

T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL
THE DEPARTMENT OF ARCHITECTURE
MASTER PROGRAM IN ARCHITECTURE

**A SUSTAINABLE APPROACH TO TEMPORARY ACCOMMODATION
PROVISION FOR MIGRANTS: THE ZAATARI CAMP CASE**



MASTER'S THESIS

ARMIN FARSHAD

ISTANBUL 2025

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

A SUSTAINABLE APPROACH TO TEMPORARY ACCOMMODATION PROVISION FOR MIGRANTS: THE ZAATARI CAMP CASE

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The rising number of displaced populations due to natural disasters, conflict, and climate change highlights the urgent need for better refugee shelters. Current camps often suffer from poor design, inadequate materials, and low comfort, worsening both social and environmental conditions. As with shelters, there is a growing emphasis on adopting sustainable design approaches to address these challenges, aiming to enhance discomfort hours, embodied CO₂, operational CO₂, and total primary energy use of migrant camps and shelters. Focusing on a typical shelter from Zaatari Refugee Camp (ZRC) as a base case, this study analyzed the existing condition of accommodations for conducting its thermal comfort, Life Cycle Assessment (LCA), and energy efficiency. Fourteen plan layouts were developed by altering design elements, including envelope materials, insulation, Window-to-Wall Ratio (WWRs), shading, and window opening rate.

DesignBuilder optimization produced 63,154 iterations, resulting in 243 optimal designs. Two Multi-Criteria Decision-Making (MCDM) methods—Pareto Optimal and Equal Weighted Decision Making (EWDm)—were applied to identify the best options. The study found that replacing Zinc with Hardwood and adding 9 cm of XPS insulation significantly reduced embodied CO₂. Among all layouts, the Linear-shape plan Li1-3 emerged as the most effective. Compared to the base case, it achieved a 44.48% reduction in discomfort hours, 69.46% in LCA impact, 84.55% in embodied CO₂, 40.44% in operational CO₂, and 60.09% in total primary energy use. These findings confirm that optimizing shelter design and materials greatly enhances

performance, improves thermal comfort, and reduces environmental impact and energy use in refugee camps.

Keywords: Thermal Comfort, Sustainable Temporary Accommodation, Life Cycle Assessment (LCA), Optimization, Decision Making



ÖZET

MÜLTECİLERE GEÇİCİ BARINMA SAĞLANMASINA YÖNELİK SÜRDÜRÜLEBİLİR BİR YAKLAŞIM: ZAATARI KAMPI ÖRNEĞİ

Armin, Farshad

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Küresel ölçekte göç etmek zorunda kalan insan topluluklarının ve dolayısıyla mülteci kamplarının sayısının artışı; doğal afetler, siyasi çatışmalar ve iklim değişikliği gibi faktörlerden kaynaklanarak acil bir sorunu gözler önüne sermektedir. Yetersiz planlanmış, sürdürülebilir olmayan kamplar ve barınaklar—kötü tasarım, uygun olmayan malzemeler, yetersiz yalıtım, kısa ömür ve düşük konfor standartlarıyla—mültecilerin yaşam kalitesini düşürmekte, sosyal ve çevresel sorunları derinleştirmektedir. Bu sorunlara çözüm bulmak amacıyla sürdürülebilir tasarım yaklaşımları sunan çalışmalar artmaktadır. Bu çalışmalar, mülteci kamplarındaki barınakların termal konforunu, gömülü ve işletim CO₂ salınımını ve birincil enerji kullanımını iyileştirmeyi amaçlamaktadır.

Bu çalışma, bir barınağı örneklem durum olarak ele alarak, Zaatarı Mülteci Kampı'ndaki konaklama koşullarını termal konfor, yaşam döngüsü ve enerji verimliliği açısından değerlendirmiştir. İyileştirme amacıyla yapı kabuğu malzemeleri, yalıtım, pencere-duvar oranları, gölgeleme elemanları ve pencere açıklıkları gibi değişkenlerle on dört plan şeması önerilmiştir. DesignBuilder optimizasyon algoritması kullanılarak, bu senaryolar toplam 63.154 iterasyonla değerlendirilmiş ve 243 optimal tasarım elde edilmiştir.

İki çok kriterli karar verme yöntemi—Pareto optimal ve eşit ağırlıklı karar verme—uygulanarak yapılan analizlerde, çinkonun ahşapla değiştirilmesinin (9 cm XPS yalıtımı ile) gömülü CO₂ salınımını önemli ölçüde azalttığı tespit edilmiştir. Lineer plan şeması (Li1-3), ideal tasarım olarak öne çıkmış ve temel örneklem ile

karşılaştırıldığında; termal konforda %44,48, yaşam döngüsünde %69,46, gömülü CO₂'de %84,55, işletim CO₂'de %40,44 ve toplam enerji kullanımında %60,09 iyileşme sağlamıştır. Bu analizler, malzeme ve tasarım optimizasyonunun barınak performansını artırarak çevresel etkileri ve enerji tüketimini azalttığını göstermektedir.

Anahtar Kelimeler: Termal Konfor, Sürdürülebilir Geçici Konaklama, Yaşam Döngüsü Değerlendirmesi, Optimizasyon, Karar Verme





To People Who Have Supported Me

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
BBBC	Bag Box Building Cloud
CG	Cellular Glass
DM	Decision Making
DNSR	Direct Normal Solar Radiation
EPS	Expanded Polystyrene
EPW	Energy Plus Weather (File)
ESE	East-Southeast
EWDM	Equal Weighted Decision Making
GW	Glass Wool
LCC	Life Cycle Cost
MCDM	Multi Criteria Decision Making
MOEAs	Multi Objective Evolutionary Algorithms
NGOs	Non-Governmental Organizations
NNE	North-Northeast
NSGA-II	Non-dominated Sorting Genetic Algorithm II
PMV	Predicted Mean Vote
QSAND	Quantifying Sustainability in the Aftermath of Natural Disasters
RCs	Refugee Camps
RW	Rock Wool
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UN	United Nations
UNHCR	United Nations High Commissioner for Refugees
WNW	West-Northwest
WSM	Weighted Sum Model
XPS	Extruded Polystyrene
ZRC	Zaatari Refugee Camp

Chapter 1

Introduction

In recent history, migration has experienced overwhelming challenges in adaptation, and modern society is witnessing a heightening of mobility. In recent practice, migrant accommodation is usually the rapid construction of tents and prefab buildings, which are expedient to erect but do not withstand the test of time and are environmentally harmful in terms of uncontrolled energy consumption and high carbon emission due to using unsustainable materials. Regarding this issue, the world presents a diverse situation whereby short-term camps transform into semi-permanent locations lacking adequate quality of life and sustainability.

Temporary accommodation services are essential as they offer security, a roof, and a measure of dignity in times of trouble. These accommodations are not only about sheltering people from the harsh conditions of weather but also serve as gateways to engage with the community, maintain health care, and foster a sense of belonging within the host community when migrants are displaced.

Sustainable approaches ensure that the environmental impact is minimized, resources are utilized with maximum efficiency, and the social and economic fabric of both the host and migrant communities are positively reinforced. Additionally, sustainable practices help temporary accommodations to be easily adaptable or repurposed, lowering wastage and promoting an immediate response to the changing dynamics of migration patterns. Therefore, strategic designs should focus on addressing particular climatic issues to improve the situation. Passive cooling methods, efficient ventilation, shading elements, and suitable construction materials can be incorporated. (Ziersch et al., 2017)

The current global landscape of migrant accommodation, characterized by an urgent need for temporary housing solutions, calls for a deeper understanding of sustainable practices. This thesis navigates through this complex terrain, evaluating the temporary accommodation types and provisions and their interaction with environmental and social sustainability factors. It explores how to meet the immediate

needs of migrants while also laying the groundwork for the future, a sustainable transition for the period of accommodation, and being environmentally friendly. Through an investigation of existing literature, analysing an existing shelter case at Zaatari Refugee Camp, design proposals, and application of MCDM methods, the study significantly contributes to the existing sustainable methods and optimization within short-term accommodation for migrants. It advocates for a future where the provision of migrant accommodation prioritizes not only shelter but also environmental and social sustainability, marking a transformative shift in the approach to humanitarian aid and migration management.

1.1 Problem Statement

The Zaatari Refugee Camp, located in Mafraq, Jordan, is home to thousands of displaced individuals who have fled from conflicts, primarily from Syria. Most camp housing has been constructed with tents or iron containers (Dalal, 2022). It is analyzed through the lens of the UN 2030 Agenda, revealing failure to achieve environmental and social sustainability. In Zaatari, unauthorized modifications of dwellings—such as combining containers and building indoor facilities—highlight social unsustainability issues (Wardeh & Marques, 2021). Such accommodations are usually made up of non-renewable materials or materials that do not help energy consumption, thermal comfort, and carbon emissions. Currently, container shelters at Zaatari Refugee Camp face significant challenges due to poor thermal insulation and inadequate ventilation. Moreover, the reliance on an LPG gas heater (La Rose, 2021) combined with unsuitable envelope materials results in uncomfortable indoor temperatures throughout both summer and winter. As a result, these shelters tend to experience high indoor temperatures during the summer and inadequate warmth in the winter, leading to discomfort and adverse health effects (Moran et al., 2021; Wardeh and Marques, 2021).

The shelters at Zaatari Refugee Camp are built using materials that contribute to a significant environmental impact over their life cycle (Tiwari et al. 2023). Current construction practices lack comprehensive life cycle assessments (LCAs). The use of carbon-intensive materials, such as zinc sheets and limited insulation, increases the camp's overall carbon footprint and contributes to unsustainable resource

consumption. Without proper LCA integration, the shelters' environmental impact is exacerbated, highlighting the need for more sustainable design and material choices that reduce embodied and operational carbon emissions and improve overall environmental sustainability.

1.2 Research Questions

The focal point of this study is to provide sustainable temporary accommodation for migrants by studying the existing case of the Zaatari camp. It investigates sustainable design methods to optimize the indoor comfort of migrants' camps and decrease the environmental impact. Within the scope of this study, the research examines the topic based on the following questions:

- (a) What is the current thermal comfort, environmental impact, and total primary energy use level in Zaatari Refugee Camp?
- (b) How do material selection and design configurations impact the sustainability and performance of temporary shelters?
- (c) How does the life cycle assessment (LCA) change with different design configurations and material combinations of shelters over 30 years?

1.3 Purpose of the Study

The purpose of this study is to explore and re-evaluate a temporary accommodation for migrants through a sustainability-subjected approach to improve the environmental and social atmosphere. Given the urgency of the global migration crisis and the pressing need to offer habitable and environmentally conscious housing solutions, this research aims to investigate both the building scale of the migrants' camp, the viability of sustainable construction materials, their adaptability and suitability to living comfort standards and minimize the environmental impacts aligning with migrants' social and climatic contexts.

The research intends to bridge the gap between temporary housing needs and sustainable design, considering environmental sustainability, and social adaptability. It explores how traditional and local materials can be reinterpreted and utilized in modern construction to meet contemporary needs. Through a detailed analysis of historical and present models, the research will synthesize new design strategies for

temporary accommodations that are environmentally friendly, and socially inclusive. Finally, this thesis aims to generate a concrete analytical design method and propose a sustainable short-term accommodation principle that maintains relevance for policymakers, resource organizations, and architects.

1.4 Scope of the Study

This study develops a sustainable approach to migrants' temporary accommodation, focusing on the typical hot-arid climate region and the Zaatari refugee camp in Jordan as a case study. The investigation explores the broader applicability of sustainable design principles and sets boundaries through precise criteria to promote a complete examination. The geographical and contextual aspect of this study concentrates on the unique challenges and potentials of the hot-arid environment of Jordan that can be applied to similar temporary accommodations within comparable climates. The current accommodation set-up of the Zaatari camp, predominantly composed of prefab containers, serves as a basis for analysing existing conditions. Thermal comfort and environmental impacts are the main focus of the analysis of the case study that delves into the integration of sustainable practices within the existing fabric of the Zaatari camp, specifically about energy efficiency, thermal comfort, and carbon emissions, as these pertain to temporary housing structures.

By utilising the passive and sustainable design methods and standards for the living comfort of migrants, an energy model of the proposed designs will be evaluated by DesignBuilder software to provide a comparative analysis of the current accommodations against proposed scenarios developed in this research. Passive and sustainable design methods are specialized to address the crucial comfort demands and limit ecological harm and the carbon footprint, including fourteen dwelling plan layouts, envelope materials, insulation thicknesses, WWRs, shading devices, and window opening rates. Parameters for comparison strictly include thermal discomfort (all Clo), LCA, embodied CO₂, operational CO₂, and total primary energy use.

1.5 Significance of the Study

Existing temporary shelters for migrants prioritize a fast and cost-effective response, often neglecting environmental impact and thermal comfort. Current models

show poor thermal efficiency and high carbon emissions. This study advances the state-of-the-art by using a multi-criteria optimization approach to balance sustainability, comfort, and material efficiency. Through energy modelling and decision-making methods, it proposes design strategies that outperform conventional practices, offering a framework for environmentally and socially responsible short-term housing in migration crises.

The outcomes of this study can transform the method into short-term sustainable accommodation guidelines for migrants and urgent trouble in the global migration disaster context. Central to this research is the environmental impact and thermal comfort of such accommodations and the pursuit of environmentally sustainable solutions. This thesis provides an in-depth analysis of current base case conditions and proposed scenarios, aiming to guide stakeholders, inform resource allocation, and inspire innovative, environmentally sustainable, and socially responsible temporary accommodation solutions that address the crucial demands of displaced populations. This comprehensive strategy suggests advancing sustainable development objectives by offering a framework for future short-term housing projects that are environmentally and socially sensitive.

1.6 Limitations of the Study

The study is limited to considering the design and sustainability of housing within the camp without addressing broader issues of camp management, service provision, or resettlement policies. In addition, the analysis of economic sustainability parameters is out of the scope of this study due to the complexity of accurately projecting long-term costs and benefits within an ever-changing market. Some data related to the operation of dwellings and usage schedules are derived from the digital sources to be used in the energy modelling software of DesignBuilder, such as the heating schedule. On the other hand, this study focuses on the hot-arid climate of Mafraq, Jordan. Therefore, the findings, shelter designs, and recommendations are optimized for this particular climate. Application of the results to regions with significantly different climatic characteristics (e.g., humid, cold, or tropical zones) may require further adaptation or recalibration. Therefore, the generalizability of the results across diverse climatic contexts is limited.

1.7 Methodology

The methodology consists of six main steps. The first step is the determination of climatic regions and migrant camps that identify the geographical and climatic context relevant to the study by selecting regions and camps based on predefined criteria. Climatic regions are determined using classification systems like Köppen, focusing on extreme conditions such as high temperatures or severe cold. The Refugee Camp is chosen based on its population size, operational history, data availability, and typical shelter designs, with a preference for those experiencing significant energy and thermal challenges. The analysis of the climatic region and refugee camp case as the second step involves a detailed evaluation of the selected region and camp, focusing on climatic features such as temperature, humidity, solar radiation, wind, and precipitation. It analyses climatic factors that influence the camp's environment and shelter performance, including physical and spatial analysis, and environmental impact analysis.

The third step, determination and analysis of the camp unit as a Case Study, evaluates a typical shelter unit as the base case for analysis, representing the standard construction and operational conditions within the camp. This step involves detailed modelling of the unit's materials, architectural features, three-dimensional models, thermal properties, active systems usage, operational systems and energy performance. The base case establishes benchmarks for evaluating proposed design improvements, focusing on thermal comfort, energy efficiency, and sustainability.

Subsequently, the design proposal step develops alternative design scenarios aimed at improving shelter performance at the dwelling scale. Proposed enhancements include fourteen plan layouts by developing the selected base case and variables such as envelope materials, insulation thicknesses, WWRs, shading devices, and window opening rates.

Then, within the energy modelling and calculation step, by applying various options for each variable to the proposed plan layouts in DesignBuilder, scenarios are prepared for the optimization process. This step calculates critical metrics, including two optimization objectives of discomfort all Clo (hr), LCA (kg) and three additional outputs of embodied CO₂, operational CO₂ and total primary energy use.

Two-step decision-making, as the final step, involves ranking optimal designs concluded from the optimization process to select the final optimal design (the ideal alternative). First, using the Pareto optimal method, the ideal alternative is identified from a pool of generated optimal designs. Next, the Equal Weighted Decision Making (EWDM) method ranks these designs based on the optimization objectives criteria, including discomfort all Clo (hr) and LCA (kg), to score each optimal design and ensure the selection of the most optimal one (ideal alternative).



Chapter 2

Refugee Accommodation Types and Sustainability Aspects

2.1 Overview of Refugee Accommodation in Global Context

For the past seventy years, the refugee camp has been considered a primary response to forced migration and people displacement (McConnachie, 2016). The definition and purposes of refugee accommodations encompass a multifaceted approach. Refugee accommodations are designed to provide temporary shelter and support for individuals who have been compelled to flee their home countries due to persecution, conflict, or natural disasters. These accommodations can take various forms, including camps, urban apartments, and hybrid settlements, and aim to empower refugees, facilitate their resettlement, and ensure their well-being (Kreichauf, 2018).

Camps are described as expansive areas characterized by precarious and often temporary or exceptional legal statuses. These camps are set up to house large groups of individuals under poor living conditions, utilizing tents, containers, and makeshift shelters. The term extends beyond just enclosed centers with fortified boundaries and surveillance, encompassing any location that systematically segregates refugees. Kreichauf (2018) highlights the ambiguous nature of refugee camps, noting their positioning on the spectrum between formal and informal settings, between being places of movement and stasis and straddling the line between temporary and permanent solutions.

The purpose of these accommodations is to improve refugees' physical and mental health through intervention strategies that target the enhancement of living conditions (Chen & Knöll, 2022). Additionally, the spatial characteristics of refugee accommodations can impact the physical activity of refugee children, highlighting the importance of providing adequate space and access to communal facilities (Chen & Knöll, 2022). Furthermore, the accommodation of refugees is closely linked to human rights, as there are implications for the treatment of refugees with disabilities and the need for reasonable accommodations (Crock, 2021). The concept of self-reliance and

social networks is also relevant in explaining refugees' reluctance to relocate, emphasizing the importance of sustainable livelihood opportunities and access to services in refugee accommodations (Betts et al., 2020). Moreover, the accommodation policies for asylum seekers are often developed under emergencies, and the process of assimilation and acculturation is considered in the context of refugee accommodations (Papatzani et al., 2021). The spatial reality and formation of discourse within refugee accommodations function to control the population by its norms, rules, and regulations (Kreichauf, 2018). Refugee accommodations are framed more broadly as biopolitical environments that deprive refugees of their political agency and inscribe individuals into a state of perpetual transience (Kreichauf, 2018).

The global context of refugee accommodations is multifaceted and encompasses various dimensions. Refugee camps, as the primary form of accommodation, have been the subject of extensive research. Studies have highlighted the need for sustainability in refugee camps to ensure refugees' dignity and improve their quality of life, thereby helping them become independent and self-reliant (Wardeh & Marques, 2021). Additionally, the organizational structure within refugee camps has been explored, revealing a parallel structure where the institutional worlds of camp officials and refugees coexist (Chaux et al., 2018).

Furthermore, the use of pre-digital media practices in refugee camps has been identified as a coping mechanism for refugees to comply with or resist the power structures imposed upon them (Seuferling, 2019). Moreover, the environmental exposure of refugee camps has been studied, emphasizing the importance of responsive camp management strategies, especially in protracted refugee situations (Kruczkiewicz & Hoek, 2023).

The role of adult education in refugee livelihood adaptation and progression toward self-reliance has been recognized as significant, highlighting the importance of education in facilitating refugees' adaptation to their new environment (Awidi & Quan-Baffour, 2020).

These studies collectively provide a comprehensive overview of the challenges and opportunities within the global context of refugee accommodations, shedding light on the need for sustainable, inclusive, and supportive environments for refugees.

2.2 Historical Evolution of Refugee Camps

2.2.1 Origins and early forms. During ancient Rome, military camps provided temporary shelter for soldiers and civilians during campaigns (Fradley et al., 2023). Public buildings, such as temples, also served as places of refuge. Materials included simple tents made of canvas or animal skins and basic huts constructed from wood or thatch. These structures were integrated into the urban context by being located near amenities and having security measures like fencing and controlled access (Harris, 2022). Table 1 illustrates the overall features of refugee accommodation during the ancient period.

Table 1

The Architectural And Constructional Features Of Refugee Accommodations During The Ancient Period

Feature	Time Periods	
Form and Shape	-Roman Military Camps: Temporary camps for soldiers and civilians during campaigns. - Asylum in Rome: Temples as places of refuge.	
Materials	- Tents: Canvas or animal skins. - Temporary Structures: Basic huts or lean-tos.	
Urban Context Integration	- Proximity to Services: Located near amenities. - Security Measures: Fencing and controlled access.	
Psychological	Considerations	- Privacy: Balancing communal living with individual privacy. - Cultural Sensitivity: Designs respecting diverse cultural norms.
Example Picture		
	The Roman camp layout	
Reference	(Harris, 2022), Pic: (Jasiński, 2024)	

2.2.2 Developments through the century. The refugee camps throughout history have been shaped by various factors and purposes. Refugee camps have been used for different purposes, including protecting and controlling refugees, the internment of prisoners of war, and rounding up civilians for political reasons (Jahr & Thiel, 2022). The design of these camps often follows a generic top-down framework, with standardization and modular spatial hierarchy being common features (AlWaer et al., 2023). In the United States, military bases have been transformed into refugee camps, highlighting the militarization of refugee and migration policy (Lipman, 2014). These camps have been created through the adaptive reuse of existing sites, such as hotels or military camps, and their previous uses have influenced the experiences of the displaced population (Mackinnon & White, 2023).

Table 2 presents an overview of the evolution of refugee accommodation strategies over time, emphasizing the shift in approaches and types of housing provided to refugees.

Starting from the late 19th and early 20th centuries, initial formal accommodations such as asylum homes and hostels were established by charitable organizations and religious groups.

Post-World War II saw the establishment of refugee camps by governments and international agencies to manage the large influxes of displaced persons.

From the 1950s onwards, there was a shift towards settlements and resettlement programs aimed at integrating refugees into local communities, offering permanent housing solutions and paths to citizenship.

In the 1970s and 1980s, there was recognition of refugees living in urban settings, leading to support programs for urban accommodation.

The 1990s and 2000s introduced temporary protection and asylum centers in response to specific crises, providing immediate shelter to large numbers of displaced persons.

The 21st century has seen an increased focus on community hosting and integration projects, aiming to integrate refugees into host communities through shared housing and community sponsorship.

From 2015 onwards, cities like Hamburg have been responding to new waves of refugees with innovative housing solutions such as modular homes, highlighting a shift towards more sustainable and inclusive housing solutions.

Table 2

Refugee Accommodation Development In Time (Refugee Timeline | USCIS, 2023)

Period	Type of Accommodation	Description
Late 19th - Early 20th Century	Asylum Homes & Hostels	Initial formal accommodations are often set up by charitable organizations and religious groups to house refugees fleeing conflicts and persecution.
Post-World War II	Refugee Camps	Established by governments and international agencies like UNHCR to manage large influxes of displaced persons due to war.
1950s Onwards	Settlements and Resettlement Programs	Initiated by countries to integrate refugees into local communities, offering permanent housing solutions and paths to citizenship.
1970s - 1980s	Urban Accommodation	Recognition of refugees living in urban settings leads to support programs for housing in cities rather than camps.
1990s - 2000s	Temporary Protection & Asylum Centers	In response to specific crises, such as the Balkan conflicts, temporary accommodations were established to offer immediate shelter to large numbers of displaced persons.
21st Century	Community Hosting & Integration Projects	Increased focus on integrating refugees into host communities through shared housing, community sponsorship, and local integration projects.
2015 Onwards (Hamburg Example)	Innovative Housing Solutions	Cities like Hamburg responding to new waves of refugees with modular homes and integration-focused accommodations, highlighting a shift towards more sustainable and inclusive housing solutions.

During the late 19th and early 20th centuries, asylums played a crucial role in treating individuals with mental illnesses as temporary accommodation for these people. These institutions were purpose-built, reflecting both medical beliefs and societal attitudes. Asylums varied widely, from large orderly structures to “cottage plan” villages with separate buildings. Often situated on scenic hills, they aimed to provide a therapeutic environment, with designs including conglomerate, corridor, and pavilion types. These architectural choices shaped patient care and reflected evolving treatments, as summarized in Table 3 on late 19th- and early 20th-century asylum features.

Table 3

The Architectural And Constructional Features Of Late 19th And Early 20th-Century Asylums

Feature	Description
Purpose and Beliefs	- Designed to house and treat individuals with mental illnesses - Belief in the environment's impact on mental health.
Architectural Features	- Large, orderly structures - Cottage plan (village-like clusters) - Sited on hills with a beautiful perspective
Types of Asylums	- Conglomerate (mix of structures) - Corridor type (wards connected by corridors) - Pavilion type (rows of blocks).
Examples	- Buffalo State Hospital for the Insane: Gothic castle-like architecture - Colney Hatch Lunatic Asylum: Long corridors - Leavesden Hospital: Pavilion type

Table 4 reveals the Post-war architectural and constructional features of Post-World War II refugee camps, which emerged as urgent responses to the massive displacement caused by the war. Initially designed as temporary shelters, these camps prioritized simplicity, low-cost materials, and rapid construction. They often featured grid layouts with rows of identical shelters, centrally located communal facilities, and basic amenities. Shelter types ranged from tents to prefabricated units. Over time, some camps evolved into semi-permanent settlements. Despite challenges like overcrowding and limited infrastructure, these camps played a crucial role in providing immediate relief to displaced populations (Mackinnon & White, 2023).

Table 4

The Architectural And Constructional Features Of Post-World War II Refugee Camps

Feature	Description
Purpose and Beliefs	- Designed as temporary shelters for displaced populations - Initially short-term but often became semi-permanent settlements.

Table 4 (cont.d)

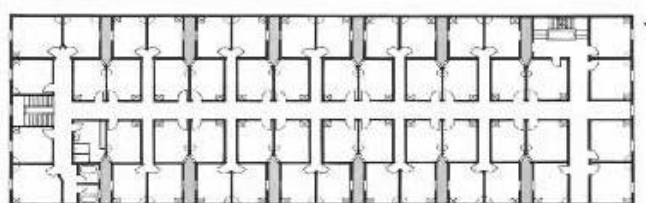
Architectural Features	- Immediate Response: Hasty establishment to meet urgent needs. - Temporary Nature: Simplicity, low-cost materials, rapid construction. - Spatial Organization: Grid layout with common facilities centrally located.
Materials	- Lightweight Materials: Tents made of canvas or plastic. - Metal and Wood: Prefabricated units use metal frames and wooden panels. - Adaptive Materials: Incorporation of local materials.
Shelter Types	- Tents: Initially used for portability. - Prefabricated Units: Replaced tents with more robust structures. - Transitional Shelters: In-between tents and permanent housing.
Challenges	- Overcrowding: Privacy and sanitation issues due to rapid influx. - Infrastructure: Limited access to water, electricity, and sanitation. - Health and Safety: indoor environmental quality, and fire risks.
 German Refugees Post-World War II (Welle, 2019)  Belgian Refugees Post-World War II (Kemp, 2020)	

Table 5 outlines the architectural and constructional features of Urban Accommodation for refugees during the 1970s and 1980s. These accommodations were designed to efficiently house a large number of refugees within urban areas. Key features include multi-story buildings, apartment complexes, and repurposed existing structures. Construction materials such as concrete, brick, and steel were used, with interior partitions made of plywood or gypsum board. Shared facilities like common kitchens and bathrooms were central. Due to limited urban space, vertical density was achieved through multiple floors and staircases. The strategic urban location promotes integration and social inclusion, exemplified by the San Francisco Hotel's second-floor plan, repurposed for refugee housing.

Table 5

The Architectural And Construction Features Of Urban Accommodation For Refugees During The 1970s And 1980s

Feature	Description
Architectural Features	- These buildings were designed to accommodate a large number of refugees efficiently within urban areas. - The shape varied based on available space and architectural styles prevalent in each city. - Multi-story buildings - Apartment complexes - Converted existing structures
Materials	- Construction materials were influenced by local availability and economic constraints - Concrete, brick, and steel. Interior partitions are often made of plywood or gypsum board.
Shared Facilities	- Common kitchens, bathrooms, and laundry areas shared among residents.
Vertical Density	- Due to limited urban space, vertical density was a key feature - Multiple floors to accommodate several families. - Staircases and elevators for movement.
Adaptation of Existing Structures	- Repurposing existing buildings (schools, factories) for housing.
Integration with Urban Fabric	- Strategic location within cities close to amenities and employment opportunities - Integration with the existing urban fabric was essential to foster social inclusion and prevent isolation



Second-floor plan of San Francisco Hotel, SRO housing
(History of S.R.O. Residential Hotels in San Francisco – Central City SRO Collaborative, n.d.)

2.2.3 Modern adaptation and innovations. The modern adaptation and innovations of refugee accommodations encompass a diverse range of initiatives and approaches. These include efforts to address mental healthcare barriers among refugees and asylum seekers, such as adapting psychological interventions for use with specific refugee populations (Kiselev et al., 2020). Additionally, studies are focusing

on the role of media in promoting the dehumanization of immigrants and refugees, highlighting the need to address uncertainty and threats in shaping public perceptions (Esses et al., 2013). Furthermore, there is a growing emphasis on sustainable operational innovations for refugee camps, aiming to ensure a higher quality of life and progress toward sustainability (Seifert et al., 2023). Advancements in technology, such as earth observation and remote sensing, have facilitated the assessment of population dynamics and camp evolution, providing valuable insights for humanitarian responses during crises (Lang et al., 2010). Additionally, the role of information and communications technology (ICT) in supporting refugee entrepreneurship has been recognized, with ICT playing a significant role in facilitating the survival and growth of refugee businesses (Brown et al., 2021).

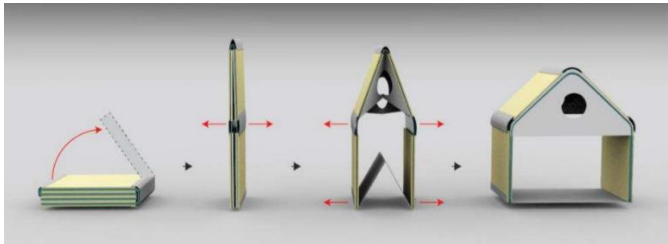
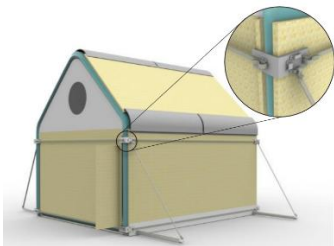
As described in Table 6 Monticelli (2019) presents a proposal for a refugee shelter design using a "pneumatic sandwich" structure, which is a prefabricated structure made of pneumatic material and lightweight timber panels to provide a shelter that can be easily transported and quickly assembled without requiring any technical skills.

