy (group A) and arid (group B) climates. Additionally, climatic variables such as temperature ranges, humidity levels, and solar exposure were incorporated into the analysis to understand their influence on thermal regulation and ventilation [62]. Another critical aspect was the design of the building envelope, which included data on the size, placement, and orientation of openings, such as windows, doors, and ventilation systems. These features were assessed for their role in facilitating natural light penetration, improving air circulation, and ensuring thermal stability within the shelters. The insulation properties of the envelope were also taken into account, as they play a key role in reducing heat loss or gain depending on the climate context. The program developed Indoor Environmental Quality (IEQ) parameters, including air quality, natural lighting, and thermal comfort, after entering the input data. Ventilation rates and airflow efficiency were measured to assess air quality, while natural light levels were quantified using the Daylight Factor (DF) method derived from information given based on plans and models found in catalogs. The thermal conditions of each shelter were assessed based on the performance of the envelope, in particular, its ability to mitigate extreme temperatures and maintain a stable indoor environment [47,51].

Through a series of structured interviews with over 20 professionals—including industry experts, NGO workers, and local construction specialists—alongside surveys and consultations, critical data were collected to inform the analysis.

The interviews were designed to gather insights into key aspects such as material availability, construction techniques, shelter performance under various climatic conditions, and occupant feedback (cf. Table 5). The participants were carefully selected to represent diverse perspectives, including designers, project managers, and field operatives involved in the implementation of emergency shelters. A semi-structured format was adopted to ensure consistency across interviews while allowing for in-depth exploration of specific challenges. Key topics included the adaptability of shelter designs, the effectiveness of materials in different climatic zones, and logistical constraints in emergency contexts. Open-

ended questions encouraged detailed responses, while more targeted questions facilitated comparisons across regions and case studies.

Table 5. Stakeholder category summary.

Category	Role/Expertise	Number of Participants	Description
Industry experts	Architects, engineers, designers	7	Professionals specializing in shelter design and materials.
NGO stakeholders	Project managers, field coordinators	6	NGO representatives managing shelter implementation.
Local construction specialists	Builders, craftsmen, contractors	5	Experts with local knowledge of construction techniques.
Policy advisors	Planners, logistics coordinators	2	Advisors on policy, logistics, and resource allocation.

These interviews, complemented by survey data and consultations, provided a nuanced understanding of the practical challenges associated with emergency shelter construction. The insights gathered were instrumental in evaluating the performance of the selected shelters, enabling a critical assessment of their suitability across varying climatic conditions and construction methods.

Consequently, the case studies were selected to represent a broad spectrum of scenarios, providing a robust basis for assessing the energy efficiency and health-related performance of buildings, as well as for validating the Active House Protocol [36]. By integrating a range of variables that differ among shelter types, Active House ensures that the buildings evaluated are appropriately designed for their specific climatic context and intended function.

The analysis was conducted on a wide range of projects, as shown in Table 4, useful to evaluate the performance of various building envelopes when located in different climatic zones. More particularly, projects located in different climatic regions, including temperate, tropical, and arid zones, had been used to ensure that the analysis results were relevant and applicable to a wider range of situations [51]. By examining a variety of building types and envelope materials in different locations, Active House was able to provide valuable insights into the performance and suitability of different building techniques and materials in different contexts [58].

One of the key inputs, extremely variable among the different shelter types, is the size and layout of the buildings themselves. In addition, the type of shelter also affects the type of heating and cooling systems, as well as the insulation layers, and the installed windows. Another fundamental input is the location of the building. Different climates and weather patterns show a significant impact on a building's energy efficiency and users' comfort, so it is important to consider the specific climatic conditions when designing a building and evaluating its performance. In any case, all the case studies were chosen to provide a diverse range of examples useful to analyze the performance of energy-efficient and healthy buildings and—also—test the Active House Protocol [62]. By pondering the various input values, which can vary among the different shelter types, Active House helps to ensure that the evaluated buildings are suitable for the specific considered location and use.