Table 6

Innovative Features Of Monticelli (2019) Shelter

Features	Description
Lightweight	Easy to transport and carry.
Foldable	Quick assembly and storage.
Pneumatic	Utilizes air for prefabricated structure setup.
Timber Panels	Thin panels on both sides for external protection, strength, and thermal insulation.
Movable Base	Designed for compatibility with various geographic areas.
Thermal Insulation	Provides comfort in hot or cold climates.
Expandable	by connecting more components or installing solar panels on the roof

Table 6 (cont.d)

Visuals	
	
The main structure installation steps	The enhancement structures
Reference: (Monticelli, 2019)	

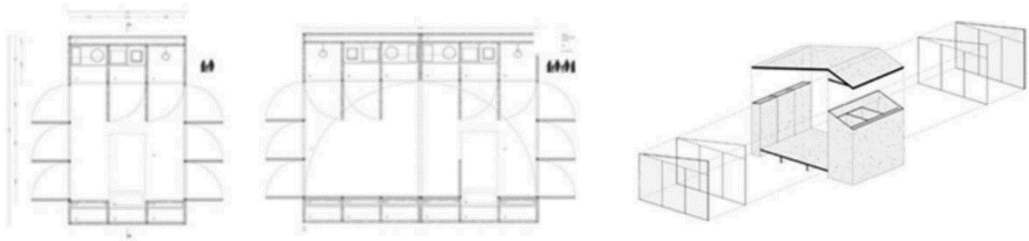
Santos and Louro (2022) proposed the reinvention of dwelling in the context of humanitarian emergencies, with a focus on providing design solutions for shelters that allow refugees to rebuild their quality of life and recover a sense of belonging, restructuring their mental and emotional capacities. The proposed shelter is made from 100% recycled materials, mainly plastic, to provide temporary housing for refugees or others in need. The architectural and construction features of the shelter have been summarized in Table 7.

Table 7

Innovative Features Of Santos And Louro (2022) Shelter

Features	
Two volumes	One for infrastructure (kitchen, bathroom, shower) and one for sleeping and storage - Allows for flexibility and modularity, can be attached to another shelter to form a larger unit
Retractable panels	Enables adaptation to different climates and seasons, creates a connection with the outside - ventilation
Prefabrication	Reduces the construction time and cost, facilitates transportation and installation - Limited the customization
Recycled plastic panels	Utilizes waste plastic as a resource, reduces the environmental impact, and provides thermal and water resistance - Light and resistant May not be aesthetically pleasing, may degrade over time, may emit harmful substances

Table 7 (cont.d)

Sustainable systems	The shelter integrates rainwater harvesting, filtering, solar energy, and snow-melting systems. This complexity and maintenance may not be reliable in all situations.	
Visuals		
	Plan of Shelters for Housing	“Kit house” model
Reference: (Santos & Louro, 2022)		

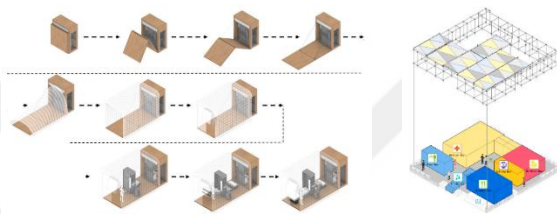
Li et al. (2024) developed a modular emergency shelter prototype (Table 8) called the “Bag Box Building Cloud” (BBBC) to address sustainability and energy resilience in humanitarian action. Guided by the QSAND tool, they integrated passive design, energy storage, and a combined DC/AC power system. The BBBC is solar-powered, reusable, versatile, safe, and affordable, aiming to meet local requirements while promoting sustainability and resilience.

Table 8

Innovative Features Of Bag Box Building Cloud (BBBC) Shelter

Features	
Size and Dimensions	The total area of the prototype is 100.8 m ² , consisting of 14 modules with an average area of 7.2 m ² each. Each module measures 2.4 m (width) × 3 m (length) × 2.8 m (height).
Layout	The prototype features a U-shape layout that encloses a central courtyard, providing natural lighting, ventilation, and outdoor activities.
Materials	Paper tubes, steel frames, prefabricated panels, double-glass photovoltaic modules, and composite energy storage batteries.
Construction Techniques	Construction techniques involve modular design, suspended seismic foundations, flexible connections, and plug-and-play installation.

Table 8 (cont.d)

Innovations and Sustainable Features	- Hybrid power system (DC and AC modes) - Cloud-intelligent disaster preparedness system - Lightweight and recyclable materials - Integration of sustainability principles - Use of solar energy as the main power source - Passive design strategies for thermal comfort and air quality
Pros and Cons	Pros: - Meets diverse needs during disaster response - Enhances safety and well-being - Contributes to sustainable recovery Cons: - Higher initial investment and maintenance costs - Technical and operational challenges in some contexts - Social and cultural barriers
Visuals	  Building a roof and photovoltaic panels . Independent module and Combination of the multi-function module of BBBC
Reference: (Li et al., 2024)	

Energy-smart building design plays a crucial role in managing energy effectively within shelters. Recently, researchers have explored solar power as a means to enhance energy resilience in emergency structures. For instance, Liu Chang integrated solar cells into the building envelope, while Kalpana et al. developed solar power generation systems for constructing small, energy-resilient shelters.



Figure 1. IKEA's solar-powered flat pack shelters approved for Syrian refugee housing (Cameron, 2013)

The IKEA Refugee Housing Units (Figure1), designed to improve living conditions for refugees, offer 188 square feet of space, capable of accommodating up to five individuals, and feature solar-panelled roofing for safer lighting, reflective

exterior panelling for thermal insulation, and a durable structure that lasts up to three years—significantly longer than the standard tents currently in use.

The Politecnico di Milano conducted a collaborative project called “S(P)EEDKITS: rapid deployable kits as seed for self-recovery” funded by the EU 7th Framework Programme. The project aimed to develop novel emergency solutions for humanitarian organizations (NGOs) in disaster scenarios. The research focused on sustainable design applied to textile-based shelters, emphasizing adaptability, prompt repair, and effective protection. Field tests in Burkina Faso and Senegal evaluated the environmental performance of these shelters (Viscuso & Zanelli, 2016).

The most significant heat loss occurs due to air infiltration. In their study, Manfield et al. (2004) found that adding a liner (composed of polyester wadding and moisture-permeable spun-bonded polymers) to insulate the interior of a tent could improve efficiency and reduce heat loss by up to 50%. Mark et al. (2022) use the methods of the Min-Max protocol for a Rapid Shelter Kit and Adaptive structural engineering principles for connection joints, framing, and enclosure components to propose rapid shelter kits which aim to minimize dependence on external resources and maximize local building practices and materials (Mark et al., 2022). Table 9 describes the various sustainable innovations offered for refugee camps.

Table 9

Sustainable Innovations Offered For Refugee Camps

Sustainable innovations	Description
Solar Energy Parks	Solar parks in refugee camps deliver sustainable energy, cut traditional fuel use, and boost eco-sustainability. (Seifert et al., 2023)
Recycling Projects	It focuses on collecting and treating waste to improve management, lessen environmental harm, and foster sustainability. (Seifert et al., 2023)
Hydroponics Gardening	It introduces soilless farming in refugee camps, using water solutions for sustainable food production and security. (Seifert et al., 2023)

Table 9 (cont.d)

Iris Scanning Technology	Iris scanning in refugee camps aids in identification, access control, and resource management, boosting security, efficiency, and administrative streamlining. (Seifert et al., 2023)
Participatory approaches	Involving refugees in decision-making to legitimize changes and uphold dignity. (Seifert et al., 2023)
Cash-for-work opportunities	Allowing refugees to take up employment opportunities to contribute to the development of the camp. (Seifert et al., 2023)
Information and Communications Technology (ICT)	It improves business communication and growth while also addressing access challenges due to security and surveillance concerns. (Brown et al., 2021)

The modern adaptation and innovations of refugee accommodations also encompass efforts to address the mental health and well-being of refugees, such as the use of music therapy as a non-inferior treatment for traumatized refugees in mental health care (Beck et al., 2021). Music therapy offers a culturally sensitive, nonverbal approach in refugee camps, effectively addressing trauma and improving well-being, sleep, and social function. Equally effective as standard psychological treatments, it overcomes language barriers and can be tailored for various trauma-affected groups, including war veterans and abuse survivors (Beck et al., 2021).

Furthermore, there are discussions on the enhanced local-level willingness and ability to settle refugees, emphasizing the importance of capacity building and diverse learning tools to adapt approaches to the local context and specific refugees to be settled (Søholt & Aasland, 2019). There are discussions on the racial capitalism and logic of the refugee accommodation market, shedding light on the profit-driven nature of refugee shelters and their impact on racialized and low-income populations. Moreover, there are reflections on the mediated and lived geographies of asylum accommodation, discussing examples of local innovation in asylum accommodation and their impact on refugee experiences.

2.3 Strategies Behind Refugee Accommodations

2.3.1 Humanitarian response vs. long-term urban planning. The humanitarian response to crises, particularly in urban settings, prioritizes immediate assistance to affected populations, often necessitating regulatory exemptions to expedite aid delivery. This approach focuses on short-term relief to mitigate the immediate impacts of disasters or conflicts, potentially bypassing standard governmental protocols to ensure rapid deployment of services (Hacker et al., 2021). The key difference between humanitarian response and long-term urban planning is that Humanitarian response prioritizes immediate assistance and may involve circumventing government institutions, while long-term urban planning focuses on long-term structural and societal transformation for sustainable growth. Both approaches have some degree of overlap, but they differ in their priorities, operational roles, and time frames for related projects. Humanitarian response may prioritize immediate shelter and is executed by emergency managers, while long-term urban planning involves strategic plans designed over extended periods by a team of city planners and planning officials. This contrast showcases two competing institutional logics, with humanitarian response working around governments and systems, while long-term urban planning is focused on working through them (Hacker et al., 2021).

This response involves the establishment of refugee camps, which initially consist of temporary structures but may evolve into more permanent settlements over time (Sanyal, 2017). As the refugee situation becomes protracted, the camps develop into important economic spaces that intersect with local, national, and international economies in complex ways (Sanyal, 2017). The humanitarian response also involves the use of earth observation and remote sensing to assess population dynamics and camp evolution, providing valuable insights for humanitarian responses during crises (Gella et al., 2022; Lang et al., 2010).

Conversely, long-term urban planning for refugee accommodations involves a more structured approach, integrating sustainability and development into the fabric of city planning. This includes designing refugee accommodations with a view toward long-term integration and sustainability, ensuring that such planning serves not just as a temporary solution but as a component of broader urban development strategies

(Dalal et al., 2018). Additionally, there is a growing emphasis on sustainable innovations for humanitarian operations in refugee camps, aiming to ensure a higher quality of life and progress toward sustainability (Seifert et al., 2023). Also, there is a multidimensional approach to the design of refugee camps in terms of urban planning development, recognizing the complex conceptualizations involved (Aburamadan, 2023).

The urbanization of humanitarian crises presents unique challenges and opportunities, necessitating a blend of immediate humanitarian responses with long-term urban planning strategies to ensure resilience, integration, and sustainability. This duality is crucial for addressing the complex dynamics of urban crises and ensuring that refugee and migrant accommodations contribute positively to urban development and policy formulation (Archer & Dodman, 2017; Konduri & Lee, 2023). The humanitarian response and long-term urban planning of refugee accommodations are also influenced by geopolitical shifts, immigration policies, and social integration efforts.

2.3.2 Integrated approaches to refugee accommodation in city planning.

Integrated approaches to refugee accommodation in city planning require a comprehensive understanding of the roles and interactions of governmental and non-governmental actors, as well as the social, economic, and political dimensions of refugee integration. Cheung & Phillimore (2013), Valenta & Bunar (2010), Thompson (2020), Kreichauf (2023), Hellmann et al. (2021), Bauder (2021), and Scholten & Penninx (2016) provide insights into the multifaceted nature of refugee accommodation and the diverse approaches to urban planning and integration.

The relationship between social capital and labour market integration of new refugees in the UK sheds light on the social and economic dimensions of refugee integration (Cheung & Phillimore, 2013). The refugee integration policies in Scandinavian welfare states provide insights into the interplay between cultural and structural dimensions in the process of acquiring civil, political, and social citizenship rights (Valenta & Bunar, 2010). The emergence of New Municipalism and its impact on refugee action is exemplified by the Sanctuary Cities network in the USA and Barcelona's establishment of the Refuge City plan to welcome refugees and asylum-

seekers (Thompson, 2020). The racial capitalism and logic of Berlin's refugee accommodation market shed light on the political and economic dimensions of refugee housing and urban planning (Kreichauf, 2023).

Hellmann et al. (2021) investigate factors that increase citizens' willingness to help refugees, providing insights into policy approaches that avoid the creation of marginalized communities and prioritize the dispersion of refugees for integration. Bauder (2021) discusses urban migrant and refugee solidarity beyond city limits, highlighting the role of cities in developing practical approaches towards migrant and refugee accommodation and integration. Scholten & Penninx (2016) provide insights into the multilevel governance of migration and integration, offering a comprehensive understanding of the political and governance dimensions of refugee accommodation and integration. The mentioned writers offer diverse perspectives on the complex interplay between governmental and non-governmental actors, policy approaches, and social dynamics in the context of refugee accommodation and urban planning.

2.4 Types of Refugee Accommodations

Throughout history, short-term housing has been established with various types of structures. Del Sabet (2023) defines four transitional phases from the moment of the disaster to back to normal life and permanent accommodation. These four phases are Emergency Shelter, Temporary Shelter, Temporary Accommodation, and Permanent Accommodation. These phases come after each other and include a period in which displaced populations accommodate there.

Temporary shelters for displaced populations are categorized into four main types based on their purpose, construction method, durability, and use duration, spanning from emergency to more stable solutions. Each category is designed to address different stages of refugee accommodation and varying needs during crises.

Initially, "Emergency Shelters" like tents and prefabs offer quick relief with rapid deployment and lightweight materials for short-term crises. These shelters are designed to offer minimum habitability conditions and are adapted to various climates

and terrains. Innovations in emergency shelters focus on flexibility, lightweight construction, and thermal acoustic capacities.

Following this, "Transitional and Prefabricated Units" provide a more durable option for those transitioning to permanence, using materials like corrugated metal sheets for greater stability.

The third category, "Durable Shelters," moves closer to permanency with robust materials like bricks and concrete, aiming for longer-lasting, comfortable environments.

Lastly, "Adaptations of Existing Structures" repurpose buildings like old offices for refugee housing, focusing on sustainability and integration into the urban fabric, marking a shift towards more permanent, integrated housing solutions.

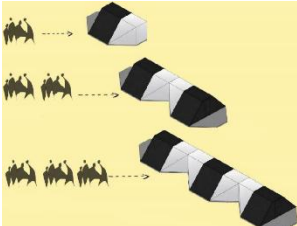
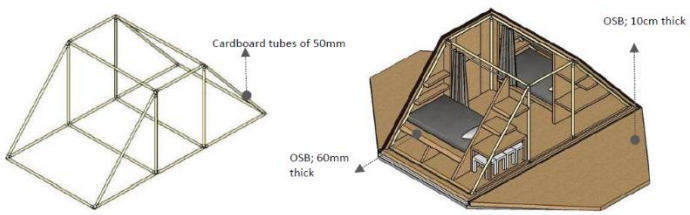
2.4.1 Emergency shelters. Emergency shelters are a critical component of refugee accommodation, providing immediate and temporary housing for displaced populations during crises and disasters. These shelters serve as a vital resource for ensuring the safety, protection, and well-being of refugees in emergencies. The selection of emergency shelter sites for seismic disasters in urban areas underscores the strategic importance of emergency shelters as disaster-prevention facilities in densely populated regions (Liu et al., 2011). According to Li et al. (2024) five various types of emergency shelters exist, including Temporary Tents, Prefabricated Modules, Emergency Flat Pack shelters, Solar-powered emergency shelters, and containers. Global shelters encompass the UNHCR family tent and flat-packed refugee housing developed by Better Shelter (Albadra et al., 2018).

Emergency architecture focuses on creating temporary shelters that provide minimum habitability conditions for displaced individuals, often using prefabricated or standard materials. Oliveira & Campos (2019) propose a flexible and temporary modular system for emergency shelters which provides the adaptation opportunity to different spaces and climatic scenarios (Oliveira & Campos, 2019). The key features of their flexible refugee shelter proposal have been described in Table 10 including being Temporary and Transitory, Modular and Flexible, Primordial Base Structure,

Lightweight Construction, Good Thermal Acoustic Capacities, Exterior, and Interior Spaces, and PVC Structural Basis to stabilize the shelter on the ground, allowing for easy implementation and levelling with the terrain (Oliveira & Campos, 2019).

Table 10

Architectural Features Of Flex Refugee Shelter (FRS)

Features	
Size and Dimensions	The shelter has an irregular octagonal shape with a base area of 18.5 m ² and a height of 2.5 m. It can accommodate up to four people.
Shape and Form	A modular design that allows it to be connected horizontally with other units. It has two separate entrances, a central circulation and social zone, and two resting and storage zones. The outer zones can be folded for transportation and deployment.
Materials	The shelter mainly uses three materials: cardboard tubes, OSB boards, and cork agglomerate. These materials are sustainable, durable, lightweight, and easy to acquire. The shelter uses cork agglomerate as a lining material, which has efficient thermal, acoustic, and rain-resistant properties. It also has openings for air circulation and natural light.
Construction Techniques	A PVC pipe structure stabilizes it on the ground and facilitates its adaptation to different terrains.
Innovations and Sustainable Features	in its flexibility, adaptability, and functionality. It responds to the needs of the refugees in terms of comfort, privacy, and dignity. It also allows the creation of different spatial configurations and communal areas.
Visuals	 Flex Refugee Shelter (FRS) Capacity  Interior structure (Left); 3D representation of the inner materiality (Right)
Reference: (Oliveira & Campos, 2019)	

According to Albadra et al. (2018), Emergency shelters are constructed on-site using locally available materials, often timber structures. The typology of Zaatari camp shelters is considered both built-on-site and transitional at the same time since the Tents are the initial response to the disaster, constructed on-site, but the container-like

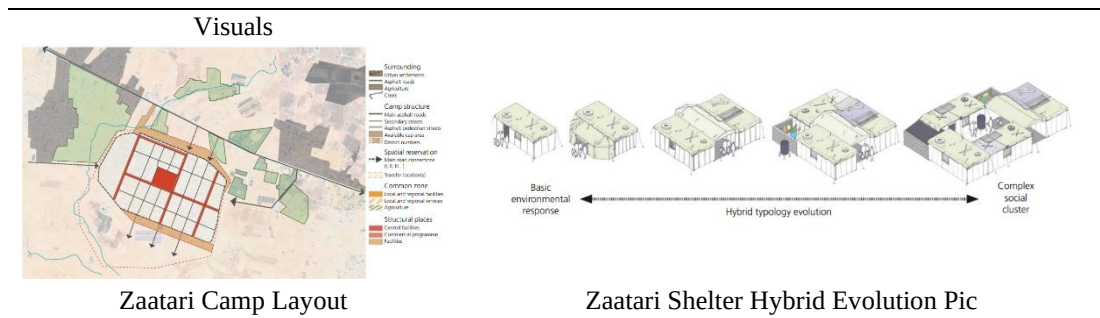
structures that are used to house the refugees are manufactured and shipped to the site. Additionally, tents and container-like structures have formed the shelters of Zaatari Camp. 11% of the Containers are fixed with screed flooring, and the rest are mobile and have suspended timber floors, sometimes upgraded by refugees with cement mortar. Container roofs and walls consist of 40mm polyurethane-insulated sandwich panels with outer surfaces made of either 0.35mm steel sheet or timber. Table 11 reveals the shelter features of the Zaatari camp.

Table 11

The Features Of The Zaatari Refugee Camp

Form of Shelter	Architectural Features	Sustainability Features
The Zaatari refugee camp- Container and Tent	Camp Layout: - Divided into 12 districts with individual facilities and services. - Grid of roads with a main T-shaped axis and a ring road. - Covers an area of 5.5 km² (530 ha). Form: - Rectangular units that can be combined or modified by refugees.	- Innovations: Built with local materials (adobe plastering with branches of local wooden poles). - Challenges: High relative humidity, low ventilation.
	Material: - Containers: Metal, Wood, Plastic and Fabric. - Refugees also use other materials, such as corrugated sheets, concrete blocks, and cement, to improve or expand their shelters. Facilities: - The shelters have basic features, such as doors, windows, insulation, and ventilation¹. Some shelters have electricity, water, and sanitation facilities, depending on the availability and accessibility of these services in the camp.	Thermal Comfort: - High thermal mass and inertia: Stable temperature range. - Low-temperature variation.
	Camp Facilities: - Schools, health centers, markets, mosques, playgrounds and sports fields - Construction of shops, workshops, gardens, and farms, within or near their shelters by refugees	- Privacy: None (open design). - Comfort: Best thermal stability.

Table 11 (cont.d)



References

Info: (Dalal, 2022), Layout: (AlWaer et al., 2023)

In addition, Domínguez-Amarillo et al. (2021) declared that the Tent Shelter, developed in Afghanistan, and the Tukul Shelter, developed in South Sudan, are classified as emergency shelters, which are listed in Tables 12 and 13.

Table 12

The Features Of The Gulan Refugee Camp

Form of Shelter	Architectural Features	Sustainability Features
The Gulan refugee camp (Tent Shelter)	Wall: - UNHCR tarpaulin	- Innovations: Lightweight and easy to deploy. - Challenges: Low thermal mass, high-temperature peaks, and quick reaction to external conditions.
	Roof: - UNHCR tarpaulin with bamboo structure	
	Floor: - Tarpaulin	Thermal Comfort: - Poor thermal performance: Tarpaulin walls and roof. - High-temperature variations.
	Door: - UNHCR tent	
	Window: - None	
	Size: - 38.7 m ²	- Privacy: None (open tent design). - Comfort: Highly dependent on external conditions.
	Density: - 0.103 people/m ²	

Table 12 (cont.d)

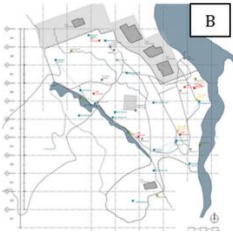
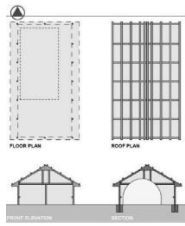
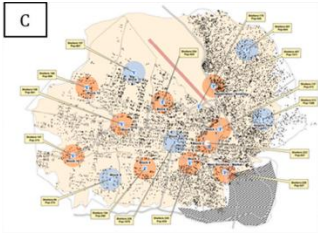
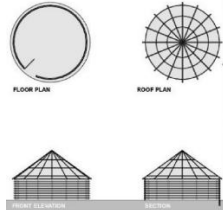
Visuals		
		
Gulan Refugee Camp Map	Gulan Refugee Shelter Model	Gulan Refugee Shelter Diagrams
		
Gulan Refugee Pic.	Gulan Shelter Pic	Gulan Shelter Pic
References		
Info, Pic and Maps: (Domínguez-Amarillo et al., 2021), Pic: (MyNorthwest, 2022)		

Table 13

The Features Of The Ajuong Thok Refugee Camp

Form of Shelter	Architectural Features	Sustainability Features
The Ajuong Thok refugee camp (Tukul Shelter)	Wall: - Adobe plastering with branches of local wooden poles	- Innovations: Built with local materials (adobe plastering with branches of local wooden poles). - Challenges: High relative humidity, low ventilation.
	Roof: - Thatch with branches of local wooden poles	
	Floor: - None	Thermal Comfort: - High thermal mass and inertia: Stable temperature range. - Low-temperature variation.
	Door: - Adobe plastering with branches of local wooden poles	
	Window: - None	- Privacy: None (open design). - Comfort: Best thermal stability.
	Size: - 21.6 m ²	
	Density: - 0.214 people/m ²	

Table 13 (cont.d)

Visuals		
		
Tukul Camp Map	Tukul Shelter Model	Tukul Shelter Diagrams
		
Tukul Camp Layout	Tukul Shelter Pic	Tukul Shelter Pic
References		
Info, Diagrams and Map: (Domínguez-Amarillo et al., 2021), Pic.: (Bloesch et al., 2013), Layout: (Mutuli, 2023)		

Zhao et al. (2015) discuss how the organization and distribution of earthquake emergency shelters operate as life-saving safe places and escape routes in disaster contexts. The use of insecticide-treated plastic sheeting for emergency malaria prevention and shelter among displaced populations has been discussed by Burns et al. (2012), emphasizing the multifunctional role of emergency shelters in protecting them from health risks during crises. Additionally, Li et al. (2020) emphasize the importance of refugee parks as emergency shelters in urban planning, recognizing their role in providing safe and practical spaces for residents during severe disasters.

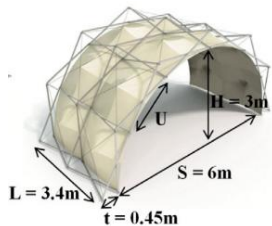
These shelters aim to meet the minimum conditions of habitability for the victims until they can be relocated to more permanent housing (Rubanenko, 2023). The design of these shelters considers the need for quick construction and low-cost assembly while also considering the comfort and well-being of the occupants (Geng et al., 2020). The shelters are often located in controlled and delimited spaces, such as refugee camps, and may consist of random tents or modular structures (Angi et al., 2022). The goal is to provide adequate and comfortable living spaces for a short period, considering factors such as adaptability to different terrains and climatic conditions (Naldini, 2022). The optimization of shelter location and distribution is also important,

considering the needs of the victims and the availability of relief materials. The aim is to create a solution that compromises multiple objectives and ensures the best possible living conditions for the refugees

2.4.2 Transitional and prefabricated housing units. Darling (2016) sheds light on the challenges and complexities of providing housing for refugees during the resettlement process, particularly addressing the accommodation process for asylum seekers in the UK. Transitional housing plays a crucial role in providing temporary and supportive accommodation for displaced populations as they transition from emergency shelters to more permanent living arrangements. The architectural features of transitional housing are specifically designed to offer a safe, stable, and supportive environment for refugees during their resettlement process.

Table 14

Transitional And Pre-Fabricated Shelter Sample

Type	Technical Features	Picture
Prefab Containers (Module-T containers)	- Modular and spreadable in one or two levels - 40-foot shipping container - Rigid steel or aluminum structures as a framework - Innovative insulation panels - Metal panels or engineered wood for roofs and floors - Pre-installed electrical and plumbing systems - Offering open-plan layouts to separate spaces - Rapid construction	 Ref.: (Module-T, 2024)
Manufactured and shipped to the site	- Deploying scissor arches with a membrane - Lightweight, Compact folded, Reusable, Adaptable, rapidly deployable	 (Mira et al., 2014)
Manufactured and shipped to the site	- The 'Rapid Deployment Module' designed by Visible Good - 11.7 m2 area produced by plastic panels and a fabric roof, small vents, very compact layout	 (Russell, 2015)

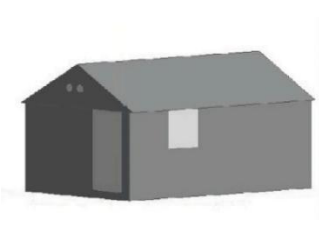
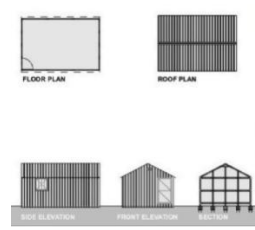
The design of transitional housing is an important area of research in architecture, with a focus on prefabricated and transportable homes that can be quickly implemented (Roguski & Cygańczuk, 2023). The evolution of construction systems using prefabrication for temporary and permanent housing has shown that prefabrication is not only an option for temporary and emergency housing but is now considered for high-standard permanent housing as well. There are projects, such as "Healthy Housing for Displaced" from the University of Bath, which study the adaptability of prefabricated construction systems for both temporary and permanent housing solutions. This indicates a shift in the perception of prefabrication from being solely for temporary shelters to being a viable option for long-term, high-quality housing (Roguski & Cygańczuk, 2023).

Table 15

The Features Of The Azraq Refugee Camp

Form of Shelter	Architectural Features	Sustainability Features
Azraq Refugee Camp (T-Shelter)	Wall: - IBR sheeting with expanded polyethylene insulation	- Innovations: Uses IBR sheeting with expanded polyethylene insulation for walls and roof. - Challenges: Limited ventilation and high-temperature values in extreme climates.
	Roof: - IBR sheeting with expanded polyethylene insulation	
	Floor: - Steel window frame	Thermal Comfort: - Moderate thermal performance: Insulated walls and roof.
	Door: - Clad with flat corrugated iron sheeting and filled with expanded polyethylene insulation	- Balanced relative humidity.
	Window: - Short lengths of 152mm pipes on the gables	- Privacy: The structure is clad with flat corrugated iron sheeting, limited openings
	Size: - 24 m ²	- Comfort: Moderate thermal mass.
	Density: - 0.166 people/m ²	Easy manufacturing, reusability, and positive impact on the local labor market. Protect against strong winds, dust, and extreme climate changes.

Table 15 (cont.d)

Visuals		
		
Azraq Camp Layout	Azraq Refugee Shelter Model	Azraq Refugee Shelter Diagrams
References		
Info and Pics: (Domínguez-Amarillo et al., 2021), Map: (Jordan: Azraq Refugee Camp, 2018)		

Transitional shelters are more durable and built on-site, such as the Azraq camp shelters in Jordan and compact bamboo shelters in Ethiopia (Albadra et al., 2018). The Azraq Refugee Camp features over 13,000 shelters constructed using Inverted Box Rib (IBR) corrugated sheets and are classified as transitional shelters by UNHCR and IFRC. These shelters have a steel frame, a concrete floor, and walls composed of two layers of IBR sheets with a 10-15mm core of aluminium foam insulation. The roof consists of a single layer of IBR with the same foam insulation, covered on the interior surface with tent materials (Albadra et al., 2018).

Roguski & Cygańczuk (2023) mentioned two types of temporary accommodations, including 1- Factory-made ready-to-use elements that are transported to the place of their future location, requiring simple assembly works on-site. 2- Supplies for the housing kit comprising all the components that make up the housing solution, which are assembled on-site. These homes are often made up of modular elements that can be assembled on-site and easily disassembled for reuse (Angi et al., 2022). Transitional housing can be located within urban centers as part of broader urban regeneration projects aiming to go beyond the emergency model and create inclusive spaces (Kreichauf, 2023).

2.4.3 Durable shelters. Durable shelters are a form of temporary accommodation for refugees, offering a more secure and long-lasting solution than emergency tents. These shelters, such as the Refugee Housing Units (RHUs), are robust and provide better protection against weather conditions, privacy, and comfort.

They are often built using local materials and expertise, fostering a sense of ownership and self-reliance. The design of these shelters is adaptable, considering factors like geographical context, climate, cultural practices, and local availability of skills and construction materials. Durable shelters are designed to last longer, providing a space where families can live with dignity and play a crucial role in improving the living conditions of refugees and displaced people worldwide.

Durable shelters, like one-room shelters in Pakistan, L-shaped shelters in Iraq, and Super adobe Earth Bag Shelters in Iran, are made with bricks, concrete blocks on concrete foundations, and earth bags, providing a more durable and locally friendly solution (Albadra et al., 2018). The Architectural Features of Super Adobe Earthbag Shelters, as a case of durable shelters, have been explained in Table 16.

Table 16

Sample Of Durable Shelters

Construction type	Shelter Name, Features	Picture, Reference
Built On-site	- Superadobe Earthbags by Iranian architect Nader Khalili - Use of natural sources such as mud, water, and fire, Flexible and variable spaces, Native and Recyclable, Good ventilation, Lighting, and Insulation, Sustainable and ecological, Participatory Construction Approach by refugees	 (Zhao et al., 2015) (Albadra et al., 2018) (Canadell et al., 2016)

2.4.4 Adaptations of existing structures. The architectural origins of refugee camps, shaped by the adaptive reuse of existing sites, influence the experiences of their residents and reflect how they are viewed by authorities (Mackinnon & White, 2023).

Adapting existing structures for refugee accommodation is a complex and multifaceted process that involves various stakeholders and considerations. McCleary et al. (2018) emphasize the importance of cultural and logistical adaptation of existing services to promote refugee integration, highlighting the need for a bidirectional process of mutual learning and adaptation. This aligns with the findings of Auslender (2021), who addresses the adaptation of multi-level governance and collaborative

governance in local refugee housing and integration management, emphasizing the significance of collaborative approaches in addressing refugee accommodation.

Furthermore, Bullen (2007) discusses the significant shift from new buildings to the adaptation and rehabilitation of existing structures, indicating a growing trend towards adaptive reuse and sustainability, which has implications for refugee accommodation. Additionally, Albadra et al. (2020) highlight the use of participatory design methods in refugee camps, where refugees are involved in proposing and modifying shelter designs, underscoring the importance of involving refugees in the adaptation process.

The use of multi-criteria shelter assessment tools can help in measuring the suitability of existing buildings for this purpose. Idemen and Şener (2022) proposed a multi-criteria shelter assessment tool (CS/ARP) for pre-disaster and rapid post-disaster uses of existing buildings in densely built environments.

Architectural adaptation of shipping containers has been considered as an option for accommodating internally displaced persons, with various adaptation modes identified. Obia (2020), by Quantitative field survey using questionnaires and Descriptive and inferential statistical analysis methods, proved refugees were comfortable with various architectural adaptation modes for shipping containers, and they also mentioned highly favoured adaptation options should be used for constructing accommodations for IDPs (Obia, 2020).

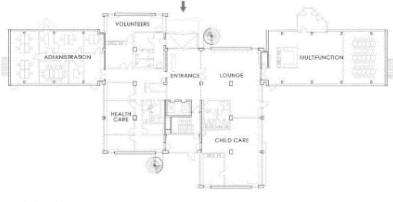
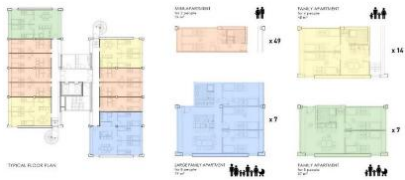
Stakeholders involved in the provision of centralized accommodations for displaced persons have shown preferences for solutions such as modular housing and the renovation of unused buildings (Faure, 2017). He mentioned that Short-term accommodations like sports halls were least preferred, while modular housing and renovation of unused buildings were most preferred.

One of the examples of utilizing existing buildings for refugee accommodation is an old office building in Munich (Table 17) that has been transformed into a residential complex with 77 apartments. The ground floor features common areas for 245 residents, including both refugees and locals seeking accommodation. The design

incorporates varied typologies to cater to diverse resident needs, emphasizing structural flexibility (Pilar, 2020).

Table 17

Architectural Features of Munich Old Office Utilized as Refugee Accommodation

Features	Description	Visuals
Function	The office building underwent a complete transformation to become residential apartments. Each apartment now includes kitchens and bathrooms, enhancing liveability. Additionally, the ground floor was modified to accommodate shared spaces for the residents.	
Common Spaces on the Ground Floor	- Entrance, Reception desk. - Lounge - Multifunction area with kitchen and dining room. - Childcare area - Volunteer area - Administration area - Healthcare area	 Ground Floor Plan
Plan Typologies	The apartment options vary based on family size, accommodating a maximum of two, four, five, or eight people each	 Typology of Housing Units
Reference: (Pilar, 2020)		

2.5 Elaboration of Refugee Accommodation Categorization

2.5.1 By construction material. Refugee accommodations can be categorized based on the construction materials used. To categorize refugee accommodations by construction materials, it is essential to consider the materials used in the construction of shelters. According to Maqusi (2017), the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA) began replacing all refugee tents with prefabricated shelters made from various materials, including zinc sheets, wooden sheets, and corrugated metal roofs (Maqusi, 2017). These materials are commonly used in refugee accommodations and provide insight into the construction materials

utilized in such shelters. The construction materials used in refugee accommodations include zinc sheets, wooden sheets, corrugated metal roofs, steel, concrete, bamboo, wood, tarpaulin, aluminum, and bamboo (Kudrat-E-Khuda, 2020). These materials are chosen based on factors such as durability, resistance to natural hazards, energy efficiency, and the ability to provide thermal comfort for refugees. For instance, the use of zinc sheets, wooden sheets, and corrugated metal roofs in prefabricated shelters has been observed in refugee camps (Maqusi, 2017). Additionally, tarpaulin, aluminum, and bamboo are widely used as major shelter materials in specific refugee camp areas (Kudrat-E-Khuda, 2020).

Misselwitz & Steigemann (2022) in their study discussed communicative constructions of space in refugee camps and argued that understanding spatial practices can help understand societal changes. Their investigation focused on using locally available sustainable construction materials and techniques, such as earth-bag construction, to achieve sustainability and energy efficiency in refugee shelters and concluded that spatial and material appropriations in refugee camps transform shelters into homes (Misselwitz & Steigemann, 2022). Ibrahim et al. (2023) proposed the use of earth architecture, specifically earth-bag construction, as the primary building technique for refugee housing units in Northern Serbia. The proposed prototypes reached the accepted levels of thermal comfort and predicted mean vote (PMV), which can save up to 10,000 kWh of energy per unit per year (Ibrahim et al., 2023).

Christian & Feriadi (2022) developed a modular temporary shelter model using local materials and architecture, considering the local elements and space requirements for refugees. The use of local plant-based materials, such as straw, reeds, wood, and clay, can reduce the carbon footprint of temporary shelters, achieving a negative carbon impact (Christian & Feriadi, 2022). Additionally, Cicevic & Gamble (2020) proposed the use of earthbag construction for refugee housing in Southeastern Europe. The proposed housing unit utilizes the efficiency of the hexagonal form to create communal housing clusters (Cicevic & Gamble, 2020). Construction materials have an important impact on the carbon footprint of shelters, as highlighted in a study on the carbon footprint of transitional shelters (Kuittinen & Winter, 2015). They concluded that the choice of construction materials significantly influences the

environmental sustainability of refugee accommodations. Table 18 describes various types of refugee accommodation categorization based on the construction materials.

Table 18

Refugee Accommodation Categorization Based On Construction Materials

Type	Material		Description
Tents	Canvas, Polyester	Nylon,	Pros: - Valuable in the immediate relief phase - Lightweight for transport and distribution - Proven design - Can be winterized - Large production capacities - Quick to install Cons: Inflexible - May be unstable in high winds or heavy snow - Difficult to heat Reference: (Handbook, 2024)
Prefabricated Units	Metal, Plastic	Wood,	Pros: - More durable than tents - Provide better insulation and security - Modular nature allows for flexibility in layout and expansion Cons: - Higher initial cost and logistical challenges in transportation and assembly - May require more time to deploy than tents Reference: (Handbook, 2024)
Emergency Housing Units (EHUs)	Lightweight Metal Frames, Insulated Panels, Weather-Resistant Fabrics, Plywood, Composite Flooring		Pros: - Prefabricated modular units designed for quick assembly - Insulated, weather-resistant, and often stackable – Resource Efficiency Cons: - Limited Lifespan – Cost – Limited indoor space for larger families - Lack in access to water, sanitation and electricity Reference: (Gutierrez, 2017), (Oliva, 2022)
Container Homes	Corten Steel, Spray foam, fiberglass, rigid foam boards for insulation, Interior: Plywood, drywall		Pros: - Repurposed shipping containers converted into living spaces - Sturdy, stackable, and adaptable – Weather-resistant – Modularity – Easily modifiable and combinable Cons: - Standard container dimension of 20 or 40 feet brings limited space – Insulation challenge – Transportation cost – Industrial appearance may cause psychological impacts Reference: (Baumann, 2020)
Adapted Buildings	Existing materials (brick, concrete, wood)		Pros: - Better protection and comfort than temporary shelters - May require less investment in construction materials Cons: - Limited availability and the potential need for significant refurbishment - May not be designed for housing large numbers of people - leading to overcrowding Reference: (Asylum Information Database, European Council on Refugees and Exiles, 2023)

Table 18 (cont.d)

Earth-bag construction	Earth-bag	Pros: - Cost-Effective - Sustainable - Versatile - Durable and Strong Cons: - Labor Intensive - Long-Term Durability Concerns - Regulatory and Cultural Acceptance Reference: (Ibrahim et al., 2023)
Traditional Shelters	Natural materials (bamboo, straw, mud)	Pros: - local materials – engagement of the local community in the construction process – Quick deployment - Customization Cons: - May not provide adequate protection against harsh weather conditions - Durability and safety can vary based on construction quality – Infrastructure challenges Reference: (Kudrat-E-Khuda, 2020) (Kuittinen & Winter, 2015)
Timber studs	Wood	Pros: - Environmentally friendly (if sustainably sourced) - Carbon-absorbing properties - Suitable for creating a homelike environment Cons: - May require skilled labour for construction - Limited availability in some contexts- Short durability (life span) Reference: (Wood Is a Sustainable Construction Material for Refugee Camps and Helps to Create a Homelike Environment, 2022), (Albadra et al., 2018)
Plastic Sheeting	Plastic Sheeting	Pros: - Flexibility for use in both urban and rural settings - Often combined with rigid materials- Lightweight and versatile Cons: - Not as durable as other materials - May degrade over time - VOCs emitted by plastic can cause respiratory irritation, headaches, and other health issues. In crowded refugee accommodations, poor ventilation may exacerbate these effects Reference: (Handbook, 2024), (From Plastic Problem to Shelter Solution NRC, n.d.)

2.5.2 By Duration of use. Refugee accommodations can be categorized based on the duration of use. Short-term accommodations are equipped with basic living facilities and provide temporary refuge (Costa et al., 2019). Mid-term accommodation offers concentrated assistance facilities for a stay of up to 30 days, along with medical assistance (Chu & Xiang, 2013). Long-term accommodations have comprehensive facilities and are intended for stays longer than 30 days, including some emergency rescue functions (Mercader-Moyano & Porras-Pereira, 2023). The type of accommodation available to displaced individuals is influenced by the duration of use and by various environmental and anthropological factors (Roguski & Cygańczuk, 2023). The aim is to provide a shelter that offers warmth, security, and comfort,

allowing refugees to gradually resume their lives until they can return to their country of origin (Krämer et al., 2019). The housing situation of refugees in destination countries often falls below the average housing standard, with shared accommodations being common. These shared accommodations can include flats, old factories, gyms, hotels, container buildings, or tents. Table 19 demonstrates the categorization of Refugee Accommodation based on their duration of use.

Table 19

Refugee Accommodation Categorization Based On Duration Of Use

Accommodation Type	Duration of Use	Example
Arrival Centers	Short-term (Days to weeks)	Initial reception centers where refugees are first housed upon arrival in a host country. (Chen & Knöll, 2022)
Homestay Accommodation	Medium-term (Months)	Refugees live with host families, integrating into local communities while longer-term solutions are sought. (Bassoli & Luccioni, 2023)
Resettlement Housing	Long-term (Years)	Permanent housing is provided as part of the resettlement process, aimed at facilitating long-term integration into the host society. (Brown et al., 2022)
Mixed Accommodation Options	Variable	Depending on individual or family needs, a mix of short-term and longer-term housing solutions, including temporary shelters, homestays, and resettlement housing. (Housing Support for Ukrainian Refugees in Receiving Countries, n.d.)

Environmentally friendly camps can improve environmental quality and decrease ecological impact. Higher priority is considered for environmental and social sustainability than economic for temporary accommodations by camp organizations. However, sustainable camps frequently enhance operational efficiency, leading to decreased maintenance expenses and ultimately yielding financial advantages (Larson et al., 2023). Ravi (2019) studied the link between refugee camp sustainability and dehumanization to find out the sustainable development of refugee camps. In this context, he defined sustainable development as a systems approach employed to deeply understand the relationship between people (social), economic and environmental aspects, in which social and environmental sustainability aspects are mainly focused on in the present thesis.

Wardeh and Marques (2021) compared refugee camps, such as Zaatari in Jordan and Dadaab in Kenya, regarding the United Nations 2030 Agenda to analyze the Sustainability Development Goals in the context of these camps. They revealed that both camps have failed to provide environmental and social sustainability. The unauthorized intervention in the planning and placement of dwellings in the Zaatari camp reveals the social unsustainability of migrants (Wardeh & Marques, 2021), which led people to combine containers and construct indoor toilets, bathrooms and kitchens. These initial life requirements are not provided with the existing layout of these camps. Sustainable prototypes for displaced people should also consider aspects such as lifespan, socio-cultural and affordability, thermal performance, energy efficiency, and environmental impact. (Ibrahim et al., 2022).

Table 20 illustrates the 17 global Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development, which aimed at addressing various social, economic, and environmental challenges to achieve a more sustainable and equitable future for all.

Table 20

2030 Agenda Sustainability Goals Adopted By The United Nations In 2015 (THE 17 GOALS | Sustainable Development, N.D.)

SDGs	Goals	Description
SDG1	No Poverty	End poverty in all its forms everywhere.
SDG2	Zero Hunger	End hunger, achieve food security, and promote sustainable agriculture.
SDG3	Health and Well-Being	Ensure healthy lives and promote well-being for all at all ages.
SDG4	Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
SDG5	Gender Equality	Achieve gender equality and empower all women and girls.
SDG6	Clean Water and Sanitation	Ensure the availability and sustainable management of water and sanitation for all.
SDG7	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all.
SDG8	Decent Work and Economic Growth	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.

Table 20 (cont.d)

SDG9	Industry, Innovation and Infrastructure	Develop robust infrastructure, encourage inclusive and sustainable industrial growth, and nurture innovation.
SDG10	Reduction of inequalities	Reduce inequality within and among countries.
SDG11	Sustainable Cities and Communities	Create inclusive, safe, resilient, and sustainable urban areas.
SDG12	Responsible Consumption and Production	Ensuring sustainable consumption and production patterns.
SDG13	Climate Actions	Taking urgent action to combat climate change and its impacts.
SDG14	Life Below Water	Promote sustainable ocean use for development.
SDG15	Life on Land	Promote sustainable land use by conserving ecosystems, managing forests, and combating desertification.
SDG16	Peace, Justice, and Strong Institutions	Promote fair, sustainable, and inclusive communities with accessible justice and efficient institutions.
SDG17	Partnership for the Goals	Enhance the mechanisms for implementation and rejuvenate global partnerships to promote sustainable development.

2.6 Environmental Sustainability

Environmental sustainability involves the responsible management of natural resources to fulfil current needs while ensuring future generations can also meet theirs. This approach requires a careful equilibrium among environmental, societal, and economic considerations, fostering a symbiotic relationship between humanity and nature. Actions aimed at preserving natural habitats, minimizing pollution, encouraging sustainable behaviours, and tackling global warming are pivotal in securing a thriving Earth and enhancing the quality of life universally. (Gulzar et al., 2023) Additionally, environmental sustainability involves aspects such as access to clean water, sanitation facilities, waste management, and energy efficiency. (Khalil et al., 2022)

The Handbook for Emergencies (3rd edition), published by UNHCR (2007), provides guidelines for planning refugee camps. It discusses the environmental aspects and sustainability of temporary camps in a limited way. De Rooij and colleagues (2016) emphasized the Handbook for Emergencies' limitations, especially regarding sustainability parameters, including emission control and green infrastructure. They gathered an internal report focusing on sustainability strategies such as efficiency of

resources, climate-proof, socially inclusive, resilient, and self-regenerative to increase the liveability and resilience of refugee camps. The UNHCR Emergency Handbook (2015) emphasizes that selecting appropriate sites for refugee camps is crucial for ensuring a safe and healthy environment for displaced individuals. De Rooij et al. (2016) mention the important factors to consider for the selection of sites, including Topography, Water resources, Land rights, Accessibility, Security, Environment and Vegetation (De Rooij et al., 2016: P.8).

Temporary accommodation suffers from both environmental pressures and inadequacies of services and facilities. Tiwari et al. (2023) proposed a sustainable refugee camp and recommended both the site and building scale of the camp for the Bekka Valley in Lebanon. Within this study, they investigated the present challenges including climate matters, unplanned growth of shelters, and social and physical infrastructure availability to apply sustainable design interventions such as rainwater provision, basic unit dimensions, components installation, flood resilience techniques, sanitation and health facilities, solar panel installations, water and solid waste management techniques and green recreational spaces.

Shelter and Settlement Standard 7, which emphasizes environmental sustainability, highlights the importance of establishing, restoring, and promoting safe, reliable, affordable, and environmentally sustainable energy supply systems. This measure aims to balance present needs without compromising the ability of future generations to meet their requirements (Li et al., 2024). Table 21 declares the environmental opportunities and strategies to bring sustainability into the refugee camps to make them resource-efficient and climate-proof.

Table 21

Environmental Opportunities And Strategies To Bring Sustainability Into The Refugee Camps

Strategy	Description	Visuals
Energy	- Installing solar roofs on community buildings and creating shaded areas in agricultural zones can decrease reliance on the power grid by 30%. Reference: (Tiwari et al., 2023)	-

Table 21 (cont.d)

Greenery and heat stress	- Trees alongside the road, Rooftop gardens, Gardens next to the shelters - Reduction of heat stress and air pollution, rainfall retention, insulation, improvement of well-being, food production potential Reference: (De Rooij et al, 2016)	-
Waste Management	- Compressed solid waste -Earthquake resistant, Bio-degradable Reference: (De Rooij et al, 2016)	-
Water supply	- Implementing water recycling, rainwater harvesting, and groundwater recharge reduces reliance on external water trucks and associated costs Reference: (Tiwari et al., 2023)	-
Recreational Spaces	Vegetable garden and play garden in units for the utility and recreation of the community Reference: (Tiwari et al., 2023)	
Rainwater harvesting (RWH) provision	Utilizing each unit to RWH pipe Reference: (Tiwari et al., 2023)	
Flood resilience	Construction of shelters 1 m elevated from the +0.0 ground using corrugated flexible RP sheets stacked in honeycomb (HC) cells Reference: (Tiwari et al., 2023)	

2.6.1 Environmental impact. Environmental impacts associated with refugee camps can detrimentally affect local ecosystems, leading to issues such as pollution, deforestation, and overuse of water resources. Recognizing and addressing these challenges is pivotal for devising effective mitigation strategies. This includes the adoption of more ecologically responsible waste management practices and the careful management of natural resources to prevent their exhaustion. By implementing these strategies, the long-term viability of refugee camps can be greatly improved, allowing them to coexist harmoniously with their natural surroundings.

The UNHCR acknowledges that while their efforts have generally sustained refugee populations, there's a growing awareness of the environmental consequences tied to refugee situations. These include damage from concentrated refugee populations and the absence of consistent policies for rehabilitating affected areas after repatriation. Uncontrolled use of natural resources (like fuel wood and water and poaching) is also a concern. Importantly, these environmental impacts can adversely affect both the local population and the refugees' well-being (De Rooij et al., 2016).

The Environmental Guidelines stress that the condition of the environment significantly impacts the welfare and well-being of individuals residing in the area, including refugees, returnees, and local communities (De Rooij et al., 2016).

The use of fossil fuels and unrennewable energy sources for camps and migrants' temporary accommodations is not only an unsustainable energy method. It increases the environmental impacts but also has negative consequences on health conditions (Neves et al., 2021). Excessive use of natural resources, materials, energy, land, and money are other environmental impacts caused by increased displaced people, directly increasing pollution and waste.

Jacobsen (1997) declared that the environment is directly impacted by the location and type of the camp, which results in environmental degradation. Ravi (2019) mentioned two categories of camps regarding their environmental impacts in the theoretical background of their thesis, including a) camps that did not have much environmental impact because they were located in areas with no resource abundant, b) camps that inappropriate design and management led to environmental impact in a long time and the pollution caused "by the material (Food and NFIs) brought into the camp by INGOs. Kaiser (2006), however, criticizes this method and states that an increase in family members increases the need for intensive farming, which may result in faster soil degradation and bring more environmental impact, such as floods. Table 22 mentions the environmental impacts of each refugee camp category based on Ravi's (2019) vision.

Table 22

Ravi's (2019) Vision On The Environmental Impacts Of Three Refugee Camp Categories

Category	Environmental Impact	Definition
Emergency Relief Camps	Impact on water resources	Emergency camps often rely on nearby water sources, leading to overuse and contamination. Increased demand can strain local water availability.
	Deforestation	The need for firewood and shelter materials results in deforestation around these camps, affecting local ecosystems.
	Soil erosion	High population density and inadequate infrastructure can lead to soil erosion, especially during monsoons.
	Waste management	Improper waste disposal can pollute the environment and harm nearby water bodies.
Planned Agricultural Settlements	Land use changes	These settlements require land for agriculture, potentially altering natural habitats.
	Water management	Irrigation systems and water usage impact local water availability.
	Soil degradation	Intensive farming practices may degrade soil quality over time.
	Biodiversity	Agricultural activities can affect local flora and fauna.
Long-Term Camps	Long-Term Impact	Protracted camps exist for years, leading to cumulative environmental effects.
	Overuse of Resources	Continued reliance on wood for fuel, water, and other resources can strain ecosystems.
	Waste Accumulation	Waste generation increases over time, challenging waste management systems.
	Habitat Fragmentation	Camp expansion can fragment natural habitats and disrupt wildlife.

According to Neves et al. (2021), due to economic limitations, the energy supply for camps is lower than the actual demand and usually utilizes an old method, which is not only not cost-effective but also is an environmental pollutant. Numerous refugee camps persist for extended periods, spanning years or even decades. Despite concerted global efforts, these camps continue to expand in both size and population, exerting significant impacts on regional sustainability including alterations in land use, resulting in the loss of natural and agricultural areas, soil degradation through sealing and erosion, increased water consumption and pollution, elevated greenhouse gas

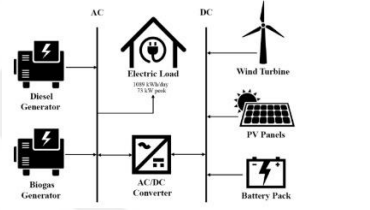
emissions due to traffic, supply logistics, heating, and energy usage, long and often unstable food supply chains, leading to food insecurity and wastage, social isolation and conflicts arising from high population density and a lack of open spaces (De Rooij et al, 2016). Table 23 illustrates the list of environmental impacts caused by the unsustainability of the migrants' accommodation.

Table 23

The Environmental Impacts Caused By The Unsustainability Of Refugee Camps

Environmental Impacts + Resources	Reason and Solution	Visuals
Loss of natural and agricultural land (De Rooij et al, 2016)	Substantial land use	-
Soil sealing and erosion (De Rooij et al, 2016) (Jacobsen, 1997)	- Reason: Overuse of land, insufficient fallow periods - Solution: Sustainable land-use practices, integration with the local community	-
Deforestation (Jacobsen, 1997)	- Reason: Clearing land for camps, need for firewood and shelter - Solution: Reforestation projects, improved stove dissemination	-
Water Source Depletion (De Rooij et al, 2016) (Jacobsen, 1997)	- Reason: Increased water consumption and pollution - Solution: Improved water management, technical assistance	-
Greenhouse gas emissions (De Rooij et al, 2016)	Due to traffic, supply logistics, heating, and energy consumption	-
Food insecurity and food waste (De Rooij et al, 2016)	-	-
Climate hazard (Tiwari et al., 2023)	- Reason: Organic expansion of tents increases exposure to disasters like heavy winds, snow, and flooding - Solution: Implement climate-sensitive design in the master plan to safeguard against climate risks.	 Left: Flooded Streets of Dalhamiye Shelters Right: Refugees removing snow from their shelters

Table 23 (cont.d)

Water Scarcity (Tiwari et al., 2023)	- Reason: Over-reliance on water trucks and borewells due to inadequate water infrastructure. - Solution: Rainwater harvesting, water recycling, and ground water recharge to reduce dependence on external water sources.	
Deforestation (Neves et al., 2021), (Defining Clean Fuels and Technologies, n.d.-b)	- Reason: Overuse of firewood for cooking - Solution: Introduce efficient cookstoves and alternative fuels such as solar cookers, biogas stoves and electric induction cooktops	 Gaza: People turn to firewood to survive as energy prices soar, (france24.com)
Air pollution (Neves et al., 2021),	- Reason: Emissions from diesel generators and biomass burning - Solution: Implementation of hybrid renewable energy systems (HRES)	 
Waste Accumulation (Jacobsen, 1997)	- Reason: Concentration of people, inadequate disposal - Solution: Proper waste management, infrastructure planning	Waste accumulation in Dadaab refugee camp (icrc.org)

2.6.2 Resource efficiency. Resource efficiency refers to the effective and optimal use of resources in various sectors, such as agriculture and manufacturing, to maximize output while minimizing waste and negative environmental impacts. It encompasses technical, allocation and environmental skills and aims to improve productivity, reduce costs, and enhance sustainability. Resource efficiency is crucial for achieving climate protection goals and reducing reliance on international raw material markets (Maaß et al., 2017). Resource efficiency supports the shift to a circular economy by aligning resource, water, and energy use with environmental limits. It promotes substituting non-renewables, improving efficiency, recovering waste value, and unlocking broad economic benefits (Van Berkel & Fadeeva, 2020).

Building construction materials can be categorized into two main types: natural materials and synthetic materials. Natural materials include resources like earth, wood, hay, and stone, while synthetic materials encompass steel, concrete, and plastic. The selection of appropriate materials impacts various aspects, including functionality, safety, indoor environmental performance, and overall lifespan. In addition, affordability, material availability, time management, indoor environmental quality, energy efficiency, durability, aesthetics, and sustainability considerations are several main factors for the selection of material resources (Rojhat, 2023).

Table 24

Categories Of Environmental Inputs

Categories	Types and Definitions	Innovations
Raw materials (Pathak, 2024)	- Steel: Mined metal material used in construction and manufacturing. - Oil: Mined liquid resource used for energy production and industrial processes. - Grain: Plant-based crop used for food and animal feed. - Gasoline: Refined oil product used as fuel for vehicles. - Lumber: Plant-based wood material for construction and furniture.	- Recycling: Efficiently reusing raw materials to reduce waste. - Advanced Materials: Developing stronger, lighter, and more sustainable materials.
	- Plastic: Synthetic or natural polymer used in various products. - Natural Gas: Mined gaseous resource used for heating and electricity generation. - Coal: Mined solid fossil fuel used for energy production. - Mineral: Mined solid inorganic substances with various industrial applications. - Corn: Plant-based crop used for food, animal feed, and biofuel. - Forest Resources: Plant-based natural assets provide timber, biodiversity, and ecosystem services.	- Circular Economy: Designing products for reuse and recycling. - Biodegradable Plastics: Environmentally friendly alternatives to traditional plastics.

Table 24 (cont.d)

Energy (Bello, 2023)	- Solar Energy: Harvesting sunlight for electricity and heating.	- Floating Solar Panels: Install solar panels on water bodies.
	- Hydropower: Using flowing water to generate electricity.	- Perovskite Solar Cells: Efficient and cost-effective.
	- Geothermal Energy: Tapping into Earth's heat for power.	- Solar-Powered Trains: Sustainable transportation
	- Wind Energy: Using wind turbines for power generation.	
Water (Bello, 2023)	- Drinking Water: Essential for human health.	- Remote Sensing: Accurate water analysis using drones.
	- Irrigation Water: Supports agriculture.	- Virtual Collaboration Platforms: Enhance water management.
	- Industrial Water: Used in manufacturing processes.	- Water-Use Efficiency Technologies: Reduce waste.
Air	- Air Quality: Monitoring and improving air conditions.	- Catalytic Converters: Reduce emissions from vehicles.
	- HVAC Systems: Efficient heating, ventilation, and cooling.	- Smart Thermostats: Optimize HVAC energy use.
	- Air Pollution Solutions: Technologies to reduce pollutants.	- Biomimicry: Learning from nature to improve air quality
Land/Soil	- Arable Land: Used for crop cultivation.	- Drone-Based Soil Mapping: Accurate soil analysis.
	- Forest Soils: Support biodiversity and carbon storage.	- Organic Amendments: Sustainable soil enrichment.
	- Urban Soils: Found in cities and affects urban ecosystems.	- Nanomaterials for Soil Improvement: Enhance water retention

Resource efficiency in refugee camps involves using limited resources such as water, food, and building materials most effectively and sustainably. This includes strategies to ensure the efficient distribution of aid, the use of sustainable building materials for shelters, and the implementation of water-saving technologies (Rosenberg-Jansen, 2022). Equipment of camps to Zinc tanks, as a method of water resources efficiency, can reduce the Domestic Hot Water (DHW) consumption to 15 liters per person out of 30 liters from its initial consumption rate. This method

decreases the energy consumption of DHW in summer by collecting the heat from solar radiation (Site Planning and GBV Booklet (Third Edition, April 2018) | Shelter Cluster, 2017). Therefore, the use of heating energy can also be decreased by the implementation of Zinc Tanks. Jacobsen (1997) declared that agricultural settlements can be seen as a form of resource efficiency by maximizing the productive use of land and resources for the benefit of refugees and host communities. Agricultural settlements aim to help refugees become self-reliant by providing them with land and resources to grow their food. By enabling refugees to produce their food, these settlements contribute to the stability of food supplies (Jacobsen, 1997).

2.6.3 Energy efficiency. Energy efficiency in refugee camps is about reducing the amount of energy required to provide necessary services such as lighting, cooking, and heating. This can be achieved through the use of energy-efficient technologies, the adoption of renewable energy sources like solar power, and the design of energy-efficient buildings and infrastructure.

Larson et al. (2023) declared that although many camps use energy-efficient appliances such as low-flow showers and toilets, sustainable energy and water consumption are considered the largest challenges to camp organizations. According to their studies, resource-intensive and long-term solutions have not been applied by camps. For instance, camps are not equipped with sustainable methods such as renewable electricity sources, water or energy audits, fuel-efficient vehicles, and capturing and reusing rainwater or greywater.