4. Results and Discussion

The Active House program evaluated the comfort level of the chosen post-emergency shelters through three main parameters: (1) natural light, (2) indoor air quality, and (3) acoustic quality, giving a rating of 5 to 1, which is the highest rating. The Active House program highlighted that conventional post-emergency shelters often do not provide an adequate level of comfort for occupants. These shelters, designed primarily to meet basic needs, such as shelter from outdoor elements, lack essential amenities for long-term living, such as adequate heating, ventilation, and lighting. Active House was run, and results are shown in Table 6 for group A and Table 7 for group B (cf. Table 4).

Table 6. Active house group A results.

n.	Shelter	Daylight Quality	Indoor Air Quality	Acoustic Quality
1	Emergency Shelter A	4	5	3.7
2	Emergency Shelter B	3	5	3.5
3	Kutapalong B	3.8	3	3.5
4	Wooden Gable Frame Shelter	2	3	3.7
5	Steel Frame—Vietnam	3	3	3.5
6	Lombok Shelter	4	3	3.5

Table 7. Active House group B results.

n.	Shelter	Daylight Quality	Indoor Air Quality	Acoustic Quality
7	Compact Bamboo Shelter	4.2	4	3.5
8	Tuareg Tent	4	5	3.5
9	Timber Frame A IFRC	2	5	3.5
10	Timber Frame B IFRC	4	2	3.5
11	Dadaab Shelter A	4	3	3.7
12	Dadaab Shelter B	4	5	3.7

The main results obtained from the Active House program have shown that the usual post-emergency shelters often fail to provide an adequate level of comfort for the occupants. In fact, these shelters are often designed to meet only the most basic needs, such as providing a roof over the head and protection from the external elements (cold, rain, snow, etc.). As a result, they completely lack the comforts and features necessary for long-term living, such as adequate heating, ventilation, and lighting.

The results of the shelters of group A are shown in Table 4 and Figure 5 and returned the best values for cases no. 4 and no. 5, namely the Wooden Gable Frame Shelter (Figure 5D) and the Steel frame Vietnam (Figure 5E). The other shelters analyzed showed significant deficiencies in terms of natural light, indoor air quality, and acoustic quality, such as cases 1, 2, and 6 (Figure 5A,B,F), because they designed shelters with windows sized correctly for the internal surface. Emergency Shelter A (Figure 5A) has poor natural light, making the interior quite dark and heavily reliant on artificial lighting. The air quality is very poor, indicating significant ventilation issues that could negatively impact the health of the occupants. Additionally, the shelter's acoustic quality is below average, with noticeable noise levels that could disturb residents. The Emergency Shelter B (Figure 5B) provides mediocre natural light, offering sufficient illumination but still needing improvement. Like Shelter A, it suffers from very poor indoor air quality, indicating serious ventilation problems. The acoustic quality is also below average, suggesting some noise issues that might affect comfort. Kutapalong B (Figure 5C) has quite poor natural light, which is not

ideal for the well-being of the occupants. The indoor air quality is mediocre, meaning that it is sufficient but with room for improvement. The acoustic quality is below average, with noise levels that could be bothersome. The Wooden Gable Frame Shelter (Figure 5D) has good natural light, which positively contributes to the indoor environment. However, the indoor air quality is mediocre, indicating that ventilation could be improved. The acoustic quality is below average, with noise levels that might disturb the occupants. The Steel Frame shelter (Figure 5E) in Vietnam offers mediocre natural light, indicating a need for additional artificial lighting. The indoor air quality is also mediocre, suggesting that improvements in ventilation are necessary. The acoustic quality is below average, with potential noise problems. The Lombok Shelter (Figure 5F) has poor natural light, necessitating more artificial lighting. The indoor air quality is mediocre, indicating a need for better ventilation. Additionally, the acoustic quality is below average, with noise issues that could impact comfort. Due to the absence of insulating materials inside the casing of these shelters, in almost all group A shelters, the acoustic quality is medium–low.