The compact layout plan system has been found to have superior energy performance for heating, while the open layout plan system is superior for electric cooling assessment. The open-layout plan system also demonstrates superior thermal comfort performance in terms of the number of accepted hours and better results in terms of carbon dioxide (CO₂) concentration levels (Ibrahim et al., 2022). Neves et al. (2021) proposed replacing diesel generators in refugee camps with more robust, efficient, and sustainable power production systems, including hybrid renewable energy systems like mini-grids with biogas generators. Implementing hybrid renewable energy systems (HRES) that combine solar, wind, and biogas sources is recommended due to their economic efficiency and potential cost savings.

Biogas production is highlighted as an alternative energy source for cooking and power generation in refugee camps, emphasizing the collection and processing of human and organic waste. Improved waste disposal and management systems are also recommended to facilitate organic waste collection for biogas production, addressing waste management challenges while contributing to sustainable energy solutions.

Neves et al (2021) provided an energy modelling of the actual energy demand of Mantapala refugee camp, they proved that equipping camps with hybrid renewable energy mini grids instead of diesel generators can save CO₂ emissions of 55% and up to 100% if a biogas generator is considered (Neves et al, 2021).

Rojhat et al. (2022) declared that Proper planning and design systems are crucial for the sustainable and efficient construction of shelters. He mentioned that the Horizontal-compact layout plan system has superior energy performance for heating, while the Open-layout plan system is superior for electric cooling and thermal comfort. Tables 25 and 26 demonstrate the Energy Efficiency solutions for migrants' camps.

Table 25

Indoor Environmental Conditioning Technologies

Technologies	Description	Reference
Heat Recovery Ventilation (HRV) Systems	- HRV systems recover heat from exhaust air and transfer it to incoming fresh air. - They improve indoor air quality while reducing energy consumption	(Woodford, 2021)
Energy Recovery Ventilation (ERV) Systems	- ERV systems recover both heat and moisture from exhaust air. - They maintain a comfortable indoor environment while minimizing energy use	(Yang et al., 2015)
High-Efficiency Air Source Heat Pumps (ASHP)	- ASHPs extract heat from the outdoor air and transfer it indoors. - They are efficient, especially in moderate climates.	(Wang et al., 2020)

Table 26

Energy Efficiency Solutions For Increasing The Migrants' Camps Sustainability

Solutions	Description
Replacing diesel generators with hybrid renewable energy mini-grids (Neves et al. 2021)	Such as PV-biogas-batteries systems, to observe payback periods lower than five years and decrease the Cost of Energy
Implementing biogas generators (Neves et al. 2021)	To run exclusively on renewable energy, improving air quality and achieving CO ₂ emissions savings of up to 55% or even 100%.
Deploying solar lanterns for lighting purposes and phone charging (Neves et al. 2021)	To support increased security and communal activities after nightfall.
Implementing solar-powered streetlights (Neves et al. 2021)	To support increased security and communal activities after nightfall.
Installing solar PV water pumping systems (Neves et al. 2021)	To make access to water cleaner and more sustainable.
Cleaner cooking solutions (Neves et al. 2021)	By collecting biowaste from latrines for use in communal kitchens, thus solving waste management issues.
Zinc Water Tanks (Rojhat, 2023)	By implementing them on the roof of shelters, the consuming water does not need to be warmed, especially in summer. Consequently, the ratio of DHW (Domestic Hot Water) will be decreased significantly
Bottom-up construction method. (Rojhat, 2023)	Utilizing low-impact materials and methods to minimize energy use and improve indoor environmental performance. Developing core shelters' energy and thermal comfort performance.
Renewable energy-powered micro-grids (MGs) (Soudan & Darya, 2021)	An energy-efficient strategy for providing electricity in refugee camps. These MGs are based on remote hybrid power systems (RHPS) that involve the use of renewable energy sources such as solar power, coupled with storage and backup generators.

2.7 Social Sustainability

Quarantelli (1995) explains the concept of shelter as a temporary place to accommodate and live right after the disaster while he differentiates it from the meaning of housing. As he expresses, sheltering stops someone's daily activities while

housing takes them back to their usual home tasks and daily life. The essential need of migrants to have a sense of belonging when they are displaced is one of the critical aspects of the social sustainability of accommodations. Therefore, the word housing can emphasize the humanitarian acts that everyone does daily over the word accommodation (Kennedy et al., 2008).

In terms of social sustainability, Campbell (2012) and Roberts et al. (2009) investigated the camp migrants' quality of life regarding the housing conditions and environmental factors such as overcrowding negatively impacts the physical and mental health and life satisfaction of migrants.

The living conditions in the Burj Barajneh Palestinian refugee camp in Lebanon and their association with the social sustainability and health of the residents have been provided by Habib et al. (2006). Overcrowding and inadequate infrastructure in refugee camps have been linked to environmental health risks, highlighting the necessity for improved living conditions to ensure the well-being of refugees (Habib et al., 2006). Table 27 illustrates the accommodation features and their impact on social sustainability and indoor environmental quality.

Table 27

Social Sustainability And Indoor Environmental Quality Of Burj Barajneh Palestinian Refugee Camp

Features	Impact on Social Sustainability	Impact on Indoor Environmental Quality
Infrastructure & Services	Poor infrastructure contributes to social instability and health risks.	Inadequate water and sewage systems can lead to unsanitary conditions.
Housing Conditions	Substandard housing exacerbates social disparities and hinders community well-being.	Issues like humidity, infestation, and lack of heating affect residents' health.
Crowding	Overcrowding can strain social relations and limit access to private space.	High occupancy levels can increase the spread of infectious diseases.

2.7.1 Indoor environmental quality and well-being. The health and well-being of displaced individuals are closely tied to both energy availability and indoor environment quality. Indoor Environmental Quality (IEQ) includes a range of parameters that influence the comfort, health, and overall welfare of individuals inside constructed areas. These parameters are essential for establishing comfortable and efficient indoor settings, including Thermal Comfort (TC) and Indoor Air Quality (IAQ). (Diaz et al., 2021) Moran et al. (2021) concentrated on improving the indoor thermal conditions of migrant camps by studying the Azraq camp in Jordan. Two methods were used to evaluate the indoor air quality: a physical prototype of 12 laboratory shelters that have been monitored for ten weeks (active and passive improving methods applied to each case) and thermal energy modelling.

Among the shelters, one remained unchanged as a control. Eight shelters underwent passive adaptations, while two received active adaptations. Additionally, one shelter received a combination of both active and passive modifications. All these adaptations were specifically aimed at enhancing internal thermal comfort during the summer.

The result of their investigation revealed the advantages of the prototyping method over energy modelling and an improvement of indoor thermal conditions up to 6 degrees by utilizing simple adaptations. Table 28 reveals the active and passive strategies applied to the shelter prototypes to improve the indoor environmental quality.

Table 28

Active And Passive Strategies Applied To The Shelter Prototypes (Moran Et Al., 2021)

Prototypes	Applied strategies - Technical	Thermal Performance Impacts
P1: Controller	No modifications or adjustments were made to compare with the primary condition	-
P2: Desert cooler	Installing homemade evaporative coolers (desert coolers) powered by photovoltaic panels	- Reduce internal peak
Active	- Positioned on the north side of shelter - It contains a water-filled tray - Circulates water through a tube	summer temperatures

Table 28 (cont.d)

P3: Ventilated external skin	- The outer metal cladding was removed - Metal section counter battens were added to create an air path from ground level to eaves on the front/rear and one side	- Allow air to pass through the cavity
Passive	- Wall and roof cladding were removed on all external elevations. - Gaps in the insulation were filled or covered with new insulation.	
P4: Designing insulations instead of installation	- Cladding was reattached using 15 mm PVC spacers behind each screw fixing to prevent insulation compression at the metal frame. - The insulation joints were overlapped by 50 mm.	- Solving the issue of air flow through gaps between the sheets, causing a thermal bypass.
Passive	Additionally, the entrance door and kitchen extension door were insulated (previously uninsulated)	
P5: Roof and low-level vents fitted	Additional window-like openings were cut. - In Shelter S05, original vents were sealed, and new roof cowls and low-level inlet vents were added	- Additional ventilation
Passive		
P6: Wall cavity filled with thermal mass	- Adding a total mass of 3000 Kg to wall cavity (60 mm wide in main walls, 30 mm wide in gable ends) was filled with sand and gravel	- Storing heat or the cold
Passive		
P7: 3 layers of 15 mm insulation	- Two Insulation layers with a maximum of 45mm thickness were added - Joints were lapped by 50 mm and staggered.	- Enhance the U-values
Passive	- Two additional layers of insulation were added to the walls and roof. - Three insulation layers added to doors.	
P8: Complex combination of roof	- Two roof cowls and roof shading were installed. - A form of shallow earth tube was implemented using below slab air inlets.	- Improved energy efficiency and comfort
Passive and Active	- Four below-ground slab pipes were introduced, consisting of two air inlets from each gable end - The inlets were strategically located in the living area, opposite the gable inlet. - A roof shade was installed to reduce solar heat gains via the roof.	- Provides additional shading for both the walls and the south-facing window.
P9: Roof Shade	- The roof shade overhangs the existing walls by 300 mm.	- This design allows for an air path from eaves to ridge, with the air exiting through a raised ridge cap.
Passive	- The roof shade is constructed using 150 mm high × 30 mm angle frames placed at 1000 mm centres.	

Table 28 (cont.d)

P10: Thermal mass	- Adding sandbags to the internal walls. - 250 mm sandbags internally to 2.1 m.	- An increase in mass
Passive		
P11: XPS insulation + Roof Shade	- A sandwich panel consisting of metal layers with an insulating core made of expanded polystyrene (EPS). - 40 mm extruded polystyrene insulation was used as a substitute.	- Reduced mass of the frame needed. - Increased build speed.
Passive	- Earth tubes buried 1.5 meters below the surface.	
P12: Earth tube + Fan driven + PV powered	- Used three 100 mm diameter pipes instead of one 300 mm diameter pipe. - Pipes spaced 100 mm apart at the trench bottom, covered with backfill material. - Inlets with 300 W (PV powered) fans in a covered housing for sun and rain protection.	- providing an identical surface area for heat transfer - triple arrangement reduces coolth extraction (due to close pipe proximity)
Active		

Over two typical days, various interventions were monitored for their impact on internal daytime temperatures. (Moran et al., 2021) Except for the ventilated wall cavity, all other interventions resulted in lower internal temperatures compared to the control. The use of thermal mass (a passive measure) in the form of sandbags and a desert cooler (an active measure) recorded the lowest daytime temperatures. Overall, the best-performing passive measures were the addition of thermal mass and all interventions, which contributed to reducing overheating.

Ibrahim et al. (2022) used both qualitative and quantitative methods. Design principles that can be added to migrants' dwellings to increase comfort and environmental sustainability include considering the morphological, siting, and layout of zones and shelters, as well as using low-impact construction materials and techniques. According to their findings, the horizontal-compact layout of shelters brings the most effective results according to PMV and PPD indicators. On the other hand, providing a special opening schedule is suggested for the compact layout in comparison to the layouts equipped with open yards to enhance the Indoor Air Quality of shelters with compact form typology. (Ibrahim et al., 2022).

Fosas et al. (2018) proposed a cyclical process to improve the thermal conditions of migrant camps by studying the Azraq camp in Jordan. Within a field survey, they

analysed the existing thermal conditions. They proved a significant reduction of overheating by applying architectural strategies, including a shading system, thicker insulation, and greater thermal mass. In addition to passive strategies that can enhance the Indoor Environmental Quality (IEQ), an efficient active system can improve the indoor condition.

2.7.2 Thermal comfort (TC). Thermal comfort is commonly defined as the favourable state of mind individuals feel regarding their perceived warmth or coolness, closely tied to their surrounding environment. It entails sustaining an ideal temperature range to ensure occupants don't feel excessively hot or cold. Elements affecting thermal comfort encompass ambient air temperature, humidity, airflow, and attire. Effective temperature regulation and ventilation are key factors in establishing a pleasant indoor atmosphere for occupants (Özdamar Seitablaiev & Umaroğulları, 2018). Thermal comfort and daylight are recognized as crucial factors contributing to indoor environmental quality. As per the ANSI/American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 55 (2004), thermal comfort is described as the state of mind where individuals express satisfaction with the temperature environment (Yılmaz & Yılmaz, 2020). Assessing thermal comfort involves considering various factors and models. Table 29 summarises some key aspects of different thermal comfort assessment modules.

Table 29

Typology Of Thermal Comfort Assessment Modules

Types	Description	Features	Tools/Models	References
Fanger Methods	These methods were developed for mechanically conditioned buildings and are widely used in practice.	- Developed for mechanically conditioned buildings. - Deterministic, based on fixed temperature ranges.	- Predicted Mean Vote (PMV) - Predicted Percentage Dissatisfied (PPD)	(Thermal Comfort Questions CBE Thermal Comfort Tool, n.d.) (CIBSE Journal, 2017)
Adaptive Fanger Method	These models account for behavioral adaptations by occupants. Recognize that comfort varies with individual preferences, clothing, and activity levels	- Varies with individual preferences and activities. - Adaptation to changing conditions over time.	- Adaptive Predicted Mean Vote (aPMV)	(Arsad et al., 2023) (Zhao et al., 2021) (CIBSE Journal, 2017) (Yao et al., 2009) (Wei et al., 2010)

Table 29 (cont.d)

Adaptive Thermal Comfort Model	- Developed as an alternative to the Predicted Mean Vote (PMV) model. - Global standard for designing naturally ventilated buildings. - Enhances comfort while reducing energy use	- Analyzes the relationship between indoor and outdoor temperatures. - Considers psychological and behavioral adaptation by occupants. - Considers clothing level, activity, and building type. - Used for designing naturally ventilated buildings.	- Adaptive Comfort Model (ASHRAE Standard 55, 2004)	(Bienvenido-Huertas & Rubio-Bellido, 2021)
Data Driven Models	These models use simulation algorithms and real-world data.	- Incorporate dynamic factors like solar radiation, clothing insulation, and metabolic rate. - Consider indoor and outdoor conditions.	- RayMan - EnergyPlus - CBE Thermal Comfort Tool	(Alizadeh & Sharifi, 2023)
Environmental Factors	These factors influence thermal comfort beyond individual sensations	- Include climatic features (e.g., temperature, humidity), ventilation mode, and building type - Impact comfort perception - Considerations in building design, urban planning, and green spaces such as Proper insulation, glazing, shading, green spaces, tree cover, urban heat island effects.	-Considerations in building design, urban planning, and green spaces	(CIBSE Journal, 2017)

ASHRAE Standard 55 serves as a commonly employed reference for maintaining thermal comfort indoors. It outlines prescribed temperature, humidity, air movement, and clothing insulation levels tailored to various seasons and activities. Integrating both PMV and Adaptive Comfort methodologies, ASHRAE 55 furnishes guidance on achieving satisfactory thermal conditions (CIBSE Journal, 2017). The Adaptive Comfort model recognizes individuals' ability to adapt to changing thermal environments, considering factors like seasonal fluctuations, acclimatization, and personal preferences. In contrast to the inflexible PMV model, it embraces a wider range of acceptable thermal conditions, mirroring the adaptability of individuals (Zhao et al., 2021). The Fanger PMV model anticipates the collective thermal perception, as indicated by the mean vote, capturing the overall sensation of temperature among a group. It takes into consideration elements like ambient air temperature, relative humidity, air movement, insulation of clothing, and metabolic activity. The PMV scale spans from -3 (indicating cold) to +3 (indicating hot), with 0 denoting a state of neutral thermal comfort (Arsad et al., 2023).

PPD (Predicted Percentage of Dissatisfaction) is derived from the PMV model, indicating the percentage of people expected to be dissatisfied with the thermal conditions. It's calculated by comparing the predicted PMV with the desired thermal comfort level. For instance, a 10% PPD means 10% of occupants would feel dissatisfied (Arsad et al., 2023).

2.7.3 Indoor Air Quality (IAQ). The quality of the air inside and around the building is considered as the Indoor Air Quality (IAQ) that is directly contributing to the comfort and health of inhabitants. The various parameters impacting the purity of indoor air are mentioned in Table 30.

Table 30

Pollutants Influencing The Indoor Air Quality

Pollutants	Description	Reference
Carbon Monoxide (CO)	A colorless, odorless gas produced by combustion processes (e.g., gas stoves, heaters, and car exhaust).	(Tran et al., 2020)
Volatile Organic Compounds (VOCs)	Emitted from products like paints, cleaning agents, and furnishings.	(Mannan & Al-Ghamdi, 2021)
Particulate Matter (PM)	Tiny particles suspended in the air, which can originate from cooking, smoking, or outdoor sources.	(Mannan & Al-Ghamdi, 2021)
Biological Pollutants	Such as mold, bacteria, and pollen	(Tran et al., 2020)
Pesticides	Building materials such as carpet, textiles, and cushioned furniture	(Tran et al., 2020)
Radon (Rn)	Soil gas, building materials, and tap water Outdoor air	(Tran et al., 2020)

The term Indoor Air Quality (IAQ) encompasses the attributes of the air within indoor settings, affecting the health, comfort, and productivity of occupants. According to Yilmaz & Yilmaz (2020), there is a noted decrease in productivity rate, estimated at 2% per each Celsius degree rise above 25°C. Techniques for assessing IAQ encompass the use of indoor air quality monitors, conducting evaluations for

mold and radon presence, installing carbon monoxide detectors, and vigilance for signs such as inadequate ventilation. Consistent monitoring and immediate action can facilitate the creation of a healthier indoor environment. For the evaluation of indoor air quality, various crucial modules should be considered, as outlined in Table 31.

Table 31

Modules Of Indoor Air Quality Evaluation

Module	Description
Controlling Common Outdoor Sources	- Arrange rooftop structures properly to prevent contamination from nearby outdoor sources. - Consider prevailing wind directions, as they affect outdoor air quality. - Employ maintenance strategies to prevent introducing pollutants into the building.
Controlling Common Indoor Sources	- Addressing indoor pollution sources like building materials, cleaning products, and furnishings. - Maintain and manage indoor systems like HVAC and ventilation to reduce pollutants.
Controlling Pollutant Pathways	- The movement of pollutants within the building (e.g., through air circulation, ducts, and pathways). - Implement measures to prevent or mitigate pollutant transfer.
Managing Moisture and Mold	- Monitor and control humidity levels to prevent mold growth. - Address any water leaks promptly to avoid moisture-related issues
Construction and Renovation Considerations	- Take preventive measures to maintain good IAQ during these activities
Preventive Maintenance	- Regularly maintain HVAC systems, filters, and other equipment. - Address any issues promptly to sustain good IAQ
Recognizing Signs of Occupant Distress	- Indications of discomfort or health problems linked to indoor air quality.
Reference	(Visual Reference Modules for the Indoor Air Quality Building Education and Assessment Model Indoor Air Quality (IAQ) US EPA, n.d.)

Architectural decisions impact both IAQ and overall occupant well-being. By integrating the Table 32 architectural considerations, the IAQ rate can be increased to reach more sustainable spaces.

Table 32

Architectural Considerations Of The Indoor Air Quality

Consideration	Description	Reference
Ventilation Design	- Natural Ventilation: Use operable windows and vents to allow fresh air. - Mechanical Ventilation: Install efficient HVAC systems with air exchange rates.	(Ogunmola & Fadairo, 2022)
Material Selection	- Low-Emission Materials: Select paints, adhesives, and flooring with low VOCs. - Natural Materials: Use wood, stone, or clay for finishes.	(Ogunmola & Fadairo, 2022)
Building Layout and Zoning	- Zoning: Separate kitchen areas from bedrooms. - Traffic Flow: Design layouts to avoid pollutant transfer	(Smith, 2023)
Daylight and Views	- Daylight: Use large windows and skylights. - Views: Position workstations near windows.	(Feichtinger, 2020)
Moisture Control	- Waterproofing: Seal building envelopes to avoid leaks. - Ventilation: Properly ventilate bathrooms and kitchens.	(Feichtinger, 2020)
Airtightness and Insulation	- Airtight Construction: Seal gaps and joints. - Insulation: Use energy-efficient materials.	(Feichtinger, 2020)
Indoor Plants and Biophilic Design	- Indoor Plants: Place potted plants in common areas. - Biophilic Elements: Use wood textures and natural colors.	(Feichtinger, 2020)
Maintenance Accessibility	- HVAC Accessibility: Ensure filters are easily accessible. - User Controls: Provide occupants with adjustable ventilation settings.	(Ogunmola & Fadairo, 2022)

2.8 Life Cycle Assessment

Sustainability principles are most impactful when integrated into every stage of construction and operation, spanning from initial planning to the end-of-life phase (Li et al., 2024). The life cycle perspective involves considering the long-term sustainability of refugee camps, from their establishment to their eventual closure or integration into local communities. This includes planning for the sustainable development of the camp infrastructure and ensuring that the camp can evolve to meet

the changing needs of its residents over time. It also involves considering the eventual dismantling of the camp and the rehabilitation of the site.

Due to the lack of life-cycle considerations and neglect of environmental impacts, the risk of natural disasters and the increase of the displaced population is rising (Pomponi et al., 2019).

The carbon footprint (CF) can be defined as the total amount of greenhouse gas emissions and removals associated with a product system, represented in terms of CO₂ equivalent and evaluated through life cycle assessment. Reducing CO₂ emissions is crucial for several reasons: Firstly, it's the most influential greenhouse gas, with its quantities continuously increasing. Secondly, it remains in the atmosphere for extended periods, with about 20% of emitted CO₂ today contributing to global warming even after 500 years (Hansen et al. 2013). Thirdly, humanity still can decrease greenhouse gas emissions from fossil fuels and land use change, as advocated by the World Bank (Kuittinen & Winter, 2015).

Primary energy (PE) refers to energy found in nature that hasn't undergone any transformation. The efficiency of utilizing primary energy varies depending on the energy carriers used. This concept is captured by primary energy efficiency, which measures how much of the available energy potential is utilized in end-use applications (Kuittinen & Winter, 2015). Primary energy refers to the initial form of energy extracted from natural resources, such as fossil fuels (coal, oil, natural gas), nuclear energy, renewable sources (solar, wind, hydro), and biomass. It represents the raw energy content before any conversion or transformation occurs. Primary energy sources are essential for electricity generation, transportation, heating, and industrial processes (Kabeyi & Olanrewaju, 2023).

Life Cycle Assessment (LCA) is a systematic method used to assess the environmental impacts of a product, process, or service throughout its entire life cycle. It considers all stages, from raw material extraction to production, use, and disposal. LCA evaluates various environmental factors, including energy consumption, greenhouse gas emissions, resource depletion, and pollution. LCA helps decision-makers compare different options and make informed choices based on sustainability and environmental performance (Pacañot, 2022).

The Life Cycle Assessment (LCA) methodology places significant importance on primary energy when examining environmental effects. When analyzing energy systems like methods for generating electricity, LCA takes into account the energy needed at every phase— from extraction and production to operation and decommissioning. It also considers both direct and indirect energy usage across the entire life cycle, aiming to capture the total energy consumption. Through this focus on primary energy consumption, LCA offers valuable perspectives on the overall environmental impact of energy systems. It highlights areas where enhancements can be made and offers guidance for selecting sustainable energy options (Arvidsson & Svanström, 2016).

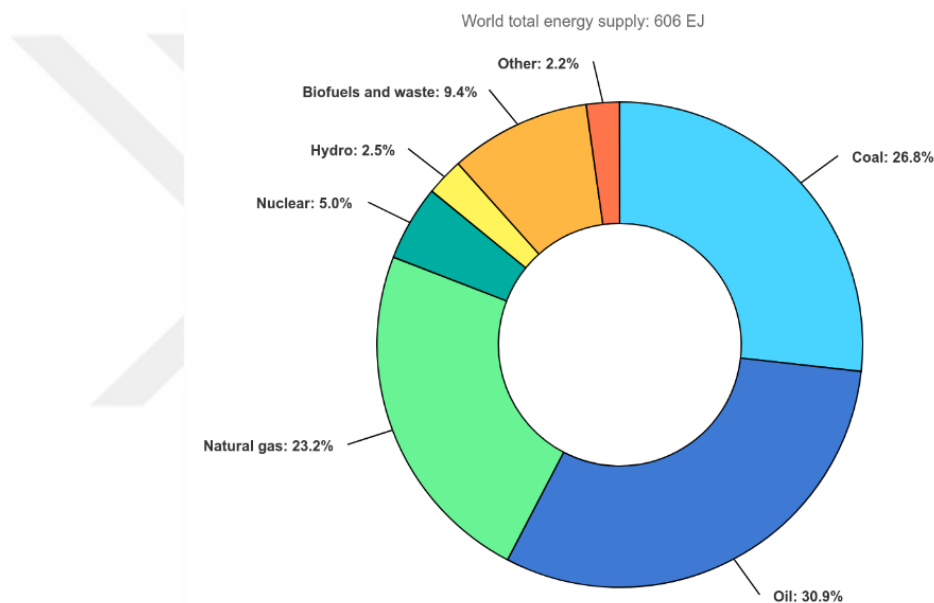


Figure 2. Global share of total energy supply by source, 2019 (Supply – Key World Energy Statistics 2021 – Analysis - IEA, n.d.)

The world's energy demands are predominantly met through the combustion of fossil fuels, a practice that significantly contributes to global warming. As shown in Figure 2, by 2019, 80.9% of the world's total primary energy came from fossil fuels, including oil, coal and natural gas, (Supply – Key World Energy Statistics 2021 – Analysis - IEA, n.d.) highlighting the close connection between primary energy usage and carbon footprint, both of which are intricately linked to climate change. It's noteworthy that constructing shelters with materials requiring minimal primary energy for production can help mitigate these impacts (Kuittinen & Winter, 2015).

The life cycle of migrants' shelters involves various aspects, including the provision of housing, support services, and protection. Ibrahim et al. (2022) investigated the Syrian refugee camp in Duhok, Iraq, and listed the most concerning sustainability issues, focusing on seven core shelter typologies. These issues include the short life span of shelters, planning and design system considerations like the randomization of block organizations and diversity, irregularity, inequality of plot size, and space isolation. The energy consumption and thermal comfort of shelters have been recorded as the main consequences of these issues.

Migrants' shelters have been assessed in terms of their lifespan and the relationship between lifespan and energy consumption and CO₂ emissions. Studies have shown that inefficient and unsustainable construction approaches have resulted in improper planning and design systems for migrant shelters, leading to short lifespans and high environmental burdens (Rojhat et al., 2022; Dabaieh et al., 2020). However, using local plant-based materials and natural construction techniques can drastically reduce the carbon footprint of temporary shelters and even achieve a negative carbon impact (Atmaca, 2017).

Atmaca, (2017) analysed the life span of containers constructed in a refugee camp in Turkey and found that energy and emission values decrease with the increase of life span. The authors make the Life Cycle Assessment (LCA) of containers constructed in a refugee camp in Turkey and reveal that the total life cycle construction and operational energy demand is 24.7 GJ/m², and the CO₂ intensity of the housing is 20.39 kg CO₂/m²-year. He investigated the relationship between life span and consumed energy with CO₂ emission values, which is an important variable in life cycle assessment.

Dabaieh et al. (2020) gathered a life cycle assessment of refugee houses, emphasizing the importance of reducing embodied carbon and energy during the pre-use phase and enhancing material recyclability due to the short life cycle of temporary shelters. They presented a life cycle assessment (LCA) of a minus carbon refugee house, focusing on its global warming potential (GWP) and sensitivity analysis.



Figure 3. The minus-carbon refugee house (Dabaieh et al., 2020).

In Figure 3, the left image depicts the refugee house under construction, revealing the primary structural components, including compressed straw panels, wood frames, and wood-fiber boards for the walls and roof. On the right, the complete form of The Minus Carbon Refugee House is shown, which is situated in the urban living lab in Brunnshög, Lund, Sweden. Notable features include the green wall on the west façade and the Trombe walls on the south façade, specifically designed for passive heating, passive cooling, and natural ventilation (Dabaieh et al., 2020).

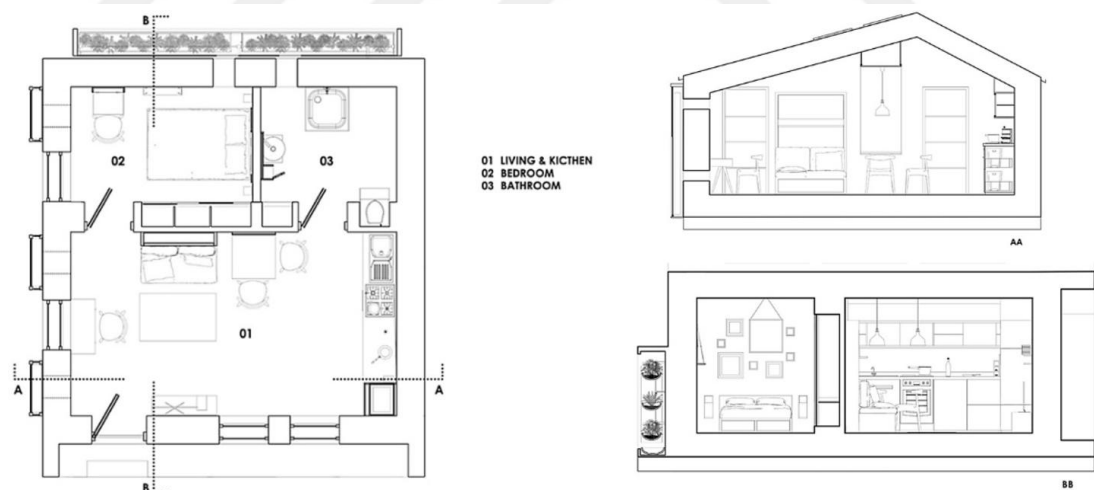


Figure 4. Plan and cross sections for the design of the minus carbon refugee house (Dabaieh et al., 2020)

Dabaieh et al. (2020) showcase a low-impact refugee house prototype that leverages natural materials and passive systems for heating and cooling to reach a minus carbon outcome over its life cycle. They found that utilizing local plant-based materials like straw, reeds, and wood, along with clay, can significantly reduce the

carbon footprint of temporary shelters, achieving a negative carbon impact. On the other hand, the Global Warming Potential (GWP) impact is highly sensitive to the variability of the GWP impact of wood fibre insulation. The GWP of the shelter without sequestration was measured at 254.7 kg CO₂ eq/m², while with sequestration, it was -226.2 kg CO₂ eq/m², indicating a substantial reduction in carbon emissions.

Table 33

Architectural Features Of The Minus Carbon Refugee House (Dabaieh Et Al., 2020)

Architectural Features	Description
Design Philosophy	The house is designed with a focus on sustainability, simplicity, and functionality according to the mild and moderate climate of Lund, Sweden.
Layout	A compact layout optimized for family living, including sleeping areas, kitchen, and communal spaces.
Natural Light	Large windows and skylights maximize natural light, reducing the need for artificial lighting during the day.
Flexible Spaces	Adaptable interior spaces that can serve multiple purposes.
Integration with Landscape	Seamlessly blends with the natural surroundings
Accessibility	Consideration for universal design principles

Table 34

The Constructional Features Of The Minus Carbon Refugee House (Dabaieh Et Al., 2020)

Categories	Description
Materials	Utilizes locally sourced materials within a 5 km radius to minimize transportation-related emissions.
Plant-Based Fibers	Incorporates straw, reeds, and wood fibers for insulation and structural elements.
Clay and Lime	Used for walls and finishes.
Low-Tech Construction	Manual labour, hand tools, and traditional building techniques.
Zero Waste Approach	Minimizes construction waste through careful planning and material selection.