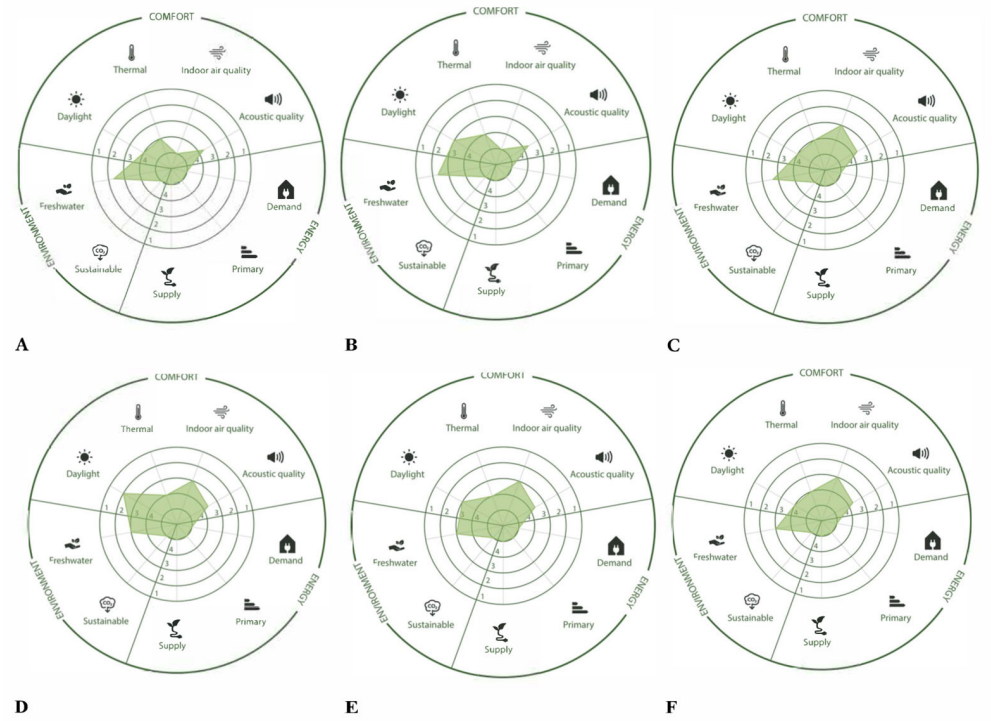

Figure 5. Active House radar, results for group A—tropical climate: (**A**)—Emergency Shelter A; (**B**)—Emergency Shelter B; (**C**)—Kutapalong B; (**D**)—Wooden Gable Frame Shelter; (**E**)—Steel Frame—Vietnam; (**F**)—Lombok Shelter.

Table 6 (Figure 6) shows the results for the shelters of group B. In general, it can be observed that the resulting quality scores are slightly higher than the shelters of group A. Among these, the IFRC Timber Frame A (no. 9, Figure 6C) obtained a good score, as it has an excellent light ratio due to its structure, the materials used, and the air circulation, also thanks to the numerous openings in the envelope.

In the case of the Compact Bamboo (no. 7, Figure 6A) it was found that the absence of openings in the room provided a poor ventilation result. Only for comparative reasons, in the Wooden Gable Frame (n. 4), it was observed that the presence of openings provided a good level of internal air comfort.

The analyses of the two groups behave in the same way; the different Koppen zone does not significantly affect the result. There are slight differences related to the different shapes of the shelters and the presence, for example, of proportionate windows, as in the

case of no. 9 (Figure 6C) or no. 4 (Figure 5D), which affects the presence of natural light and clean air.