Table 35

The Environmental Features Of The Minus Carbon Refugee House (Dabaieh Et Al., 2020)

Environmental Features	Description
Embodied Carbon	Materials chosen for their low embodied carbon footprint.
Circular Economy	Materials are reusable, recyclable, or compostable at the end of their life cycle.
Biodiversity	Encourages native plant growth around the house.
Water Management	Rainwater harvesting and efficient water use.
Local Ecology	Designed to minimize disruption to local ecosystems.

Table 36

The Energy Efficiency Features Of The Minus Carbon Refugee House (Dabaieh Et Al., 2020)

Environmental Features	Description
Passive Heating and Cooling	Utilizes Trombe walls, green walls, and Earth Air Heat Exchanger (EAHE) to regulate indoor temperatures.
Orientation	Optimized for solar gain and natural ventilation.
Thermal Mass	High thermal mass materials (clay, straw) stabilize indoor temperatures.
Energy-Efficient Appliances	Low-energy lighting, appliances, and fixtures.
Renewable Energy	Potential for solar panels or other renewable energy sources.

Kuittinen & Winter (2015) analysed the Carbon Footprint and initial construction energy demand of eight transitional shelters, with shelters constructed from Bamboo or Timber revealing the lowest carbon footprint and metal-intensive shelters revealing the highest carbon emission. The carbon storage capacity could have a similar magnifying impact. As trees and bamboo grow, they absorb CO₂, which is stored in construction materials until released through energy recovery or natural decay. This innate property of wood and bamboo aids in combating climate change, provided it doesn't contribute to deforestation from illegal or unsustainable forestry practices. Table 37 declare the Carbon Footprint situation in the end-life period of various materials.

Table 37

End-Life Situation Of Various Materials

Materials	After Life Situation	Reference
Bambo / Timber	Their bio-based and oil-based materials could be recycled into energy by burning them. Burning wood or bamboo for energy results in biogenic GHG emissions that can be assumed carbon neutral if the materials originate from sustainable sources.	(Kuittinen & Winter, 2015)
Oil-based plastics	Leads to greenhouse gas emissions from fossil fuels, adding strain to the Earth's natural carbon cycles.	(Kuittinen & Winter, 2015)
Steel	It can be repurposed for other applications once the shelter is no longer in use.	(Kuittinen & Winter, 2015)
Glass	Crushed recycled glass (cullet) can replace some raw materials, significantly reducing emissions. When cullet is melted, no CO₂ is released, and furnaces don't need to burn as fiercely as with raw materials, further saving carbon	(“Glass Is the Hidden Gem in a Carbon-Neutral Future,” 2021)
Organic Waste (e.g., food)	Organic waste generates biogas through anaerobic digestion. Impact: Composting organic waste reduces landfill emissions and contributes to soil health	(Pauliuk et al., 2021)
Textiles (e.g., clothing)	Textiles release emissions when burned. Impact: Recycling textiles or reusing them reduces the need for new production and lowers CO₂ emissions	(Pauliuk et al., 2021)
Concrete	Concrete has the lowest emissions during the end-of-life (C1–C4) stage. However, its carbon footprint during construction (A1–A3) is higher than that of timber.	(Rinne et al., 2022)

Chapter 3

Decision-Making Methods for Optimization

3.1 Overview of Decision-Making in Optimization

Decision-making in optimization encompasses a variety of methodologies and frameworks aimed at selecting the best possible solution from a set of alternatives, particularly in scenarios characterized by multiple objectives and constraints. The complexity of real-world problems often necessitates the use of advanced optimization techniques and decision-making models that can effectively handle conflicting criteria.

In the context of architectural and environmental design, such as optimizing the performance of shelters, decision-making is essential to achieve goals like maximizing thermal comfort, minimizing energy consumption, and reducing environmental impact. This process requires not only technical precision but also an understanding of how different criteria interact and influence each other.

3.2 Potential MCDM Methods

Multi-criteria decision-making (MCDM) plays a crucial role in the optimization of buildings, particularly in the context of sustainability and resource efficiency. The complexity of building projects often involves multiple stakeholders and conflicting objectives, making MCDM an essential tool for evaluating various alternatives based on diverse criteria. This approach allows decision-makers to systematically analyse and prioritize options, ensuring that the selected solutions align with sustainability goals and performance requirements. It involves a variety of methods including,

- Weighted Sum Model (WSM)
- Analytic Hierarchy Process (AHP)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
- Equal Weighted Decision Making (EWD)
- Pareto Front Optimization

3.2.1 Weighted sum model (WSM). The Weighted Sum Model (WSM) is a popular MCDM method that combines multiple criteria into a single score. Building optimization systematically evaluates design options, materials, or systems based on metrics like cost, energy efficiency, sustainability, and occupant comfort.

To apply this method, the following steps are required:

- 1- The first step is to identify the key criteria influencing decisions, such as construction costs, energy use, environmental impact, and user satisfaction, which shape building performance (Zavadskas et al., 2015).
- 2- Secondly, normalization is required to assure comparability since the criterion may be assessed on several scales. Through this method, each criterion's values are converted to a common scale, usually between 0 and 1. (Shin et al., 2013). The normalization formula depends on whether the criterion is a benefit criterion (higher values are better) or a cost criterion (lower values are better):

$$\text{Benefit Normalized Value} = \frac{\text{Alternative's Actual Value}}{\text{Max. Value among all Alternatives}}$$

$$\text{Cost Normalized Value} = \frac{\text{Min. Value among all Alternatives}}{\text{Alternative's Actual Value}}$$

- 3- Once normalized, these values are multiplied by their respective weights in the WSM calculation. The weights can be determined through various methods, such as expert judgment, stakeholder input, or statistical analysis. The sum of all weights should equal 1 to maintain proportionality in the evaluation (Yuan et al., 2020).
- 4- Finally, by summing the values, alternatives ranking is calculated and the alternative with the highest score is considered the most favourable option according to the WSM approach (Fan & Xia, 2017).

3.2.2 Analytic hierarchy process (AHP). This method allows stakeholders to systematically analyse complex problems, particularly in the context of green building optimization and Building Information Modelling (BIM). AHP's hierarchical structure facilitates prioritization, ensuring that decisions align with sustainability goals and performance metrics.

AHP helps balance environmental parameters, ensuring efficient resource use and minimizing waste, which is crucial for green building initiatives (Elshafei et al., 2022). Decision-makers perform pairwise comparisons to assess the relative importance of criteria, which can be automated to reduce effort and enhance consistency (De Oliveira & Duarte, 2024).

To apply this method, the following steps are required:

- 1- The Analytic Hierarchy Process (AHP) begins by defining the decision issue and establishing a hierarchy, with the objective at the top, criteria and sub-criteria in the middle, and options at the bottom. Factors like energy efficiency, cost, aesthetics, and occupant comfort are often used in building optimization to select the best sustainable design (Chen et al., 2012; Alharasees, 2024).
- 2- AHP uses pairwise comparisons to assess the relative importance of criteria and sub-criteria. Decision-makers rate each pair on a scale of 1 (equal importance) to 9 (extremely more important), creating a comparison matrix for each hierarchy level (Alharasees & Kale, 2022). For instance, if energy efficiency is prioritized over cost, it receives a higher rating.
- 3- AHP calculates criterion weights by normalizing the pairwise comparison matrix and deriving the principal eigenvector, representing relative weights. Consistency is verified using the consistency ratio (CR) to ensure reliable judgments (Zhu & You, 2016; Romanova & Skanavi, 2017).

To assess the normalization process, each element in a column (α_{ij} is the element in the i -th row and j -th column of the original matrix) should be divided by the sum of all elements in the j -th column to get the normalized matrix.

$$\text{Normalized Element} = \frac{a_{ij}}{\sum_{j=1}^n a_{ij}}$$

- 4- After determining weights, alternatives are evaluated against each criterion using pairwise comparisons or direct scoring. The overall score of an alternative in AHP is calculated by multiplying each criterion's weight (w_j) by the alternative's score for that criterion (x_{ij}) and summing the results:

$$S_i = \sum_{j=1}^n w_j \cdot x_{ij}$$

w_j = weight of the j-th criterion

x_{ij} = Score of the i-th alternative under the j-th criterion

This score provides a single metric that represents the overall performance of each alternative (Zhang, 2012).

- 5- Finally, alternatives are ranked by their aggregated scores, with the highest score indicating the best option based on overall performance across criteria (Zhang, 2017).

3.2.3 Technique for order preference by similarity to ideal solution (TOPSIS). In the context of building optimization, TOPSIS provides a systematic approach to identify the most suitable design, material, or system by comparing alternatives against an ideal solution. This method is particularly valuable in building projects where various performance metrics, such as cost, energy efficiency, and sustainability, must be balanced.

Various applications are mentioned for TOPSIS, including selection of construction materials (Baky, 2012), comparing design options based on aesthetics, functionality, and energy efficiency, aiding architects and engineers in meeting occupant needs and sustainability standards (Zavadskas et al., 2016), and optimization of building systems like HVAC or lighting by assessing energy use, cost, and user comfort, ensuring optimal performance and cost-efficiency (Dewi et al., 2018). The advantages of TOPSIS are mentioned below:

Advantages:

- Simplicity: Easy to understand and implement, suitable for stakeholders with diverse expertise (Bianchini, 2018).
- Comprehensive: Evaluates alternatives by considering both ideal and anti-ideal solutions, highlighting trade-offs (Kumar et al., 2020).
- Flexible: Adaptable to various contexts, criteria, and integration with methods like AHP for enhanced effectiveness (Zavadskas et al., 2010).

To apply this method, the following steps are required:

- 1- The first step in the TOPSIS process involves constructing a decision matrix that includes all the alternatives and their corresponding performance values across the defined criteria. For example, in building optimization, criteria may include initial cost, operational energy consumption, environmental impact, and occupant comfort (Madanchian, 2023).
- 2- Normalization is essential for comparing criteria measured on different scales. It converts values in the decision matrix to a common scale, typically 0 to 1, enabling fair performance comparisons across all criteria (Şahin & Yiğider, 2016).
- 3- TOPSIS identifies two reference points: the ideal solution (the best possible performance for each criterion) and the anti-ideal solution (the worst possible performance). The ideal solution represents the best outcomes for all criteria, while the anti-ideal solution represents the worst outcomes. This dual reference framework is crucial for evaluating how close each alternative is to the ideal solution (Madanchian, 2023).
- 4- The next step involves calculating the Euclidean distance of each alternative from both the ideal and anti-ideal solutions. The distance from the ideal solution indicates how close an alternative is to the best possible outcome, while the distance from the anti-ideal solution indicates how far it is from the worst outcome. These distances are essential for determining the relative performance of each alternative (Jahan et al., 2021).
- 5- The closeness coefficient (CC) is then computed for each alternative. This coefficient is defined as the ratio of the distance from the anti-ideal solution to the total distance from both the ideal and anti-ideal solutions. A higher

closeness coefficient indicates a better overall performance relative to the ideal solution.

- 6- Finally, the alternatives are ranked based on their closeness coefficients. The alternative with the highest closeness coefficient is considered the most favourable option, as it demonstrates the best overall performance across the defined criteria (Dewi et al., 2021).

3.2.4 Equal weighted decision making (EWDM). Equal Weighted Decision Making (EWDM) is a simple approach in multi-criteria decision-making, assigning equal importance to all criteria. Building optimization helps balance objectives when selecting designs, materials, or systems. The following are the advantages of the EWDM method:

- **Simplicity:** EWDM assigns equal weights, simplifying decision-making for stakeholders with limited experience (Yuan et al., 2021).
- **Balanced Assessment:** It ensures no single criterion dominates, supporting holistic decision-making in conflicting objectives (Yilmaz, 2024).
- **Flexibility:** EWDM is easily adaptable, suits various contexts, and works well for initial assessments or preliminary screenings (Xu et al., 2019).

Despite its advantages, EWDM assumes all criteria are equally important and may not align with stakeholder priorities or specific contexts. When certain criteria are more critical, this can result in suboptimal decisions. Exploring methods like the Analytic Hierarchy Process (AHP) or the Simple Additive Weighting (SAW) can offer more nuanced decision-making (Medineckienė & Džiugaitė-Tumėnienė, 2014).

To apply this method, the following steps are required:

- 1- The first step in EWDM is identifying criteria such as energy efficiency, cost, sustainability, comfort, and aesthetics that influence building design performance and acceptability.

- 2- Normalization is necessary to ensure comparability since the criteria may be measured on different scales. This process involves transforming the values of each criterion to a standard scale, typically ranging from 0 to 1. Normalization allows for a fair comparison of alternatives based on their performance across all criteria (Yao & Peng, 2012).

$$\text{Normalized Value} = \frac{\text{Min. Value} - \text{Current Value}}{\text{Max. Value} - \text{Min. Value}}$$

- 3- The overall score for each alternative is calculated by summing the normalized values of each criterion, multiplied by their respective weights. Since all weights are equal, the calculation simplifies to the average of the normalized scores across all criteria. This score provides a single metric that represents the performance of each alternative in relation to the defined criteria.
- 4- After scoring, alternatives are ranked by performance, with the highest score indicating the best option in EWDM, aiding decision-makers in selecting the optimal design or material (Simanungkalit et al., 2023).

3.2.5 Pareto front optimization method. In the context of building optimization, the Pareto front serves as a critical framework for decision-making, particularly when multiple conflicting objectives must be balanced. The Pareto front represents a set of optimal solutions where no single objective can be improved without degrading another, allowing stakeholders to visualize trade-offs and make informed decisions. The process of creation and selection of the ideal Pareto is explained below:

- 1- The process begins with defining a multi-objective optimization problem, where several objectives must be optimized simultaneously. For example, in building design, objectives may include minimizing energy consumption, maximizing occupant comfort, and reducing construction costs. Each of these objectives can often conflict with one another, necessitating a careful evaluation of trade-offs.

- 2- Various optimization algorithms, particularly Multi-Objective Evolutionary Algorithms (MOEAs), are employed to explore the solution space. These algorithms work with a population of candidate solutions, iteratively refining them to converge towards the Pareto front. For instance, the NSGA-II algorithm is widely used to generate a diverse set of Pareto-optimal solutions in building optimization scenarios (Wang et al., 2023). Koziel and Leifsson (2014) emphasize that MOEAs are particularly well-suited for multi-objective design problems, as they can identify a wide range of optimal designs that are non-commensurable in the traditional single-objective sense.
- 3- As candidate solutions are evaluated, those that cannot be improved in one objective without worsening another are identified as Pareto optimal. This set of solutions forms the Pareto front, which is typically visualized in a multi-dimensional space where each axis represents an objective. The shape and distribution of the Pareto front provide insights into the nature of the trade-offs involved (Zhou et al., 2023).
- 4- The Pareto front allows stakeholders to visualize the trade-offs between competing objectives. For example, a decision-maker can observe how increasing energy efficiency might lead to higher initial costs or how improving occupant comfort could impact energy consumption. This visualization is crucial for understanding the implications of different design choices (Kyrouti et al., 2020).
- 5- Once the Pareto front is established, decision-makers can select solutions based on their preferences and priorities. This selection process often involves identifying Pareto optimal (knee points) on the Pareto front, which represent solutions where small improvements in one objective result in significant trade-offs in others. These Pareto optimal are particularly attractive to decision-makers as they offer a balanced approach to optimization (Li et al., 2020).

The Pareto front can be refined iteratively as new data or stakeholder preferences emerge. Decision-makers may choose to focus on specific regions of the Pareto front that align with their objectives, allowing for a more targeted optimization process. This adaptability is essential in dynamic environments where project requirements may evolve (Zhu & Gao, 2016).

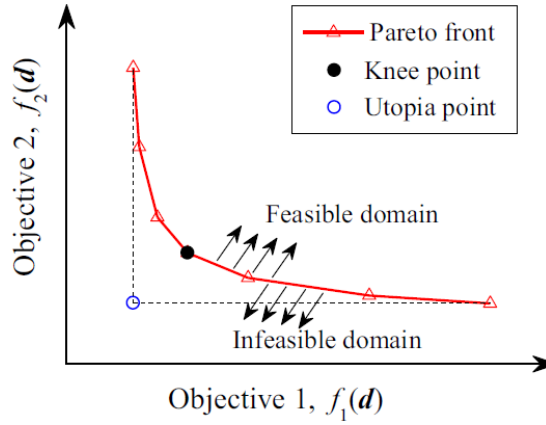


Figure 5. Pareto front and Pareto optimal (knee point) selection
(Khoshnevisan et al., 2014)

In practical applications, Pareto front optimization can be employed to optimize various building parameters, such as facade design, energy systems, and overall building performance. For instance, Wagiri (2024) explores the optimization of kinetic facade aperture ratios for daylight and solar radiation control, utilizing non-traditional methods that generate Pareto-optimal fronts. This approach allows for a broader range of solutions that can effectively balance aesthetic considerations with energy performance.

Attia et al. (2013) highlight the necessity of optimizing the combination of building geometry, envelope, and systems rather than treating them in isolation. By employing automated mathematical building performance optimization paired with building performance simulation, designers can evaluate numerous design options and identify optimal solutions that meet fixed objectives, such as achieving net-zero energy. The use of data-driven methods also enhances the effectiveness of Pareto front optimization in building performance assessment. Borodinecs et al. (2024) discuss how building management systems (BMS) can optimize energy supply and demand, thereby achieving multiple objectives related to energy efficiency and occupant comfort. By leveraging data-driven insights, stakeholders can make more informed decisions that align with the objectives represented on the Pareto front.

Overall, as Borrotti et al. (2016) highlight, the Pareto front facilitates exploring the entire optimization problem, offering a range of non-dominated solutions. This is particularly useful when decision-makers' preferences are unclear, allowing them to identify priorities through the presented trade-offs.

3.3 Evaluation of the Decision-Making Methods

Decision-making should be seen as an ongoing process from early design to construction and operation. Early decisions are crucial for environmental impact, but many parameters, like thermal bridges, are hard to evaluate at that stage and may need reassessment later (Yılmaz, 2018). The evaluation of decision-making methods involves assessing various criteria, including simplicity, comprehensiveness, flexibility, robustness, integration capabilities, and stakeholder engagement. Methods like WSM, AHP, TOPSIS, EWDM or Pareto Front each offer unique advantages and limitations, making them suitable for different decision-making scenarios. On the other hand, a multi-level approach, such as using Pareto optimal solutions and human-judgment techniques, can help combine different decisions in complex projects.

Understanding these factors helps stakeholders choose the best decision-making method for optimal building project outcomes. Table 38 compares the strengths and weaknesses of these methods:

Table 38

Features Of Various MCDM Methods

DM Methods	Strengths	Weaknesses
WSM	- Simplicity: WSM is straightforward and easy to implement, making it accessible for stakeholders with limited decision-making experience (Zeng, 2023).	- Assumption of Additivity: WSM assumes a linear, additive relationship between criteria, which may not apply in complex building optimizations (Sabarinath et al., 2014).
	- Quick Calculations: Enables rapid evaluations, ideal for situations needing timely decisions.	- Sensitivity to Weighting: The final ranking can be biased if weights are not carefully assigned (Hosseini, 2024).
AHP	- Structured Approach: AHP offers a clear framework for tackling complex, multi-criteria problems (Biswas, 2024).	- Cognitive Load: Pairwise comparisons can be time-consuming and mentally demanding with many criteria and alternatives (Tadić et al., 2011).
	- Incorporation of Subjective Judgments: Allows decision-makers to include preferences, enhancing result relevance (Krylovas et al., 2017).	- Consistency Issues: Inconsistent judgments can lead to unreliable results (Dwivedi et al., 2022).

Table 38 (Cont.d)

TOPSIS	- Comprehensive Evaluation: TOPSIS evaluates alternatives by considering both ideal and anti-ideal solutions (Deshmukh & Tjprc, 2018).	- Dependence on Normalization: Normalizing performance values can add complexity and potential inaccuracies (Mulliner et al., 2016).
	- Handling Mixed Criteria: Can manage both qualitative and quantitative criteria, suitable for diverse building optimizations (Sabzi & King, 2015).	- Sensitivity to Weighting: Results can be affected by the weights assigned to criteria, impacting final rankings (Kamble et al., 2019).
EWDM	- Simplicity: Easy to apply, accessible for stakeholders with limited decision-making experience (Shihui & Liu, 2022).	- Assumption of Equal Importance: Assuming all criteria are equally important can lead to suboptimal decisions (Brentan et al., 2021).
	- Balanced Assessment: EWDM ensures a balanced evaluation by giving equal importance to all criteria (Dwivedi et al., 2015).	- Limited Nuance: EWDM may miss key differences in criterion importance, affecting complex building optimizations (Jozaghi et al., 2018).
Pareto Front	- Visual Trade-offs: The Pareto front visually shows trade-offs between objectives, aiding decision-making (Tavana et al., 2021).	- Complex Selection: Choosing the best option from the Pareto front can be challenging and subjective (Mosadeghi et al., 2015).
	- Compromise Solutions: Helps identify solutions that balance multiple objectives effectively (Valipour et al., 2018).	- Dependence on Algorithms: The Pareto front's effectiveness depends on the optimization algorithms, which vary in efficiency and accuracy (Wang et al., 2021).

Chapter 4

Methodology and Implementation

This study aims to propose an energy-efficient and environmentally and socially sustainable refugee camp on the dwelling scale. Additionally, it provides an approach to assisting architects in designing energy-efficient refugee camps. Within this chapter, the methodology for reaching this achievement is implemented in detail. Firstly, the climatic region is determined. Following the selection of the site within the climatic region, it undergoes a thorough analysis based on its specific climatic conditions, including factors like temperature, Relative Humidity (RH), wind, solar radiation, precipitation, etc. After identifying the climatic conditions and selecting the building site, a typical existing Refugee Camp (RC) is chosen as an archetype. The archetype undergoes a comprehensive analysis, collecting data on camp availability, size, and layout and detailing its architectural features, location, climate conditions, occupancy schedules, and energy consumption levels. Figure 6 summarises the framework upon which the methodology and implementation chapter is constructed.

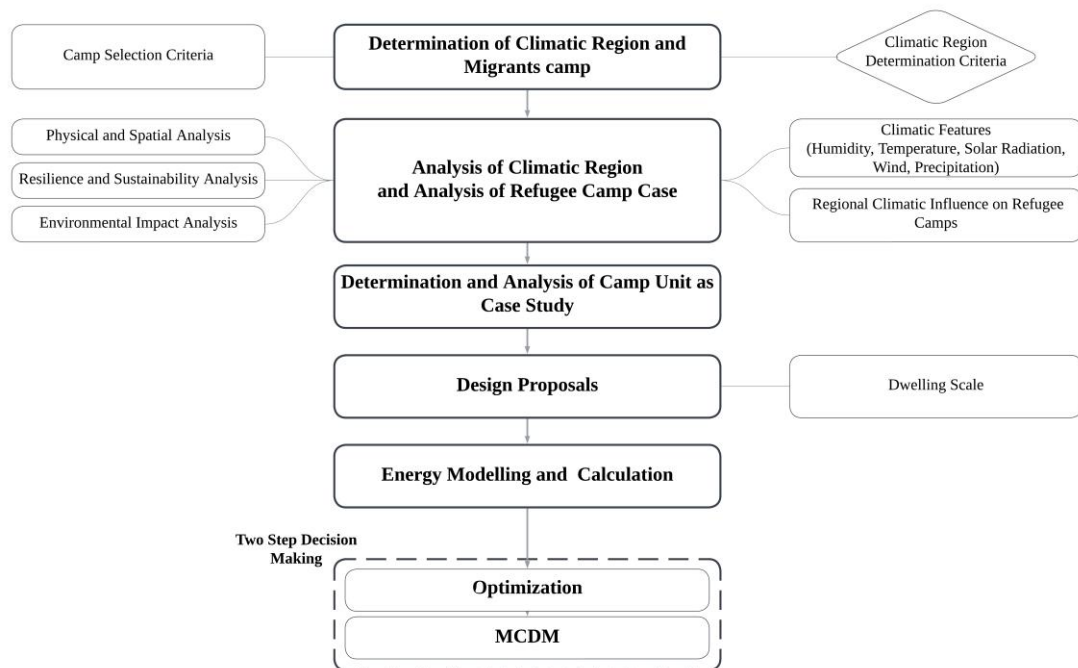


Figure 6. The structure of methodology and implementation

This guides the synthesis of climate data to understand how the regional climate influences the existing housing solution. Suitable camps are then determined based on

reliability and accessibility criteria. The camp analysis comprises Physical and Spatial, Resilience and Sustainability, and Environmental Impact analyses. These evaluate camp layouts, architectural features, lighting and heating systems, and environmental impact. Subsequently, design proposals are developed at the dwelling scale, focusing on spacing, orientation, materials, Thermal Comfort (TC), Indoor Air Quality (IAQ), and Energy Efficiency (EE). Finally, through the energy simulation tool and energy modelling, the efficiency of the proposal is evaluated.

4.1 Determination of Climatic Region and Migrants' Camp

Determining climatic regions involves analysing various data sources, including historical weather data, satellite imagery, and climate models. Climatologists use statistical methods and spatial analysis techniques to identify patterns and classify regions into different climate zones. Geographic Information Systems (GIS) software is often employed to visualize and map climate data (Gabriele et al., 2022).

Climatic regions are geographic areas characterized by similar climatic conditions, such as temperature, precipitation, humidity, and wind patterns. Understanding these regions is crucial for fields like urban planning, design strategies, agriculture, and ecology as it sheds light on regional climate variability and its impacts. Climate is influenced by several factors, including latitude, altitude, proximity to water bodies, and topography. Systems like the Köppen or Trewartha classifications categorize climates based on temperature, precipitation, and seasonal variations. These frameworks help identify global climate patterns and distinct climatic regions (Belda et al., 2014).

Criteria needed for determining refugee camps within a climatic region include addressing humanistic needs, social and cultural adequacy, sustainability, community integration, and access to essential services (Aburamadan, 2023). Additionally, considerations for thermal conditions, such as overheating assessments, alternative design strategies, and shelter operation strategies, are crucial for ensuring the well-being of refugees in inhospitable environments (Fosas et al., 2017) and can be analysed as factors for refugee camp determination.

The accuracy of climatic regions is verified through comparison with established climate norms based on the World Bank Climate Change Knowledge Portal, Energy Plus Weather (EPW) data and Weather Spark website. This verification process ensures that the selected climatic region accurately represents the climatic characteristics of the area under study.

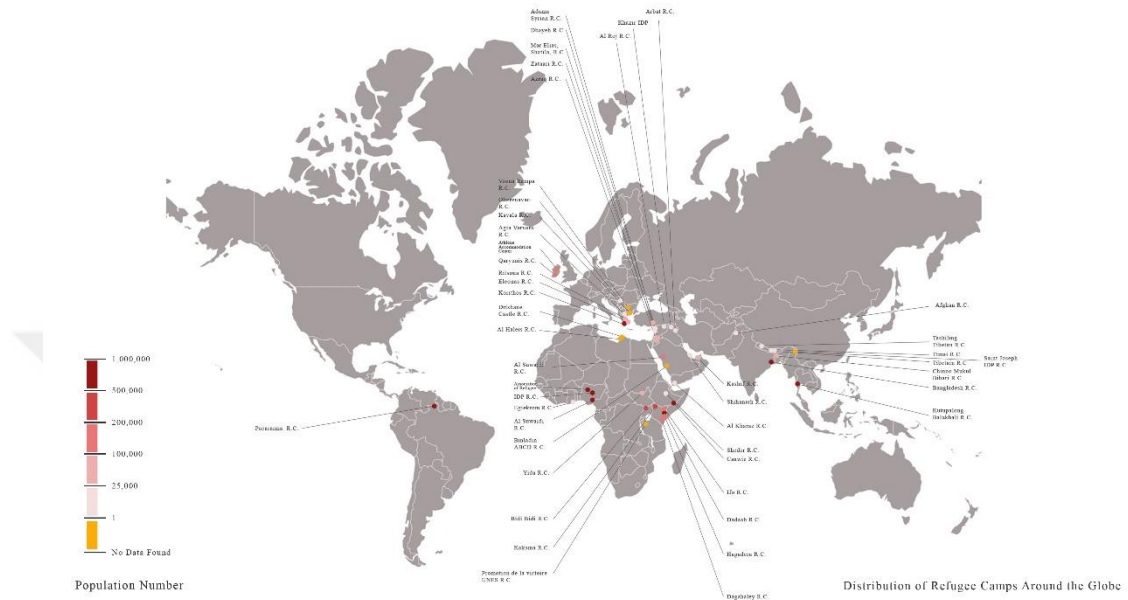


Figure 7. Map of distribution of refugee camps around the globe

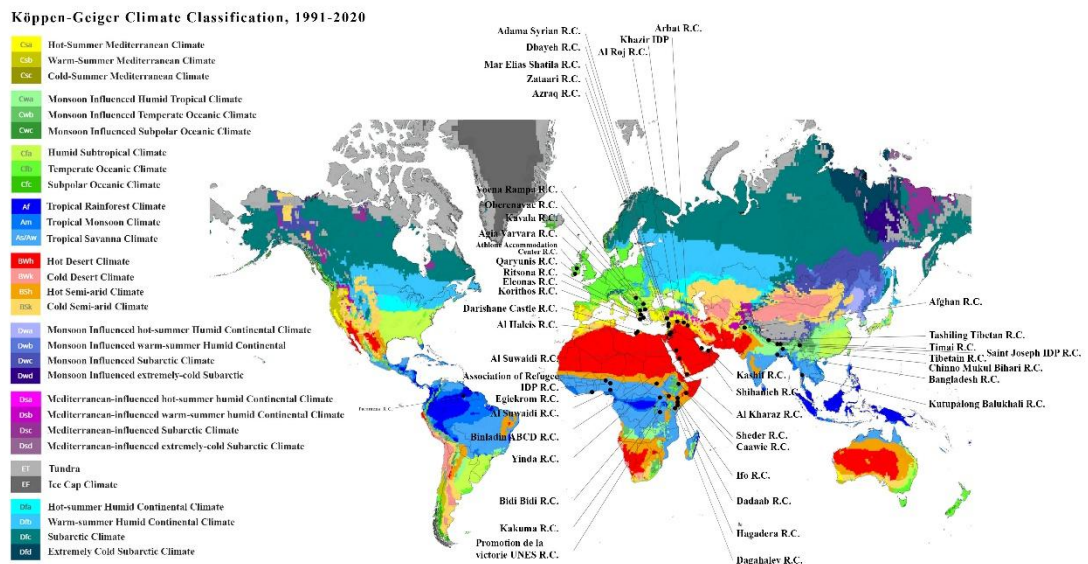


Figure 8. Map of distribution of refugee around the climate regions

Hot-arid regions often feature desert landscapes characterized by sandy dunes, rocky terrain, and sparse vegetation. However, some may also include semi-arid steppes or scrublands with slightly more vegetation cover. As illustrated in Figures 8

and 9, Hot-arid climates are classified according to the Köppen climate classification system, with the most common subtype being "BWh." In this classification, "B" denotes arid climates, while "W" indicates a desert climate. The "h" signifies hot temperatures throughout the year. Figures 8 and 9 depict the hot-arid climatic region, characterized by red regions, according to the BWh classification.