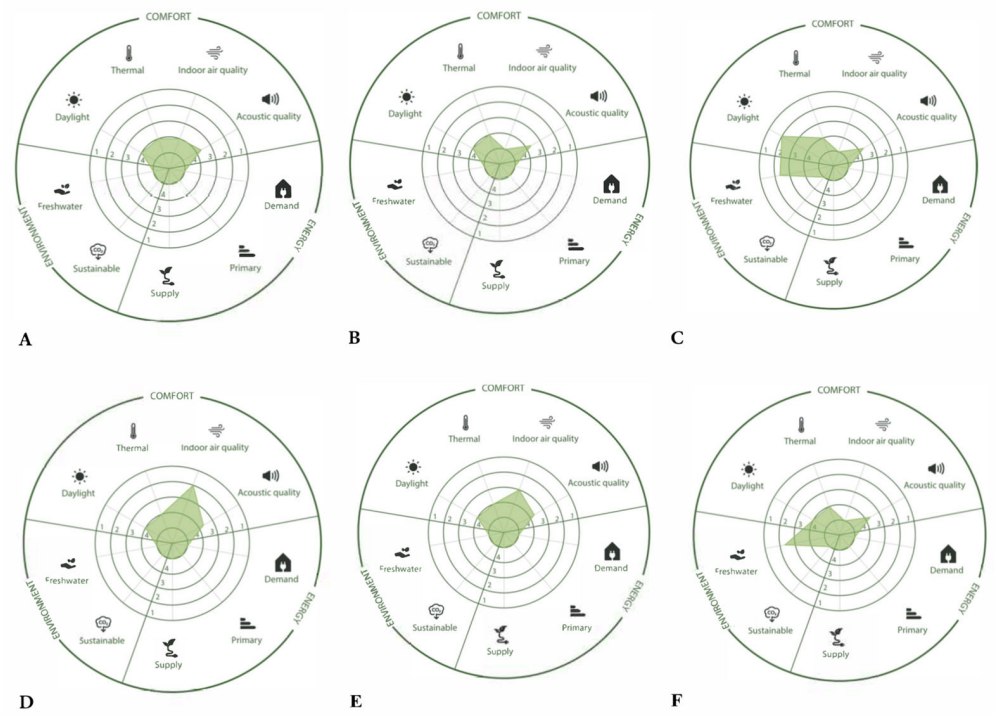

Figure 6. Active House radar group B results: (**A**) Compact Bamboo Shelter, (**B**) Tuareg Tent, (**C**) Timber Frame A IFRC, (**D**) Timber Frame B IFRC, (**E**) Dadaab Shelter A, and (**F**) Dadaab Shelter B.

The Compact Bamboo Shelter (Figure 6A) has quite poor natural light, leading to a dim interior that heavily relies on artificial lighting. Its indoor air quality is below average, suggesting that improvements in ventilation could enhance air circulation. Additionally, the acoustic quality is below average, indicating potential noise issues that might affect comfort. The Tuareg Tent (Figure 6B) also suffers from poor natural light, which means it relies on artificial lighting. The indoor air quality is very poor, signaling serious ventilation problems that could harm the occupants' health. The acoustic quality is below average, with noise levels that could disrupt those inside.

Timber Frame A IFRC (Figure 6C) benefits from good natural light, creating a well-lit environment and reducing the need for artificial lighting. However, the indoor air quality is very poor, pointing to major ventilation issues. The acoustic quality is below average, with noise control problems that could be bothersome. In contrast, Timber Frame B IFRC (Figure 6D) has poor natural light, necessitating additional artificial lighting. The indoor air quality is good, indicating effective ventilation systems. However, the acoustic quality is below average, with some noise disturbances that could be problematic.

Dadaab Shelter A (Figure 6E) has poor natural light, likely resulting in a dim interior that relies on artificial lighting. Its indoor air quality is mediocre, meaning it is adequate but could be improved. The acoustic quality is below average, with noticeable noise levels that could disturb residents.