In this study, the distribution of refugee camps around the world was analysed using Google Maps, as depicted in Figure 7. According to the analysis, there were 15 refugee camps in Africa, 13 in the Middle East, 9 in Asia, 9 in Europe, and one in Brazil. On the contrary, this distribution undergoes analysis in relation to global climatic regions. As illustrated in Figure 7, among the 47 refugee camps scrutinized in this study, 8 refugee camps are situated in a Hot Desert Climate (BWh) and 12 refugee camps in Hot Semi-arid Climate (BSh), accounting for roughly 42% of refugee camps within these Hot-arid and Hot-semi arid Regions. In this thesis, according to Figure 7, the hot-arid climatic region of Jordan, which is in BWh regions, has been determined as the study region. As depicted in Figures 7 and 8, the primary reason for the determination of hot-arid region (BWh) is that it is located in roughly 42% of refugee camps in this region.

Various criteria are considered for the determination of the Zaatari refugee camp (Z-RC), including the critical location of the Z-RC within the hot-arid (BWh) climatic region of Jordan, the availability of data and reliable sources of literature, shelter design and planning conditions of Z-RC, temporary position of Z-RC which turned to a semi-permanent architecture in time and the environmental sustainability of shelters. Refugee camps like Zaatari often become semi-permanent settlements, underscoring the need for effective urban planning and shelter design. Examining Zaatari's evolution from emergency tents to more permanent structures (container shelters) reveal insights into the adaptability and resilience of architectural solutions to long-term displacement. On the other hand, sustainable design is increasingly vital in refugee camp planning. Studying the environmental impact of shelter construction in Zaatari, along with sustainability initiatives like semi-closed spaces, informs strategies for enhancing resilience to climate change.

4.2 Analysis of Climatic Region

It is pivotal to analyse the climatic region in crafting an energy-efficient proposal for Refugee Camps, which is appropriately designed in accordance with the prevailing environmental conditions. Consequently, the evaluation of climatic regions serves as a cornerstone in the development of energy-efficient refugee camps that are resilient and environmentally sustainable. Such endeavours not only enhance the well-being of displaced populations but also contribute to broader environmental conservation objectives.

According to Maalim et al. (2021), various climatic regions exhibit distinct temperature ranges and weather patterns, exerting diverse demands on energy for heating, cooling, and overall comfort. These discrepancies underscore the necessity for nuanced approaches to energy management within refugee camps. Understanding the climatic diversities enables the deployment of appropriate energy systems and provides the opportunity to ensure a consistent and reliable energy supply while reducing the need for non-renewable energy sources and active systems. For instance, in regions characterized by extreme temperatures, innovative cooling systems, passive cooling strategies, or insulation techniques are crucial to maintaining comfortable living conditions.

To analyse climatic regions, several key criteria are essential, including Climatic features and objectivity in defining climatic regions, model data availability, share of renewable energy sources, CO₂ emissions, heat losses, primary energy factors, and heat delivery sources. Moreover, the assessment should encompass aspects like water supply vulnerability, water resource sensitivity to climate change, and the biodiversity risks and potentials.

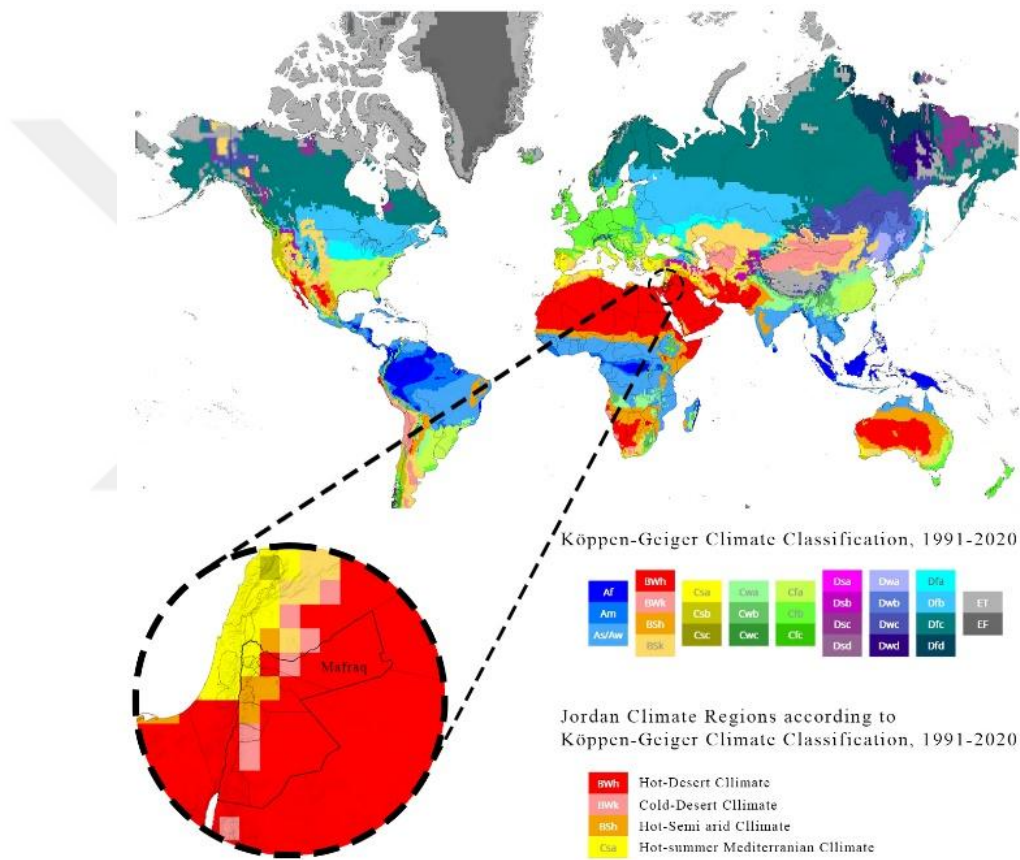
Furthermore, the classification of regions for climate purposes involves evaluating various factors such as soil productivity, topography, and geology. Additionally, the assessment should account for the resilience of urban infrastructure to climate change and the exploitation of geothermal energy.

Table 39

Criteria Categorization Of Climate Analysis

Criteria Category	Description
Climatic features and objectivity	Essential for defining climatic regions objectively, taking into account factors like temperature and precipitation patterns.
Model data availability	The availability of reliable data is crucial for accurate climate modelling and region classification.
Share of renewable energy sources	Indicates the sustainability and environmental impact of energy usage within a climatic region.
CO ₂ emissions	Reflects the level of carbon footprint and environmental impact associated with human activities.
Heat losses	Evaluates the efficiency of heat management systems within a region, influencing energy consumption.
Primary energy factors	Measures the efficiency and sustainability of energy sources used within a region.
Heat delivery sources	Identifies the sources and methods used for distributing heat within a region, impacting energy usage.
Water supply vulnerability	Assesses the susceptibility of water supply systems to climate-related challenges like droughts or floods.
Water resource sensitivity	Examines how changes in climate patterns affect the availability and distribution of water resources.
Biodiversity risks and potentials	Considers the impact of climate conditions on the ecosystem and species diversity within a region.
Soil productivity	Evaluates the capacity of soil to support agricultural activities and vegetation growth.
Topography	Examines the physical features of the land, including elevation, slope, and aspect, influencing local climate.
Geology	Considers the composition and structure of rocks and minerals, which affect soil formation and hydrological processes.
Resilience of urban infrastructure	Evaluates the ability of urban systems and infrastructure to withstand and adapt to climate change impacts.
Exploitation of geothermal energy	Examines the potential for utilizing geothermal resources as a renewable energy source for heating and power generation.

The study's analyses are centered around an archetypal refugee camp (Zaatari) situated in Mafraq's hot-dry climatic region. While the methodology employed in this thesis is adaptable to other archetypal refugee camps in diverse climatic regions, it's crucial to re-evaluate the architectural components and construction methods. Factors such as the envelope, plan layout, materials, Surface to Volume Ratio (S/V ratio), etc., need careful reconsideration to align with the specific climatic conditions and urban context of each location. Figure 9 demonstrates the division of Jordan into four distinct climatic regions, including Hot-Desert (BWh), Cold-Desert (BWk), Hot-Semi arid (BSh), and Hot-summer Mediterranean (CSa).



contributes uniquely to the characterization of climatic regions and their dynamics, which have been described in Table 40. According to Şahin and Cığızoğlu (2012), an integrated approach incorporating relative humidity (RH) and specific humidity (SH) alongside traditional metrics such as maximum temperature (Tx), mean temperature (Tm), minimum temperature (Tn), and precipitation (Pt) is recommended for the determination of climatic regions.

Table 40

Climate Analysis Criteria

Factors	Description
Maximum Temperature (Tx), Minimum Temperature (Tn)	Temperature extremes, represented by Tx and Tn, offer fundamental insights into the thermal behavior of a region.
Mean Temperature (Tm)	Provides a comprehensive view of the overall climatic conditions over a specified period.
Precipitation (Pt)	It not only influences the water balance but also shapes various ecological and hydrological processes.
Mean Wind (WN)	It contributes to the atmospheric dynamics, affecting weather patterns and climate variations across regions.
Relative Humidity (RH), Specific Humidity (SH)	They determine the moisture content in the atmosphere
Reference	(Şahin and Cığızoğlu, 2012)

According to the site design guide by Architect (2009) consideration of microclimate conditions for the site design is the initial step. Following this, it is crucial to take into consideration climatic factors such as temperature, relative humidity (RH) levels, and topography, as well as the typology of soil, vegetation, elevation, and water supply. Examining air temperature holds paramount importance in the analysis of climate. Thermal energy traverses via radiation, convection, conduction, and evaporation. In terms of evaporation, pivotal elements encompass water bodies and surrounding vegetation in a construction vicinity. These elements influence evaporation rates, thereby augmenting the quantity of water vapor in the atmosphere and consequently elevating RH levels (Pradeepa, 2018).

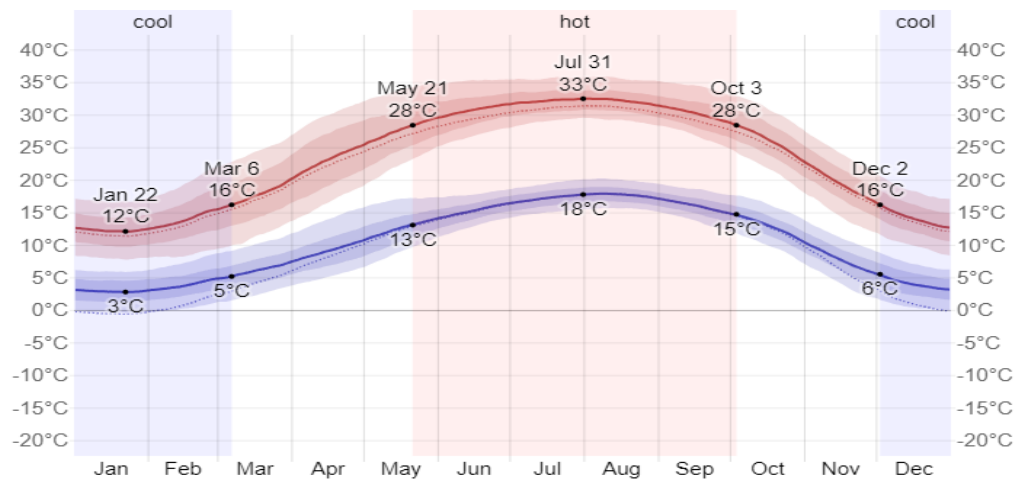


Figure 10. Average high & low temperature in Mafraq (source: © weatherspark.com)

In Mafraq, summers stretch out with their scorching heat, arid conditions, and clear skies, while winters bring cold, blustery winds and occasional cloud cover. Throughout the year, temperatures generally range from 3°C to 33°C, rarely dropping below -0°C or climbing above 36°C. The hot season persists for approximately 4.5 months, spanning from May 21 to October 3, and is characterized by daily high temperatures averaging above 28°C. August emerges as the peak of heat, with an average high of 32°C and a low of 18°C. Conversely, the cool season extends for about 3.1 months, from December 2 to March 6, marked by daily high temperatures averaging below 16°C. January stands out as the chilliest month, with an average low of 3°C and a high of 12°C. Figure 10 illustrates the average high and low temperatures in Mafraq.

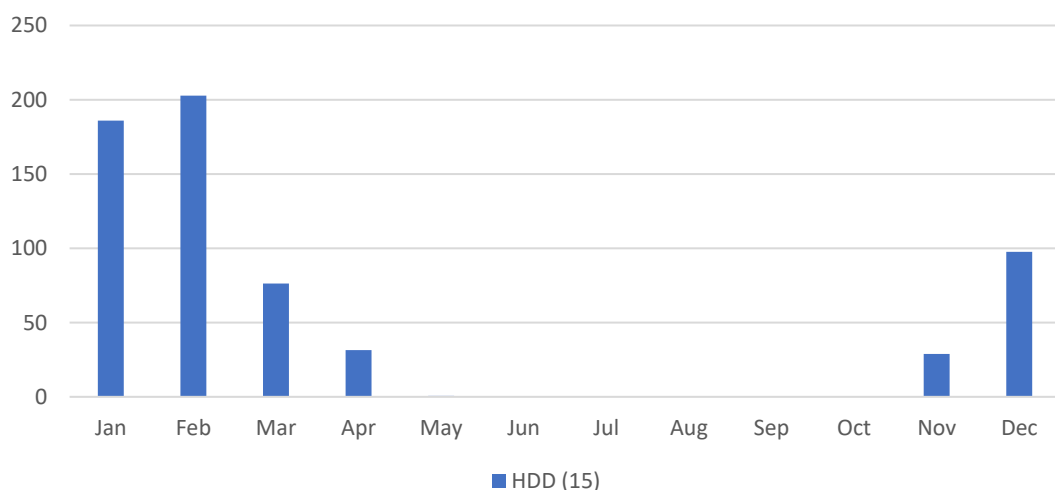


Figure 11. Heating degree days (HDD) chart of Mafraq

HDD measures the cumulative amount (in degrees and days) the outside temperature falls below 15°C, indicating heating demand for buildings. Figures 11 and 12 display the Heating Degree Days (HDD) and Cooling Degree Days (CDD), respectively, for Mafraq spanning from January 1, 2023, to December 31, 2023. These values were computed utilizing the Average Monthly Temperature, with a base temperature of 15 degrees Celsius for HDD and 22 degrees Celsius for CDD. (Source: mgm.gov.tr) Climatic data was derived from station coordinates JO_OJMF, King Hussein Air base, located at 32.356 latitude and 36.259 longitude.

Table 41

Mafraq's Heating Degree Days (HDD) Of Each Month

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HDD (15)	185.9	202.7	76.3	31.4	0.6	0	0	0	0	0	28.9	97.7

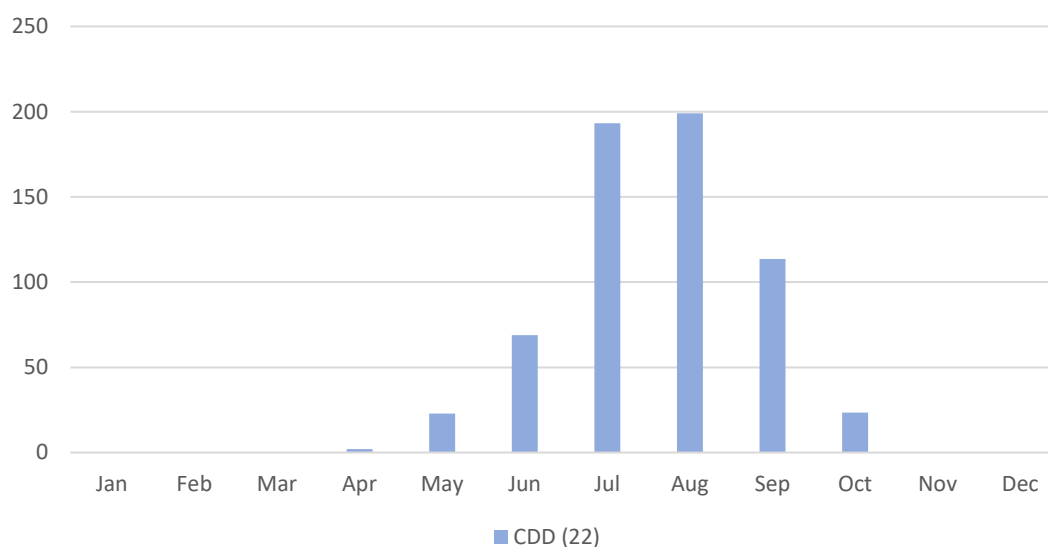


Figure 12. Cooling degree days (CDD) chart of Mafraq

Table 42

Mafraq's Cooling Degree Days (CDD) Of Each Month

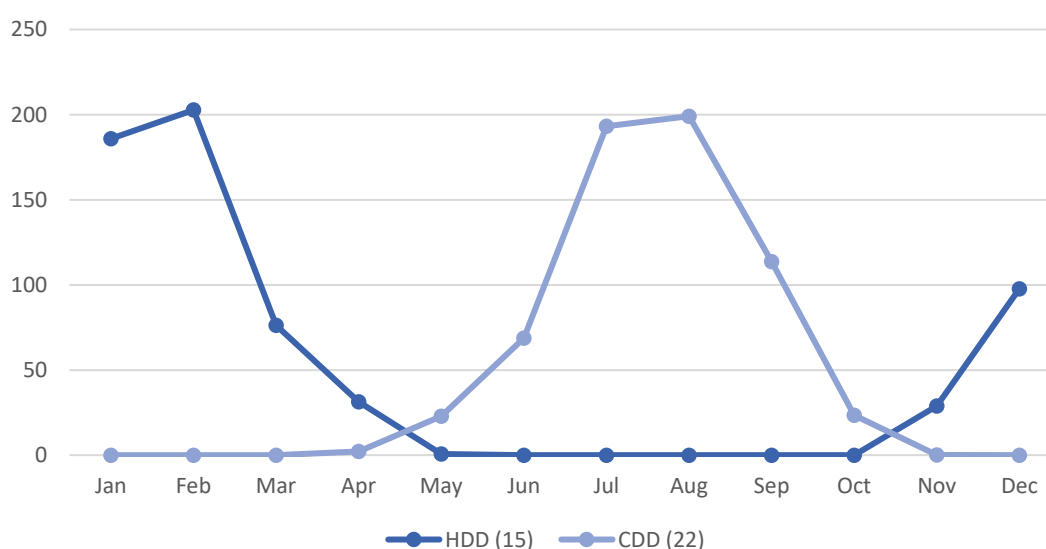
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CDD (22)	0	0	0	2.1	22.9	68.8	193.2	199.1	113.6	23.4	0.1	0

Table 43

Calculation Description Of Mafraq's Cooling Degree Days (CDD)

Parameter	Description
Method	Average Monthly Temperature
Base Temperature	22C (71.6F)
Station and Coordinates	JO_OJMF, King Hussein Air base, 32.356, 36.259

Figure 13 undertakes a comparative analysis of the Heating Degree Days (HDD) and Cooling Degree Days (CDD) for 2023 of Mafraq. From January to March, HDD values are significantly higher than CDD values, indicating that these months require more heating than cooling. From April to October, CDD values are higher than HDD values, indicating that these months require more cooling than heating. Additionally, HDD values from November and December increase again, indicating a need for heating. Ultimately, Mafraq experiences more cooling demand than heating from April to October, with July and August being the peak months for cooling. On the other hand, Heating demand dominates from November to March, with December having the highest heating demand among the winter months.

*Figure 13. Comparison of Mafraq's HDD and CDD for 2023*

The Mafraq Global Horizontal Solar Radiation (GHSR) chart (Fig. 14) illustrates the cumulative solar energy received on a horizontal surface, encompassing both direct

sunlight and diffuse radiation (scattered sunlight). Peak levels occur from early May to late July, reaching approximately 1000 Wh/m², marking the zenith of solar radiation for the year. Conversely, the lowest rates of Global Horizontal Solar Radiation (GHSR) are noted in July and December, recording around 600 Wh/m².

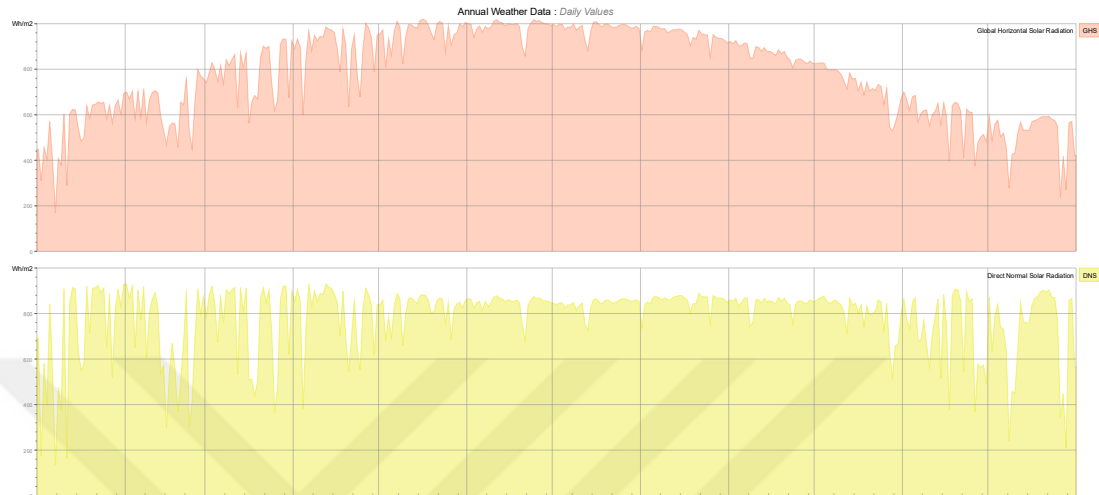


Figure 14. Solar radiation charts of Mafrq

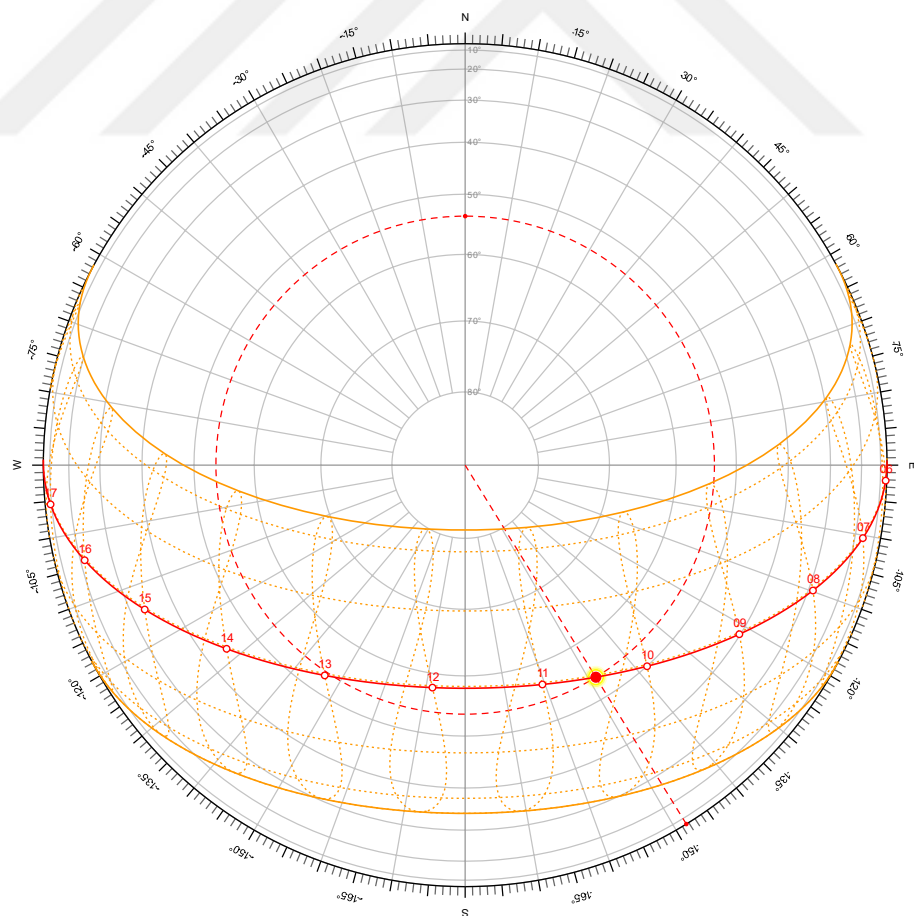


Figure 15. Sun path chart of Mafrq

The Direct Normal Solar Radiation (DNSR) chart (Fig. 14) shows the solar radiation received directly from the sun when the sun is perpendicular to the surface (i.e., no atmospheric scattering). It is essential for solar energy applications like concentrating solar power (CSP) systems and solar trackers. The DNSR monthly chart of Mafraq (Fig. 14) illustrates an approximate consistent pattern of clear days, absorbing around 850 – 900 Wh/m² solar radiation throughout the year. The sudden drops represent factors such as cloud cover, atmospheric conditions, and seasonal changes.

In Mafraq, the probability of wet days fluctuates across the year, delineating distinct wet and dry seasons. Table 44 illustrates an overview of Mafraq’s precipitation chance throughout the year. In Mafraq, February stands out as the month with the highest number of rainy days, averaging 4.8 days. According to this classification, rainfall emerges as the predominant form of precipitation throughout the year, with its peak likelihood reaching 19% on February 6th.

Mafraq undergoes noticeable seasonal changes in monthly rainfall patterns. The rainy season spans approximately 4.8 months, stretching from November 8 to April 1, and is characterized by consistent rainfall of at least 13 millimetres over 31 days. February emerges as the wettest month in Mafraq, averaging 32 millimetres of rainfall. In contrast, the dry season spans about 7.2 months, starting from April 1 and lasting until November 8. July marks the driest month in Mafraq, recording an average rainfall of 0 millimetres.

Table 44

Monthly Chance Of Precipitation In Mafraq

Days of	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain	5.2d	4.8d	3.5d	1.5d	0.5d	0.2d	0.1d	0.1d	0.2d	1.2d	2.8d	4.2d
Mixed	0.2d	0.2d	0.1d	0.0d	0.0d	0.0d	0.0d	0.0d	0.0d	0.0d	0.0d	0.1d
Any	5.3d	5.1d	3.7d	1.5d	0.5d	0.2d	0.1d	0.1d	0.2d	1.2d	2.8d	4.3d

In Mafraq, the average Relative Humidity (RH) fluctuates between 20% and 96%. It tends to peak during the winter months and levels off during the hot summer season. Figure 16 illustrates the monthly Relative Humidity of Mafraq.

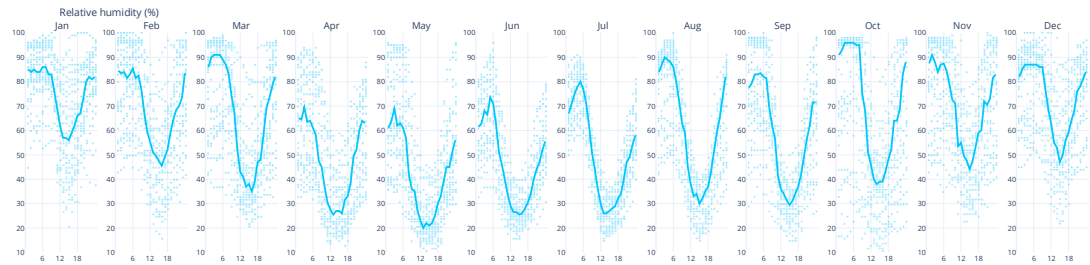


Figure 16. The average relative humidity of Mafraq

The prevailing wind direction (Figure 17) in Mafraq predominantly originates from the east for approximately 3.7 weeks, spanning from November 13 to December 9, peaking at 37% on November 26. Conversely, for the majority of the year, lasting 11 months from December 9 to November 13, the prevailing wind shifts to originate from the west, reaching its highest frequency of 37% on January 1.

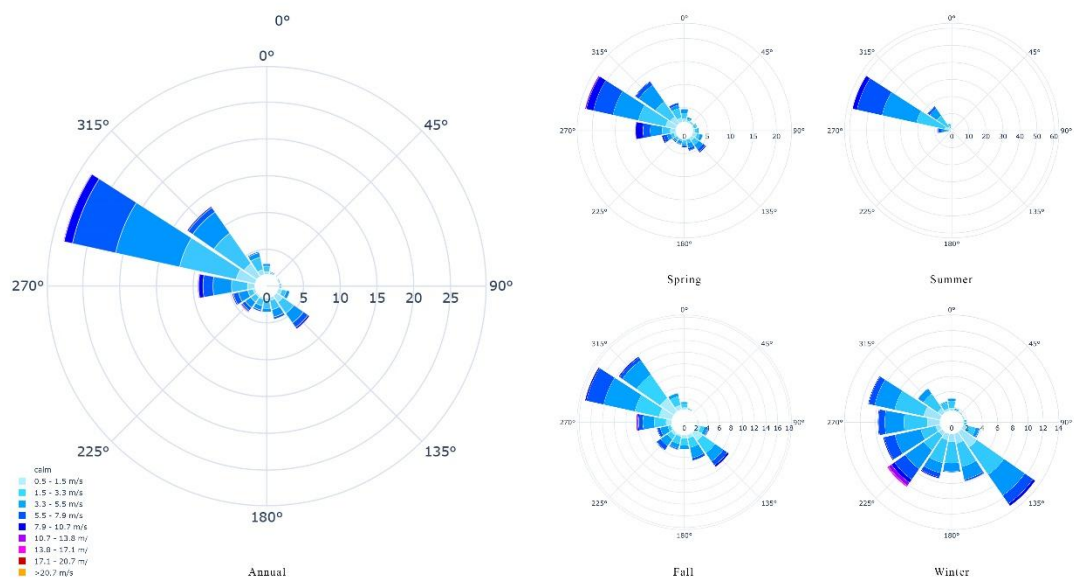


Figure 17. Yearly and seasonal wind direction of Mafraq

In Mafraq, wind speeds show mild seasonal changes throughout the year (Figure 18). The windiest period lasts about 5.6 months, from November 14 to May 1, with speeds exceeding 3.9 m/s. February stands out as the windiest month, with an average

speed of 4.4 m/s. Conversely, the calmer period spans roughly 6.4 months, from May 1 to November 14. October marks the calmest month, with speeds averaging 3.4 m/s.

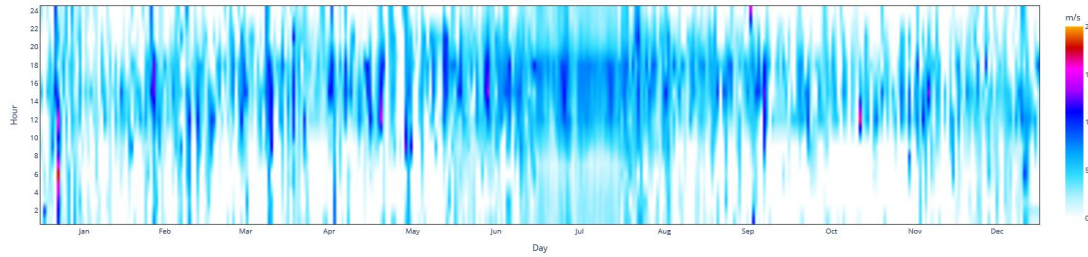


Figure 18. Wind speed chart of Mafraq

4.3 Camp Analysis

The Zaatari Refugee Camp (Z-RC) is determined as the case study in this thesis. It is located 10km east of the northern Jordanian city of Mafraq and about 12 km away from the border with Syria. Mafraq receives plenty of sunlight throughout the year, with an average of 10 to 12 hours per day in winter (January to March) and up to 14 hours and 17 minutes of daily sunlight in summer (July to August). Because Mafraq is located in the hot-arid region, it experiences a higher average absorption of solar radiation in comparison to other climatic regions. Solar radiation absorption of Mafraq ranges between 1.1 KW/m² to 6.8 KW/m² in winter and between 6.8 to 8.2 KW/m² in summer. (Source: Climate Consultant EPW of Mafraq) At an altitude of roughly 710 m, the annual precipitation in Mafraq is approximately 184mm (7.24 inches), and the dominant winds blow from the northwest.

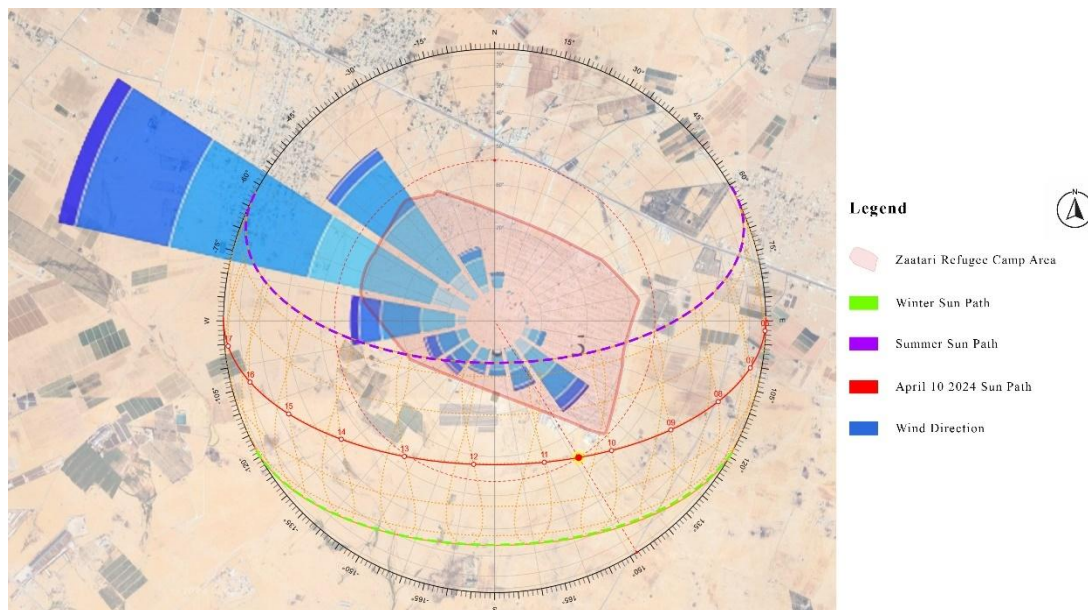


Figure 19. Zaatari refugee camp site overview

The research framework was developed by compiling and analysing key issues identified by academics and practitioners in relevant publications to document the architectural and construction details of Z-RC shelters. The sun path data, depicted in Figure 15, is utilized to analyse the Zaatari Refugee Camp (Z-RC) site, as shown in Figure 19. This illustration highlights the sun's paths and prevailing wind direction at the Z-RC location.

4.3.1 Physical and spatial analysis. Exploring the physical layout and spatial arrangement of the Zaatari Refugee Camp and its shelters unveils the practical realities and human stories behind this makeshift sanctuary. By studying how the camp is organized and the design of its shelters, the insight of people's adaptation to their circumstances is understood. Factors like camp layout, shelter orientation, materials, and spatial configurations are analysed to explore the intersection of resilience, design, flexibility, and mobility in adversity.

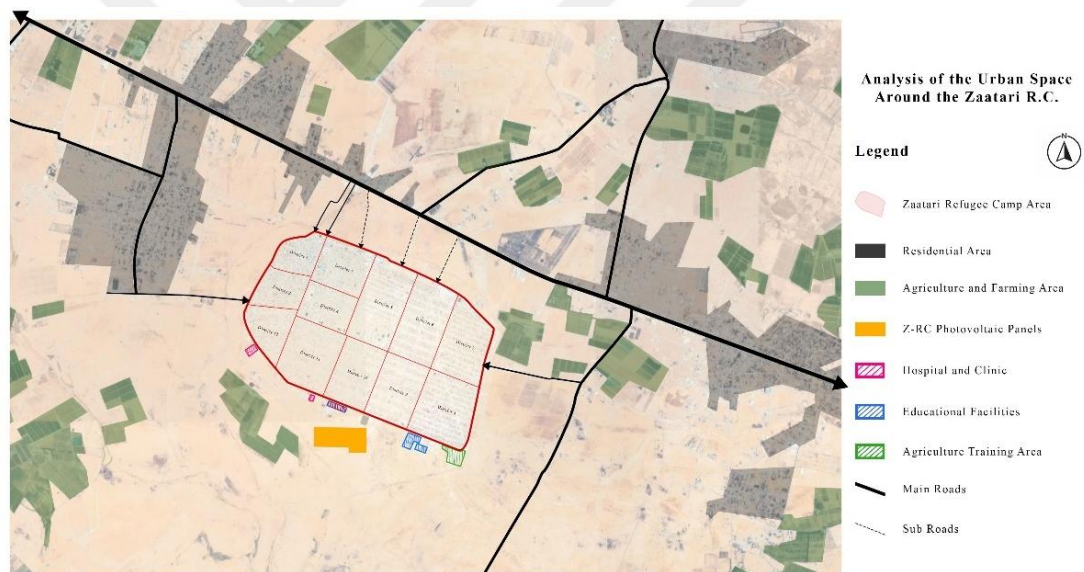


Figure 20. Analysis of urban space around the Zaatari refugee camp

The camp spans an area of 5.5 square kilometres (530 hectares), planned with a grid layout and divided into 12 districts, as depicted in Figure 20. Originating as a cluster of tents in 2012, it has since grown into an informal city, now accommodating over 26,000 containers (prefabricated shelters provided by the UNHCR) (AlWaer et al., 2023). The original top-down approach (provided by UNHCR handbook) operationalised the distributions of facilities, which is a tightly controlled approach where every detail was predetermined and enforced from the top down, leaving little

room for flexibility or adaptation. Dalal et al. (2018) mentioned that the military-style layout's rigid structure results in a 'diminishment' of cultural ties and social engagement among residents, ultimately undermining self-determination. McGrath et al. (2018) stated that over time, refugees have managed to reshape conventional humanitarian assistance into a hybrid, adaptable camp model and changed the community layers to bottom-up. As showcased in Figure 21, the camp encompasses various amenities, including shops, wash blocks, mosques, schools, playgrounds/sports courts, hospitals and clinics, a fire station, offices of the World Food Programme (WFP), and upwards of 2500 businesses operated by refugees (AlWaer et al., 2023). Figure 21 also represents the distribution of main facilities, including hospitals.

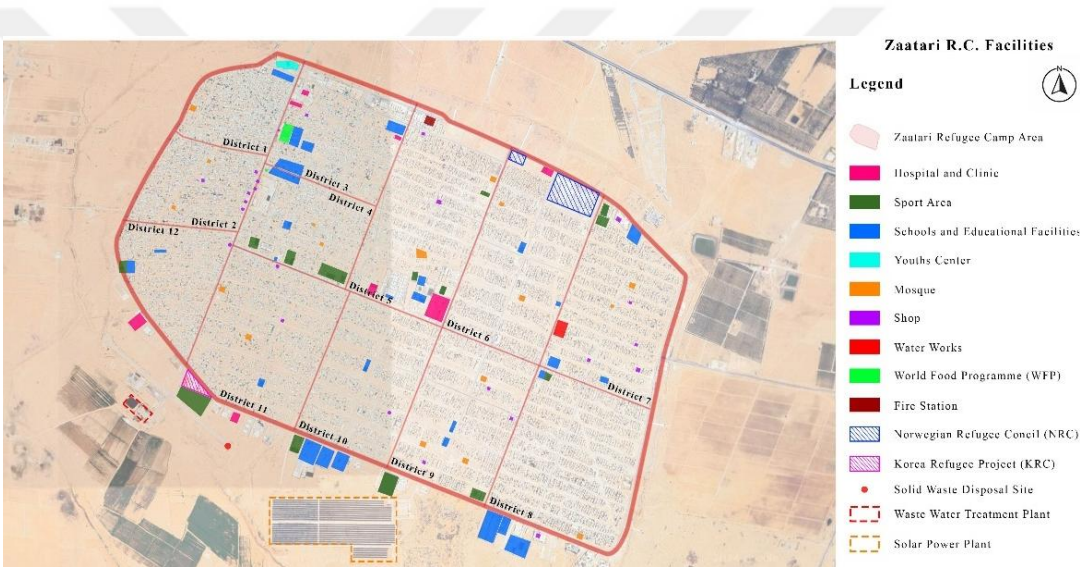


Figure 21. Zaatari refugee camp facilities map

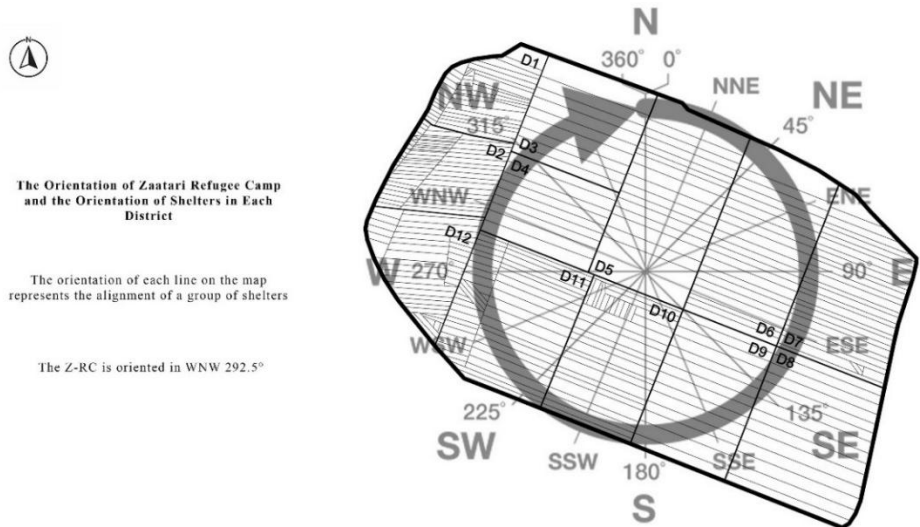


Figure 22. The orientation of Zaatari refugee camp and shelters

Figure 22 depicts the predominant orientation of shelters within Z-RC and its various districts. The lines within each district represent the alignment of groups of shelters. As indicated by Figure 22, Z-RC exhibits a primary orientation along the WNW (292.5°) axis, with shelters in districts 3 through 9, as well as the majority of districts 10 and 11, following this alignment. However, shelters in districts 1, 2, and 12 are generally oriented along the 90° E axis.

The Typology of Shelters in Z-RC

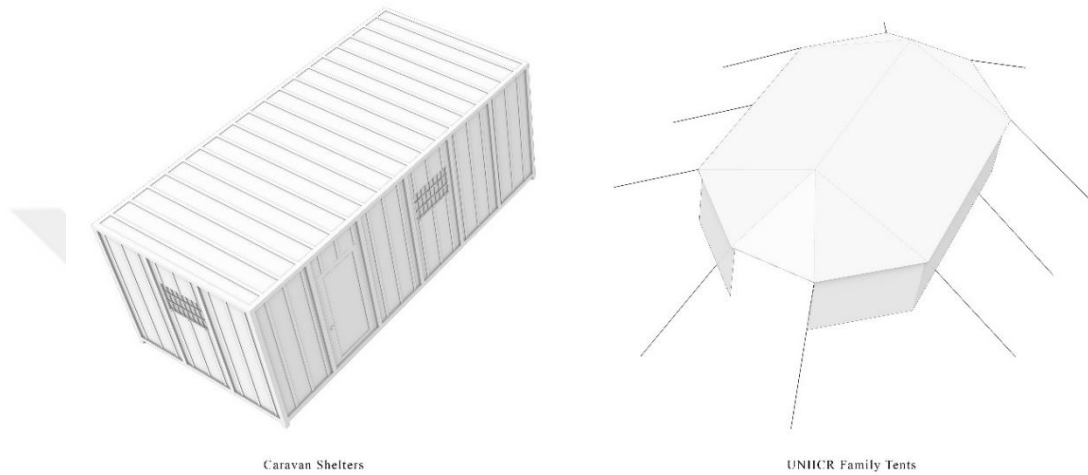


Figure 23. The typologies of Zaatari refugee camp shelters



Figure 24. The UNHCR family tents in Zaatari refugee camp. left: Amar (2018), right: Shahin (2023)

Figures 23 and 24 delineate the two primary shelter types within Z-RC: the UNHCR family tents, initially utilized as emergency accommodations for migrants during the camp's inception, and the container shelters, now employed in various configurations. The diverse preferences and needs of inhabitants have led to a multitude of shelter combinations and compositions within Z-RC. Families have the autonomy to procure shelters from camp "Realtors," as noted by Dalal (2022), and customize them according to their requirements.

According to Albadra et al. (2018), 11% of the container shelters were static, while the rest were mobile containers with suspended timber floors, although in certain instances, refugees replaced these with a layer of cement mortar over rubble. Consequently, while Z-RC shelters primarily consist of container and UNHCR family tents, there is no apparent pattern in the composition of the majority. According to the UNHCR Family Tents catalogue, tents are made from canvas and thus are like textiles or plastic sheets but heavier. They are also known for their lightweight structure, movability, versatility, and basic form. The most important features of these tents are listed in Table 45.

Table 45

The Features Of UNHCR Family Tents

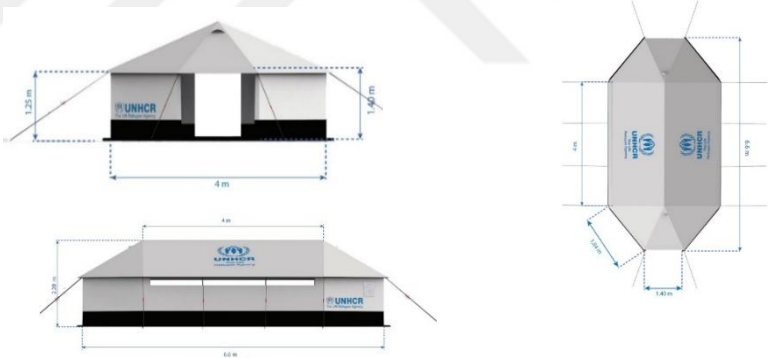
Features	Description
Area	16 m2 main floor area, plus two 3.5 m2 vestibules, for a total area of 23 m2, double fold with ground sheet.
Capacity	Up to 5 (3.5 m2 per person as recommended for hot regions)
Life span	a shelf-life of a minimum 5 years
Dimensions	

Figure 25 showcases a selection of 3D visualizations derived from the site plan of Z-RC, illustrating a range of shelter combinations, including single shelters, combinations of single shelters with self-built tents integrated onto one side of Container shelters, and configurations providing semi-closed or enclosed yards using metal sheets as roofing or fencing. Albadra et al. (2018) noted that during summer, 55% of families utilized these semi-closed (semi-outdoor) spaces due to their cooler temperatures, whereas during winter, this figure dropped to less than 30%.

The Composition and Evolution of Z-RC Shelters

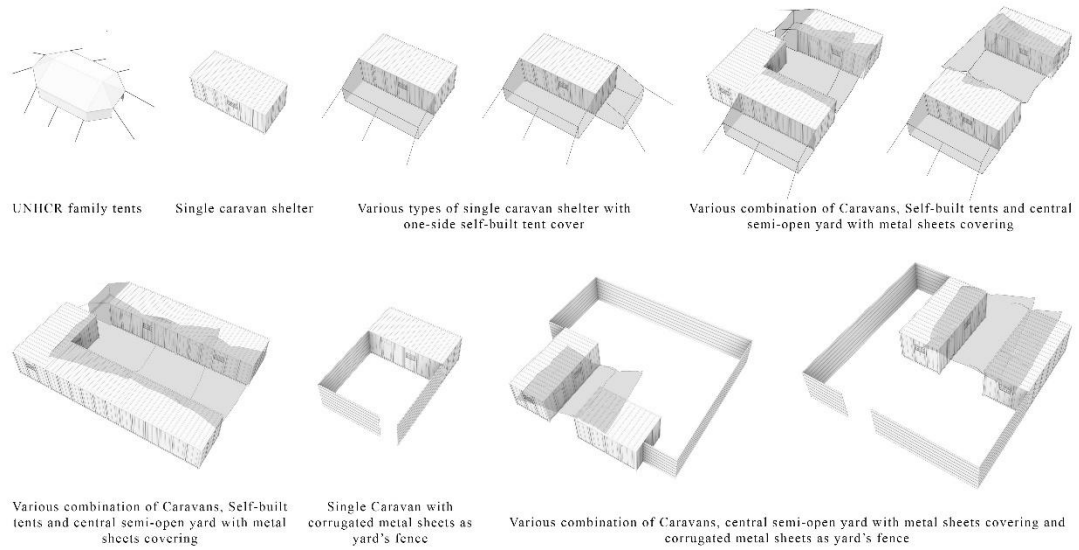


Figure 25. Various shelters configurations at Zaatari refugee camp

The Elements of Caravan Shelters of Z-RC

General types of Caravan shelters:

- Fixed
- Movable

Overall Dimensions:

- Emirati (Hilal) Caravan: 6.5×3 m
- Kuwaiti Caravan: 6×3.5 m
- Saudi Caravan: 5×3 m
- Omani Caravan: 6×3 m

Structure:

- Cubical form
- Simple metal beams 8×4 cm Or 8×8 cm

Windows:

- Two sizes: 100×100 cm and 125×100 cm
- Detachable and detachable using male/female connector
- Internal face usually covered with a thin layer of plastic

Floor:

- A metal grid base
- Film-Faced Plywood sheets covering of 244×122×1 cm
- Grid gaps filled with stone
- Internal face usually covered with a thin layer of plastic

Roof and Walls:

- Structure of sandwich panels
- Two layers of thin corrugated metal sheets (a thin layer of plywood for interior side in some cases)
- A mid layer of insulation

Roof sheets dimensions:

- 180×300×7 cm

Walls sheets dimensions:

- 12 sheets with various size
- 120×240×5 cm or 100×240×5 cm

Male/Female connector

Figure 26. The elements of container shelters at Zaatari refugee camp

Dalal (2022) identifies four distinct models of container shelters present in Z-RC, namely the Emirati (Hilal) containers measuring 6.5×3m, Kuwaiti containers measuring 6×3.5m, Saudi containers measuring 5×3m, and Omani containers measuring 6×3m. Container details vary according to the manufacturer, with some models slightly taller or longer than others. Nevertheless, they all incorporate essential components (Dalal, 2022), such as metal frame structures, walls, roofs, windows, and doors, as shown in Figure 26 and detailed in Table 46. These components are configured to accommodate various facilities, including kitchens, bathrooms, and sleeping areas.

Table 46

The Details Of Container Shelter's Materials And Components (Dalal, 2022)

Component	Material	Dimensions	Connections
Structure	Metal	Metal boxes in 4×8cm or 8×8cm	bolted
Walls	Corrugated sheets (zinc) outer surfaces of 0.35mm steel sheet and inner surfaces of either the same or plywood sheet	100×240×5cm, 120×240×7cm	Male/Female interlock bolted
Insulation	40mm polyurethane	-	-
Roof	Same material as the walls	180×300×7cm	Supported by container structure
Floor	Cement, Earth, Lumpy stone, plastic fillings, 1cm Plywood covering	-	A metal frame as a basis
Door	Wood, Metal	-	Hinged, can be locked
Windows	Single glazing, Aluminium frame	-	Fitted into wall openings

Containers are significant as they transition from standardized shelter units to architectural elements within the camp. The reassembling process of container shelters respects the camp's temporariness, with materials like tents, corrugated sheets (Zinco), concrete blocks, and cement being used. The sustainability of these materials is implied through their reuse and adaptation in the camp's evolving landscape, reflecting a response to the immediate needs and limitations of the social and material worlds in the camp.

4.4. Determination and Analysis of Camp Unit as Case Study

Container units form a significant portion of the built environment in refugee camps, directly influencing the quality of life and energy efficiency within the camp. In response to the pressing need for sustainable and thermally comfortable housing in Zaatari Refugee Camp, a standardized single-family container unit has been selected as the base case for this study (Figure 28). The chosen unit design, reflecting typical construction practices in the camp, consists of wall panels made of 3.5 mm zinc sheets, 4 cm polyurethane insulation, and a second 3.5 mm zinc sheet layer (Table 46). This archetype was modelled using DesignBuilder to evaluate its thermal performance and

energy efficiency under the specific climatic conditions of Mafraq, Jordan (Figure 27). The unit's rectangular plan and standardized façade design enable straightforward comparisons of optimized scenarios involving various plan layouts, envelope material, insulation, window design, shading, and windows' opening rate, as illustrated in Table 49. This standardized design serves as a benchmark for exploring alternative solutions aimed at enhancing thermal comfort, LCA, and energy efficiency.

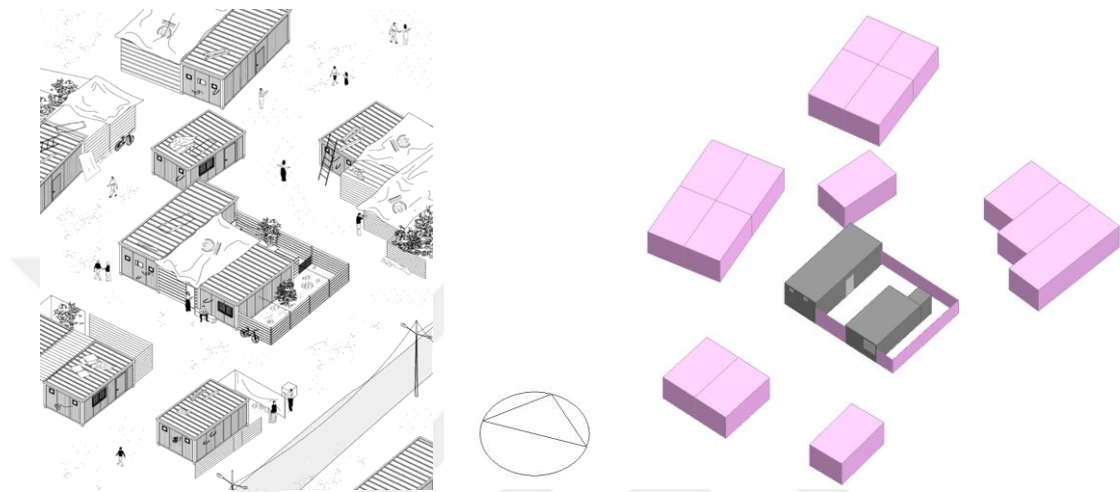


Figure 27. Left: Other shelters surrounding Omar's dwelling (Base Case) (Dalal, 2022) – Right: 3D model of the base case and adjacent shelters

4.4.1 Analysis of camp unit. According to Dalal (2022), since 2013, refugees have dismantled and reassembled tents and containers for several reasons, such as more sense of home and security, a social order that suits their privacy and family arrangements, and the unit adaptation to their needs while navigating between temporary and permanent constraints. As illustrated in Figure 25, this action led to the appearance of various configurations and plans of containers in Zaatari for each family. The current study employs Omar's family settlement as a base case, drawing upon Dalal's research (2022) detailing the migration journey of Omar and his in-laws in Zaatari in pages 122-129.

“..... The resulting dwelling, therefore, had two rooms: a large one in the Qatari caravan, separated from the kitchenette and the bathing area by a curtain, and a small room in the adjacent caravan. The large room was furnished with mattresses, car pets, curtains, LED lights, pictures, and a TV. The other caravan he used as a storage room, where electrical equipment was kept. (Dalal, 2022).”

According to Figures 28 and 30, Omar and his wife live in the larger container (Qatari Caravan: 3m ×7.5m) and have utilized the smaller (3m ×5m) as a guest room and storage area. Dalal (2022) mentions that the larger one is fixed while the smaller one is movable. Omar's dwelling is located in the eastern part of Z-RC, which is oriented along the WNW (292.5°) axis (Figure 21).

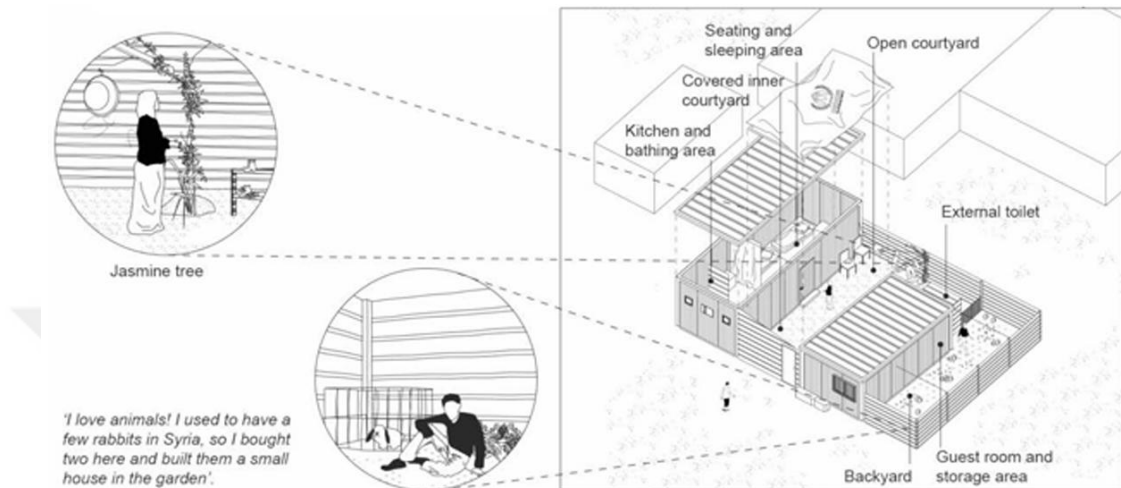


Figure 28. The Omars' settlement (base case) at Z-RC (Dalal, 2022, p.126)

By locating containers in front of each other, he created a courtyard and covered that using plastic sheets. The floor of the smaller container was added later due to financial challenges and is constructed of sand and cement. Using Zinco sheets, he created a bathing area in the back, a gardening area to plant corn and raise rabbits, and a fence around the dwelling.

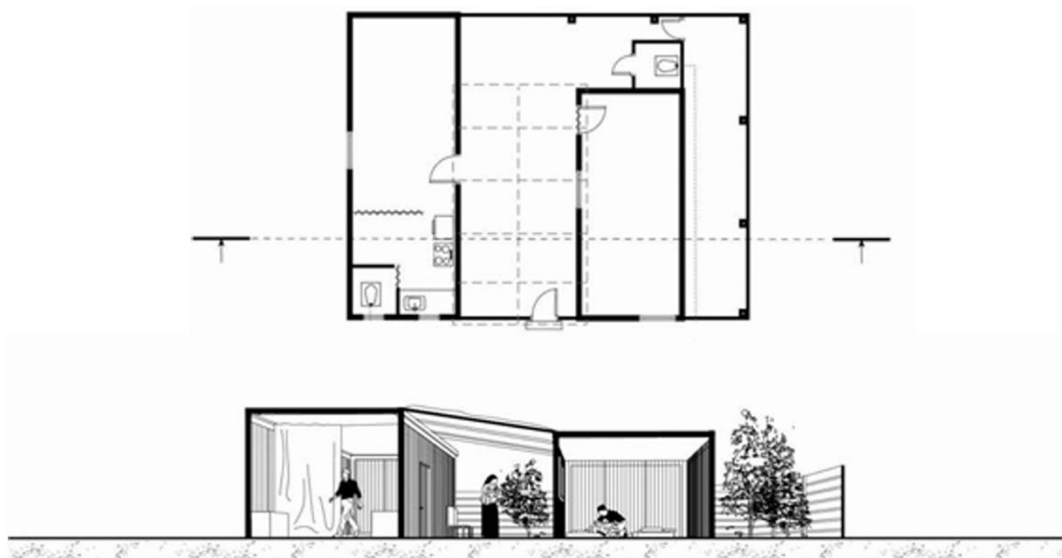


Figure 29. Detailed plan of Omars' dwelling (base case) at Z-RC (Dalal, 2022, p.126)

The floor plan of Omar's house, as outlined by Dalal (2022) in Figure 29, is presumed to be accurate and serves as the base case (BC) for evaluating the amenities, space, and measurements. The floor plan is redrawn with the same aspect ratio and dimensions for further analysis in this study (Figure 30).