Dadaab Shelter B (Figure 6F) also has poor natural light, implying a dependence on artificial lighting. Its indoor air quality is very poor, reflecting significant ventilation issues. The acoustic quality is below average, with noise levels that may disrupt occupants.

A key issue identified through the Active House simulations is the lack of thermal comfort in the majority of the selected shelters. This deficiency is predominantly attributed to the use of inappropriate materials and technologies that are ill-suited to the specific climatic conditions of the locations. Additionally, the absence of adequate insulation and/or

ventilation systems exacerbates this problem. These shortcomings lead to significant temperature fluctuations and drafts, which not only cause discomfort for the occupants but also make it challenging to maintain a stable indoor temperature. Such variability in thermal conditions undermines the overall habitability of the shelters, particularly in extreme climates.

Another critical problem revealed by the study is the poor indoor air quality observed in many shelters. This issue is likely caused by the use of construction materials that may release harmful chemicals into the air, coupled with a lack of proper ventilation systems and the absence of air filtration mechanisms. Inadequate air exchange and the accumulation of airborne pollutants can have serious consequences for the health and well-being of occupants, particularly those with respiratory conditions or allergies. This underscores the importance of selecting non-toxic materials and incorporating effective ventilation and filtration systems in shelter design.

Despite these challenges, some positive differences were noted in the shelters that emphasized the use of natural lighting and strategically placed openings for ventilation. These features not only improved indoor air circulation but also allowed for the reuse of air within the shelters, contributing to a healthier and more comfortable indoor environment. The integration of such design elements demonstrates the potential for addressing these issues when materials, technologies, and climatic considerations are thoughtfully aligned.

Overall, the findings highlight the critical need for climate-appropriate materials, adequate insulation, and ventilation strategies to improve both thermal comfort and indoor air quality in emergency shelters. Addressing these issues is essential for ensuring the health, well-being, and comfort of shelter occupants, particularly in post-disaster scenarios, where such considerations are often overlooked.

The best results were obtained by shelters with openings beyond the entrance doors and those designed with a more resistant and more comfortable shell (Figures 5D,E and 6D), also for external sounds and privacy. Shelters without windows received the lowest scores, and shelters with lighter materials (wood and bamboo) received a low comfort rating. Group B shelters (Koppen B) showed more favorable results, probably due to their adaptation to slightly higher temperatures. These shelters were designed with minimal air exchange and ample exposure to sunlight, like no. 7 and no. 9 (Figure 6A–C). These factors, combined with the choice of construction materials, contributed to slightly higher overall comfort levels. Ranking of the compromise solution(s) is shown in Table 8.

Table 8. Compromise solution from Active House Protocol.

Rank	Shelter	Daylight Quality	Indoor Air Quality	Acoustic Quality
1	Timber Frame A IFRC	2.0	5	3.5
2	Wooden Gable Frame Shelter	3.0	3	3.7
3	Steel Frame Shelter (Vietnam)	3.0	3	3.5
4	Dadaab Shelter B	4.0	5	3.7
5	Dadaab Shelter A	4.0	3	3.7
6	Compact Bamboo Shelter	4.2	4	3.5
7	Tuareg Tent	4.0	5	3.5
8	Lombok Shelter	4.0	3	3.5
9	Kutapalong B	3.8	3	3.5
10	Emergency Shelter A	4.0	5	3.7
11	Emergency Shelter B	3.0	5	3.5
12	Timber Frame B IFRC	4.0	2	3.5

5. Economic Assessment ID the Various Scenarios

The economic evaluation of the selected emergency shelters reveals a range of costs that vary significantly depending on the construction materials, dimensions, and climatic context where they are built. By analyzing the shelters features, and taking information from the UNHCR, it is possible to observe that the "cost per square meter" can serve as a useful metric to evaluate both the economic feasibility and the suitability of these solutions in different disaster scenarios.

Among the lowest-cost solutions are the Emergency Shelter A and Emergency Shelter B, both located in the Congo, with an average cost of USD 42 per square meter. Despite their affordability, these shelters rank extremely poorly in terms of indoor comfort, particularly considering the daylight and indoor air quality, which are critical factors for the well-being of occupants. While cost-effectiveness is an important factor, it is clear from the ranking that these shelters offer limited benefits in terms of comfort.

Conversely, higher-cost shelters such as the Steel Frame Shelter, realized in Vietnam, with a cost of USD 100 per square meter, offer better overall performance, especially in terms of structural durability and potential for long-term use. However, even with a higher price, the performance of this shelter type, in terms of indoor comfort, still shows room for improvement, particularly in areas like natural lighting.

The Wooden Gable Frame Shelter (South Sudan) and the Compact Bamboo Shelter (Ethiopia), both priced at around USD 70–75 per square meter, demonstrate a balanced performance with an acceptable cost. These shelters, despite being more expensive than the simpler alternatives, offer better indoor air quality and greater resilience due to the choice of materials and design. In particular, the former—which ranks second in terms of comfort—represents an optimal compromise between cost and performance.

At the upper end of the price range, the Dadaab Shelters in Kenya and the Timber Frame Shelters in Peru, whose cost ranges between USD 60 and USD 85 per square meter, provide a relatively modest indoor comfort performance compared to their cost. Although these shelters perform well in terms of air quality and ventilation, their overall comfort ranking is lower due to limitations in natural light and acoustic properties.

Interestingly, the Tuareg Tent, priced at USD 10 per square meter, stands out as an extremely low cost solution in arid climates. Despite its affordability, it ranks moderately in terms of comfort, particularly excelling in air quality, thanks to the natural ventilation properties inherent in its design. Overall, this is an extremely valuable solution for this climatic region.

Combined Performance and Cost Analysis

From a broader perspective, it is clear that the cost alone is not a definitive indicator of performance. Some lower-cost shelters, such as the Compact Bamboo Shelter, manage to balance affordability with reasonable indoor comfort, while some higher-cost solutions, such as the Dadaab Shelters, do not necessarily outperform less expensive options in all categories.

The ranking based on the Active House Protocol highlights that comfort factors such as daylight quality and indoor air quality are not solely dependent on the materials used or the price of the shelter. For example, the Timber Frame A IFRC Shelter, despite having a mid-range cost, ranks highest overall in terms of comfort due to its thoughtful design and efficient use of materials to optimize air circulation and natural light (Table 9).

In conclusion, the economic evaluation of the shelters emphasizes the need for a holistic approach in post-disaster shelter design. While affordability is a key consideration, the long-term well-being and comfort of occupants must be prioritized. The results suggest that mid-range shelters, such as the Wooden Gable Frame Shelter and the Compact Bamboo

Shelter, offer a well-rounded solution by balancing cost and performance, particularly in areas prone to recurring climatic disasters.

Table 9. Cost analyses of the various considered shelters.

Case Study	Name	Year of Construction	Köppen Climate Group	Location	Dimension (m^2)	Cost	Year Built
1	Emergency Shelter A	2019	Group A—tropical	Congo	10.0	USD 42,000	2019
2	Emergency Shelter B	2019	Group A—tropical	Congo	10.0	USD 42,000	2019
3	Lombok Shelter	2018	Group A—tropical	Indonesia	15.0	USD 100,000	2018
4	Kutapalong B	2017	Group A—tropical	Bangladesh	17.5	USD 50,000	2017
5	Wooden Gable Frame Shelter	2013	Group A—tropical	South Sudan	21.0	USD 150,000	2013
6	Steel Frame Shelter	2004	Group A—tropical	Vietnam	20.0	USD 200,000	2004
7	Compact Bamboo Shelter	2013	Group B—arid	Ethiopia	21.0	USD 100,000	2013
8	Tuareg Tent	2012	Group B—arid	Burkina Faso	49.0	USD 50,000	2012
9	Timber Frame A IFRC	2017	Group B—arid	Peru	12.0	USD 100,000	2017
10	Timber Frame B IFRC	2017	Group B—arid	Peru	12.0	USD 100,000	2017
11	Dadaab Shelter A	2000	Group B—arid	Kenya	19.0	USD 80,000	2000
12	Dadaab Shelter B	2000	Group B—arid	Kenya	19.0	USD 80,000	2000

6. Conclusions

The Active House system has proven effective even in these scenarios, emphasizing the importance of sustainability and occupant well-being in emergency shelter design. However, a critical analysis of the theoretical framework reveals both strengths and limitations in its application to emergency contexts. While the protocol excels in its holistic evaluation of energy efficiency, indoor comfort, and environmental impact, it was originally developed for permanent residential structures rather than temporary shelters. This raises questions about its adaptability to the specific constraints and priorities of post-disaster scenarios, such as rapid deployment, limited resources, and extreme climatic conditions.

In particular, the evaluation criteria of Active House, such as acoustic quality and energy efficiency, while relevant, may need recalibration for temporary shelters, where factors like durability, scalability, and local material availability often take precedence. Moreover, a comparison with other protocols, such as LEED and Passivhaus, underscores the unique focus of Active House on occupant comfort. However, these competing frameworks offer valuable insights into alternative metrics that could enhance the evaluation of emergency shelters, such as the embodied energy of materials or the carbon footprint of construction processes.

The shelters located in climate Zone A (characterized by harsh, cold winters and significant precipitation) performed worse than those in climate Zone B (known for its hot, dry summers and mild winters). This discrepancy can be attributed to differences in design and construction practices tailored to each region's climate. Shelters in climate Zone B appeared to adhere more closely to minimum standards for air turnover and insulation, driven by the necessity to manage higher temperatures effectively. This observation highlights a critical gap in the theoretical framework: the need for a more dynamic approach that adjusts design priorities based on climatic and contextual variables.

This study offers a novel application of the Active House Protocol to the design and evaluation of emergency shelters, demonstrating its adaptability and effectiveness in addressing indoor comfort within post-disaster scenarios. By correlating comfort parameters—such as natural light, air quality, and thermal stability—with specific climatic conditions and locally available materials, the analysis highlights a structured approach to assessing and improving shelter performance.

A significant insight gained is the identification of wooden structures as versatile and efficient solutions for tropical and arid zones when coupled with materials that enhance

thermal regulation and air flow. This addresses a critical gap in current research, where indoor environmental quality in temporary shelters often receives insufficient attention. Unlike traditional evaluation frameworks, the Active House Protocol enabled a quantitative assessment of comfort factors, providing a clear benchmark for performance that can be replicated in similar contexts.

Moreover, this study advances knowledge in the field of emergency shelter design by emphasizing the necessity of integrating human-centered metrics (such as occupant well-being) with practical considerations, including rapid constructability, cost-efficiency, and local material reuse. Specifically, the findings suggest that shelters incorporating passive strategies for ventilation and lighting perform significantly better in ensuring both comfort and sustainability, particularly in resource-limited environments.

Future research will build upon these findings by expanding the analysis to additional climatic zones, including cold regions, where thermal performance becomes critical. Furthermore, the exploration of alternative materials—such as clay, straw, or reused local waste—will enhance sustainability while addressing cost challenges. The development of a more refined framework, tailored to emergency contexts, will focus on balancing speed of deployment, climatic adaptability, and environmental responsibility.

In conclusion, this study demonstrates that a people-centered approach, grounded in the Active House Protocol, can provide a practical and replicable methodology for designing emergency shelters. By bridging the gap between technical performance and human comfort, this research contributes to the ongoing development of evidence-based guidelines for post-disaster reconstruction, ultimately improving the well-being of displaced communities and advancing the field of sustainable shelter design.

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