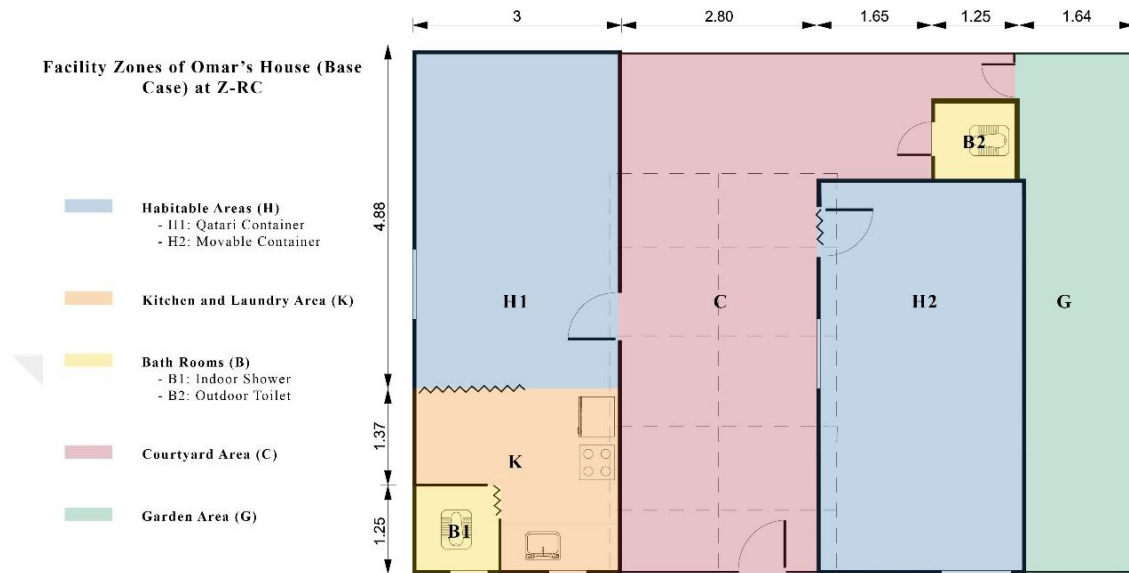


Figure 30. Facility zones of Omars' settlement (base case) at Z-RC

Table 47

Omar's Settlement (Base Case) Overview

Facilities	Code/Description	Areas
Occupants number	Two (Omar and his wife)	-
Containers Code	Qatari fixed container (H1, K, B1), Smaller movable container (H2)	(H1, K, B1): $7.5\text{m} \times 3\text{m} = 21.46\text{m}^2$ H2: $5.65\text{m} \times 3\text{m} = 16.10\text{m}^2$
Facilities area	Kitchen (K), Indoor Bath (B1), Outdoor Toilet (B2), Garden (G), Courtyard (C)	K: 5.95m^2 , B1: 1.43m^2 , B2: 1.43m^2 G: 11m^2 , C: 23.75m^2

According to Dalal (2022), corrugated metal sheets, Zinco, are used to construct kitchens, bathrooms, fencing, roofing, and external walls. Vertical metals and wooden beams are also used as supportive elements to sustain them. Zinco sheets. Cement is used to smooth the surface and floor of the courtyard area.

The walls are 5cm thick and are constructed in the form of sandwich panels from three layers including – from the exterior to interior – 0.35mm corrugated metal sheets, 40mm polyurethane insulation layer, (Albadra et al., 2018) and an inner layer of corrugated metal sheets or a thin layer of plywood. The larger container's roof (Qatari container) stands at a height of 2.4m (Dalal, 2022), while the height is 2m for the smaller container (Figures 28 and 29). Roofs are constructed using 7cm thick sheets layered in the same manner as the walls (Albadra et al., 2018).

As a self-adaptation method, more than 70% of refugees covered the open space among their containers using plastic sheets (like in Omar's case) and insulated container wall sheets arranged in gable form to create semi-open courtyards with shading. (Dalal, 2022) Due to the cooler temperatures of semi-open courtyards, 55% of families spend their daytime hours there (Albadra et al., 2018).

By 2018, *“only 5% had access to an electricity generator during the day and a fan. (Albadra et al., 2018)”* The majority employed alternative methods to stay cool, such as draping wet towels over their heads and shoulders, taking multiple showers throughout the day, and seeking shade (Albadra et al., 2018).

The containers operate no mechanical ventilation system. During summer, windows were rarely left open to prevent excess heat absorption from outside (Dalal, 2022). However, at night, 73% of families kept their windows open, citing 'sandstorms' as the primary reason for closing them. In winter, 95% of households relied on gas heaters for an average of 10 hours a day, in addition to wearing extra layers of clothing, using blankets, and laying carpets for insulation (Albadra et al., 2018).

In the existing case, the windows are single-glazed with aluminium framing. According to Dalal (2022, p.161), windows, as an extra element that can be detached and attached, come in two sizes, including 100 × 100cm and 125 × 100cm. In the case of Omar's dwelling, both containers are equipped with 100 × 100cm windows. The larger container (Qatari Container) is equipped to one window, while the smaller container originally was equipped to one window and later, he added another window to the corner of the container facing south to absorb more sunlight.

Finally, using cement as an alternative flooring material, a layer of 1cm thick Film-Faced Plywood sheets or, in some cases, “a screed of cement mortar over rubble” (Albadra et al., 2017) are fixed on a metal grid (as illustrated in Figure 26).

4.4.2 Technical data of the base case. Table 48 provides an overview of the existing environmental and technical conditions of the base case. These parameters are then applied to the DesignBuilder equally for both the base case and proposed layouts. According to the interview of Polska Pomoc (2023), indoor light availability has limited and intermittent access, particularly highlighting power cuts between 5 pm and 11 pm. The Psychrometric Chart for Mafrag (Figure 31) delineates the spectrum of temperatures and relative humidity (RH) levels pivotal for establishing comfort in a hot-dry climate region. Analysis of the chart suggests that in such climatic contexts, comfort RH levels typically span from 20% to 80%, with recommended average temperatures ranging between 21°C and 28°C.

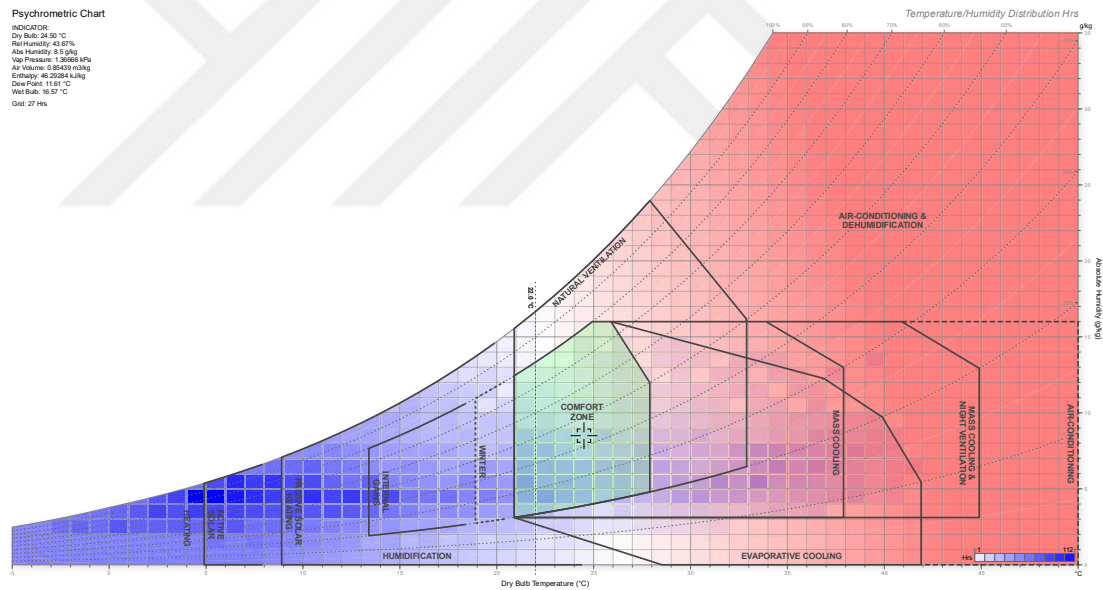


Figure 31. Psychrometric chart of Mafrag

Therefore, as listed in Table 48, natural ventilation controls are set to maintain indoor temperatures between 21°C and 28°C, consistent with the local comfort zone derived from psychrometric charts. Additionally, heating setpoints for the shelter are outlined, with a standard 21°C setpoint and a setback temperature of 15°C.

Table 48

Base Case's Technical Data Of Existing Condition

Parameter	Existing Condition	Reference
Indoor light availability	9 hours total actual availability	(UNHCR Jordan, 2024)
	Available from 12 pm to 5 pm	(Polska Pomoc, 2023: interview), (Jordan, 2022)
	Power cut from 5 pm to 11 pm Available from 11 pm to 3 am	
Outdoor temperature	Min: -2 Max: +38	Mafraq climate data: Figure E in appendix
Clothing Factor	Min. men Clo for summer 0.43 Min women Clo for summer 0.93	(Albadra et al., 2017)
Metabolic Factor	Total for men and women: $(1+0.85) / 2 = 0.925$	-
Natural ventilation limit controls	Indoor min temp. Control: 21 °C	Based on the psychrometric chart, Figure 31
Gas Heater	Model: National Excellence	(La Rose, 2021) (Derived from Figure 32)
	Gas Type: LPG	(Bisaga & To, 2021).
	Heating System Type: convective Preheat: 3 min = 0.05 hr CoP: 0.8889 ~ 0.89 Maximum supply air temperature: 75.8 °C Humidity supply: 0	Inquired from the manufacturer of the similar gas heater from China
Heating	Set Point: 21°C	Based on the Psychrometric chart, Figure 31
	Set Back: 15 °C	Based on the HDD base temp.
Winter and Summer Period	Winter: Dec. to Feb. Summer: Jun. to Aug.	Based on climatic data and the EPW file of Mafraq
	The cold season at King Hussein Air Base lasts for 3.1 months, from December 2 to March 6. During this period, the average daily high temperature is below 16.7°C.	(Source: WeatherSpark.com) ©



Figure 32. Left: National excellence LPG gas heater, (La Rose, 2021), Middle: Plywood partitions create various spaces inside the shelters (Dalal, 2022), Right: Curtains covering the windows from direct sunlight (Dalal, 2022)

4.5 Design Variables and Proposed Scenarios

To develop different scenarios, key variables and parameters were selected based on their impact on thermal comfort, LCA and energy efficiency. Firstly, as illustrated in Figure 33, fourteen plan layouts with various shapes were proposed, combining the containers of the base case (Figure 27). Each of these layouts is analyzed separately with one change in the options of the selected variables (Table 49). Envelope materials and insulation thicknesses, such as HardWood + XPS in 7 cm, 8 cm, and 9 cm configurations, were tested for their thermal performance and energy savings. Window-to-wall ratios (WWR) ranging from 10% to 30% were evaluated for WNW, NNE, and ESE orientations to balance daylight, solar gain, and heat transfer. Shading strategies, including “no shading,” “0.5m louvers,” and “0.5m louver + 0.5m egg crate (overhang + side fins)” (Figure 34) were applied to assess their impact on solar control and comfort. The last variable window opening percentages from 0% to 100% were also examined to optimize natural ventilation and airflow management.

In this context, Lechner (2008) also mentions that the adjustment of parameters such as plan layout, envelope materials, thermal insulation, window-to-wall ratio (WWR), shading, orientation, and glazing type can improve the building’s energy consumption by up to 60%. Therefore, these variables (Table 49) are proposed and combined with the fourteen layouts (Figure 33), providing a robust framework for the optimization.

Table 49

Proposed Variables And Their Options

Variables	Options		Reference
Plan Layout	- T-Shape 1 - T-Shape 2 - T-Shape 3 - T-Shape 4 - C-Shape 1 - C-Shape 2 - C-Shape 3 - C-Shape 4	- L-Shape 1 - L-Shape 2 - L-Shape 3 - L-Shape 4 - Linear- Shape 1 - Linear- Shape 2	Proposed
Envelope Materials	- 3.5mm Zinco - 1cm Hardwood - 1cm Fiber cement		(Dalal, 2022) (Design Builder, 2002)
Thermal Insulation	- 7cm XPS - 8cm XPS - 9cm XPS		Insulation Type: (Yilmaz et al., 2024) Insulation Thickness: (Alsaqabi et al., 2023)
Window-to-Wall (WWR)	Ratio	- 10% - 15% - 20% - 25% - 30%	(Alwetaishi and Benjeddou, 2021) (Shaeri et al., 2019)
Shading		- No Shading - 0.5m Louver shading - 0.5m Overhang and Side fins + 0.5m Louver shading	(Kirankumar et al., 2018)
Windows Opening Rate (%)		- From 0% to 100% with 10% increasing step	proposed

4.5.1 Plan layout. To develop the plan layout of the base case, both containers are combined which were initially separated and placed in front of each other (Figure 29). Dalal (2022) mentioned that the larger container in Omar's dwelling (base case) is fixed to the ground, while the smaller one is movable. Therefore, to answer the existing condition of the base case, the larger container is considered fixed in this study.

As shown in Figure 33, by changing the configuration of the movable container and attaching it to the fixed one, fourteen various layouts are proposed, which are categorized as T-Shape, C-Shape, L-Shape, and Linear-Shape. Each of these layouts is then modelled in DesignBuilder individually to apply the proposed variables and their options them and run the optimization process (Figure G in Appendix).

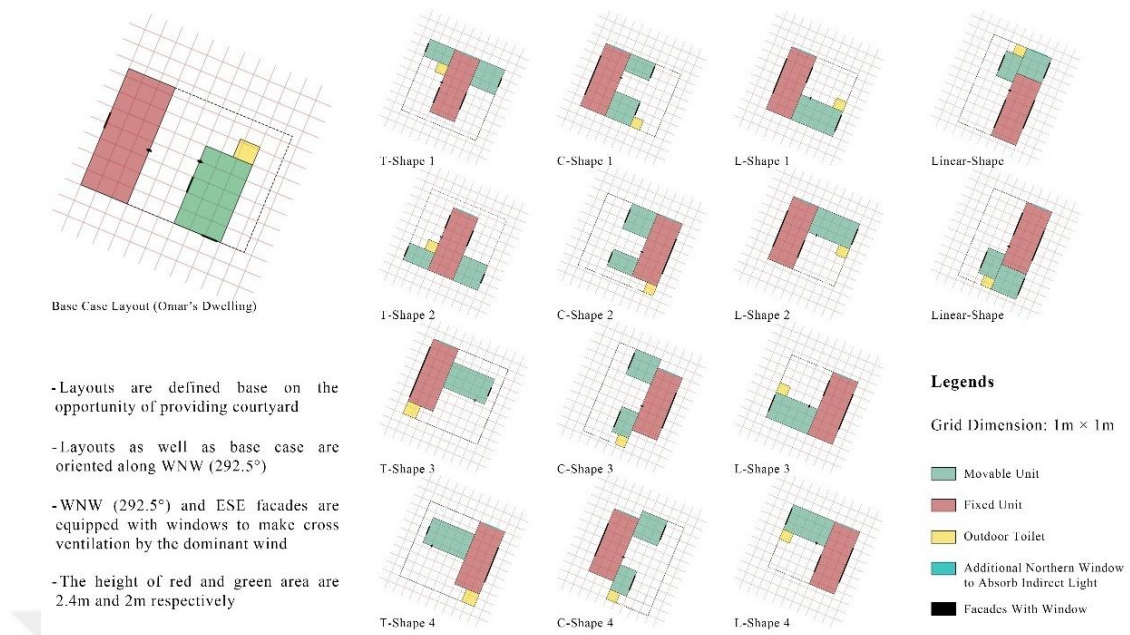


Figure 33. Base case and proposed plan layouts for the optimisation

4.5.2 Envelope configuration. The life cycle assessment methodology has been effectively utilized to quantify the embodied carbon associated with different envelope systems. For example, Udisi et al.'s research analyzed the embodied carbon intensity of 26 commonly used envelope systems, revealing that cladding materials and insulation layers significantly affect embodied carbon levels (Udisi et al., 2024). As listed in Table 50, the primary finishing material of the base case is Zinc (Zinco) sheets with a range of embodied carbon from 3.31 (derived from DesignBuilder) to 3.90 (Hammond et al., 2011).

Implementing low-carbon materials and designs can significantly reduce embodied carbon (Firley & Lüley, 2024). Therefore, to assess the energy performance of the proposed layouts, envelope finishing material is also considered as another variable. Hardwood with 0.47 kgCO₂/kg and Cement FiberBoard with 0.60 kgCO₂/kg of embodied carbon are proposed as two alternative materials that are applied to alternate Zinco in all facades of the shelter from both the inside and outside surface. However, the outdoor toilet's material, 0.35 mm Zinc sheets, remains unchanged across all design scenarios. Figure 34 presents a comprehensive overview of the combinations of three insulation thicknesses and three envelope materials.

Table 50

Base Case and Proposed Envelope Material Options

Material	Embodied Carbon	Unit	Reference
Zinc Sheets (Base Case)	3.31 3.90	kgCO ₂ /kg	DesignBuilder-ICE v1.6 (Hammond et al., 2011)
Hardwood	0.47	kgCO ₂ /kg	DesignBuilder-ICE v1.6
Cement FiberBoard	0.60	kgCO ₂ /kg	DesignBuilder-Ecoinvent v2.01

4.5.3 Thermal insulation. Thermal insulation effectiveness in building envelopes is vital for enhancing thermal performance in hot climates (Al-Homoud, 2004). Proper insulation design impacts the overall energy efficiency of buildings in hot-dry regions. Yilmaz et al. (2024) optimized the building envelope of affordable housing for energy use, cost, environmental impact, and thermal comfort, evaluating five insulation materials (XPS, EPS, RW, GW, CG) across various attributes and thicknesses for the temperate-dry climate of Ankara, Turkey. They found that XPS, despite its high cost, appeared as the first alternative among others due to its low environmental impact. On the other hand, Alsaqabi et al. (2023) assessed the efficiency of XPS insulation with thicknesses ranging from 50mm to 90mm in the hot-arid climate of the Qassim region, Saudi Arabia, finding that XPS performed best at thicknesses of 70mm, 80mm, and 90mm.

The envelopes of the base case (Omar's dwelling) are originally insulated with a 40mm layer of polyurethane sandwiched between two 0.35mm corrugated metal sheets. Therefore, to improve the thermophysical properties of the envelope and indoor thermal comfort, additional insulation is proposed as the third variable. Additional Insulation is applied to all walls and the roof from the interior side. According to Yilmaz et al. (2024), XPS insulation is proposed for the additional insulation. Options of this variable include three thicknesses of 7cm, 8cm and 9cm for XPS derived from Alsaqabi et al. (2023) analysis conducted in a similar climate to this study. These options are then combined with the proposed envelope options and create nine combinations of envelope and insulation, named as construction templates.

Nine combinations of two variables were considered: XPS insulation in three thicknesses paired with three envelope materials (Zinc, Hardwood, and Fiber Cement).



Figure 34. Nine options by combination of the proposed envelope material and insulation thicknesses

4.5.4 Window-to-wall ratio (WWR). In hot-arid climates, the Window Wall Ratio (WWR) plays a crucial role in building design for optimizing daylighting and reducing energy consumption. The original average WWR for the base case is 8.82%, with 5.56% in larger containers and 10% and 16.67% in smaller containers. According to Dalal (2022) Zaatari refugee camp's dwelling windows do not provide enough sunlight during the day and ventilation. Shaeri et al. (2019) investigated the effect of WWR from 0% to 100% with an interval of 10% for cardinal directions for a residential case in the hot-arid climate of Shiraz, Iran. They concluded 10% to 30% as the optimum range of WWR for this region. Additionally, Alwetaishi and Benjeddou

(2021) analysed the ideal WWR for energy performance and daylight for the hot climate of Saudi Arabia and resulted ranges from 20% to 30%, depending on orientation, to optimize daylight and energy efficiency. Thus, to improve the WWRs of the proposed layouts, a WWR range from 10% to 30% with an increasing step of 5% is considered.

On the other hand, to improve cross-ventilation, it is important to situate windows in a wind-driven orientation. Bangalee et al. (2013) mentioned that in a wind-driven natural cross-ventilation system, the openings should face each other, with one on the windward wall and the other on the leeward wall. Therefore, for all 14 proposed layouts, additional windows are placed in facades facing WNW (292°) and ESE (112°) directions, and one window facing NNE (22°) to evaluate the efficiency of additional sunlight in Total Primary Energy use.

4.5.5 Shading. The most effective shading device for hot-arid regions, such as Jordan, is crucial for enhancing thermal comfort, reducing energy consumption, and mitigating heat gain. Kirankumar et al. (2018) investigated the efficiency of various shading devices, including Horizontal, Louver (5 shadings), Egg-crate shading device, and a combination of Egg-crate and Louver shading devices for the hot-arid climate of Jodhpur, India. They employed a 0.5m depth for all shading methods and demonstrated that among them, Louver shading (5 shades) and the Egg-crate combined with Louver shading exhibited the highest efficiency across all cardinal directions. Notably, the combination of Egg-crate and Louver shading demonstrated the most optimal performance (Figure 35).

The base case (Omar's dwelling) does not include any window shading. To assess the impact of shading devices and determine the most effective type, three different shading configurations were applied to all ESE (112°) and WNW (292°) windows. The first configuration, serving as a baseline, involved no shading to analyse the energy efficiency of the proposed designs without any shading. The subsequent configurations included "0.5m louver shading" and "0.5m overhang and side fins + 0.5m louver shading" (which is also referred to as the Egg-crate, as described by Kirankumar et al. (2018)).

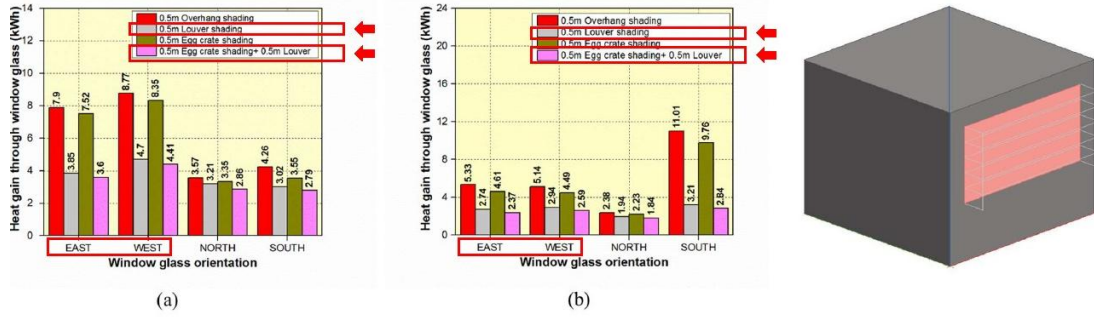


Figure 35. Heat gain into buildings through various external shading devices in the Jodhpur climate region: a) summer; b) winter; 3d model of the best shading combination (Kirankumar et al., 2018)

4.5.6 Windows opening rate. Opening windows can reduce the need for mechanical cooling by facilitating passive airflow and natural ventilation, which saves energy and enhances comfort in warm weather. Since the ideal window opening rate varies based on factors such as building orientation and climatic conditions, it is individually defined as a variable for all windows in the proposed layouts. The rate ranges from 0 to 100 percent, with adjustments in 10 percent increments, to optimize energy efficiency and comfort.

4.5.7 Orientation. As depicted in Figures 17 and 20, the prevailing wind in Zaatari refugee camp originates from the WNW (292°). Similarly, Figure 22, which portrays the predominant orientation of dwellings (sourced from Google Maps), aligns with this wind direction. On the other hand, the base case (Omar's Dwelling) is initially oriented in the same orientation. Therefore, this orientation is considered a fixed parameter for all proposed layouts.

4.5.8 Glazing type. The base case glazing consists of single clear glass with aluminum framing, causing substantial heat gains in summer and heat losses in winter. To enhance thermal performance, the proposed scenarios utilize double-glazed 6mm air-filled clear glass with aluminum framing. This configuration, selected from DesignBuilder templates, is consistently applied to all proposed layouts as a fixed parameter.

4.6 Energy Modelling

The DesignBuilder software, utilizing the Energy Plus simulation engine, was employed to perform all analyses for the base case and the proposed designs. Developed by the U.S. Department of Energy, Energy Plus is a renowned energy simulation program (DesignBuilder, 2002). DesignBuilder, developed in the UK, uses Energy Plus simulations to analyse carbon levels, lighting, HVAC systems, and comfort. It creates 3D models of buildings, comparing their performance to provide economic and environmental insights. The software evaluates energy consumption, such as heating and cooling, identifying issues like overheating, drafts, glare, and shading opportunities to optimize designs and reduce energy costs (DesignBuilder, 2002).

4.6.1 Base case energy modelling. The base case plan (Figure 30) was drawn in DesignBuilder to develop the 3D model (Figure 27: Right). Details such as building envelope components (floor, walls, roof layers, window types, and dimensions) (Figure 37) and occupancy schedules (Figure C in the Appendix) were sourced from various references (Table 48) and entered into the database to create a precise model.

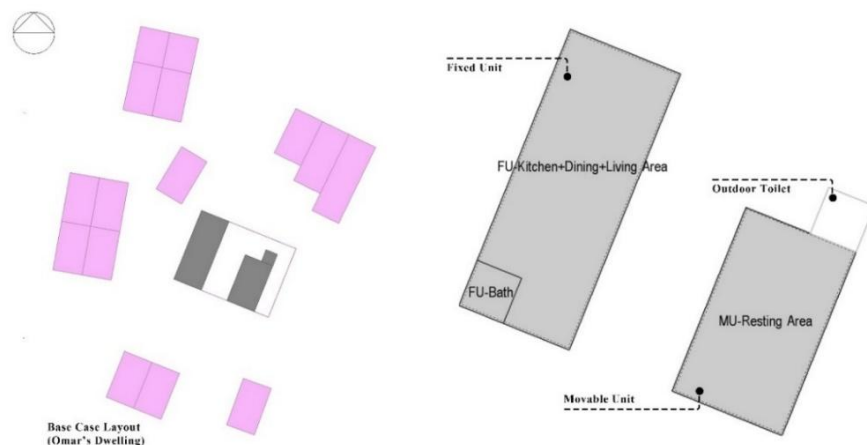


Figure 36. Base case (Omar's dwelling) layout at Zaatari refugee camp

To ensure accurate climate conditions for both the base case and proposed designs, the latest EPW file (2009–2023) from King Hussein Air Base —the nearest and most reliable weather location to Zaatari refugee camp, sourced from climate.onebuilding.org, is imported into DesignBuilder. Additional site location

parameters, including latitude (32.30°), longitude (36.32°), ASHRAE climate zone (3B), and elevation above sea level (683 m), were obtained from the EPW file. As shown in Figure 36, to account for the shading effect of surrounding shelters, their dimensions and distances from the base case were estimated from Dalal's (2022) study (Figure 27: Left) and modeled in DesignBuilder (Figure 27: Right).

Four schedules are defined for the activity of shelters, including heating devices, natural ventilation, occupancy, and lighting (Table 48), that are applied similarly to both the base case and proposed designs. The LPG heater is scheduled (Figure A in Appendix) to operate during the winter months in Mafraq (Table 48), maintaining an indoor set point of 21°C and to ensure comfort, natural ventilation is activated when the indoor temperature exceeds 28°C (Figure B in Appendix), keeping conditions within the comfort zone defined by the psychrometric chart (Figure 31). Given that refugees reside in the shelters throughout the day (Dalal, 2022), the occupancy schedule remains active year-round (Figure C in the Appendix). Additionally, lighting is provided for 9 hours each day (UNHCR Jordan: Zaatari refugee camp - Factsheet, January 2024 - Jordan, 2024), though power outages occur during the periods of 5 PM–10 PM and 3 AM–12 PM (Figure D in Appendix). Figure 37 shows the layers of the wall, roof, and floor of the base case applied into the software. For the openings, the clear single glazing with no internal shading is selected from the templates of DesignBuilder, and a semi-open weave medium drupe (Derived from Figure 32: Right) is also applied as the local interior shading that migrants commonly use.

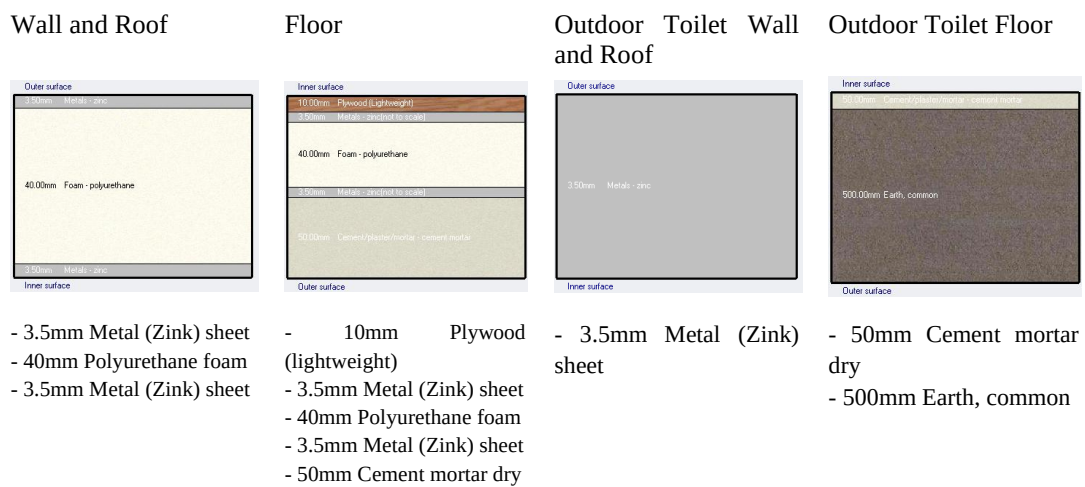


Figure 37. Existing construction detail of base case shelter at Zaatari

In DesignBuilder, the indoor lighting unit is configured using the “Absolute Zone Power (W)” setting. Suspended lights with a total power of 125W are installed for both the fixed and movable containers. The control type is set to "Linear/off," with both the minimum output fraction and minimum input power fraction set to 0. This setup simulates the functionality of a power-off button for the lights during the lighting availability schedule.

To determine absolute zone power for each space in DesignBuilder, 300 lux is set as the Target Illuminance in the Activity tab. The choice of 300 lux as a lighting level is typically based on common lighting standards and recommendations for various types of spaces. 300 lux is often cited as a minimum for general activities, providing a balance between visibility and comfort (Moustafa, 2022). Secondly, assuming the efficacy rate of 0.9 (lumens/w), the following formula is calculated for achieving the power (w) of each space:

$$Illuminance (lux) = \frac{luminous\ flux\ (lumens)}{Area\ (m^2)}$$

$$luminous\ flux\ (lumens) = power\ (w) \times luminous\ efficacy\ (lumens/w)$$

Following the heating schedule (Figure A in Appendix), the LPG heater (Figure 32: Left), with a Heating Seasonal System CoP of 0.89 and a maximum supply air temperature of 75.8°C, is integrated into the HVAC system (Technical data were obtained from a Chinese manufacturer of a similar LPG heater and verified by their laboratory report).

4.6.2 Optimization. The optimization process prioritizes two objectives, including minimizing "Discomfort ASHRAE 55 (All Clo)," which evaluates thermal comfort based on adaptive thermal comfort standards, and "LCA(Simple)" over a 30-year period, which assesses the environmental impact throughout the building's lifecycle. These objectives aim to ensure both occupant comfort and sustainability.

- LCA (Simple) calculates total lifetime carbon emissions as the sum of embodied CO₂ and operational CO₂ (years of study × annual emissions) minus on-site energy generation benefits. “LCA (Simple) is calculated simply as Embodied CO₂ + Years of study × Annual Operational CO₂ emissions” (DesignBuilder Help, 2022).

In addition to these primary objectives, secondary outputs are defined to provide a comprehensive understanding of the design's environmental and energy efficiency, which include “embodied CO₂”, “operational CO₂”, and “total primary energy use.”

- Embodied CO₂ represents the total greenhouse gas emissions associated with the materials and construction processes used in the building.
- Operational CO₂ accounts for emissions resulting from energy consumption during the building's operational phase.
- Total primary energy use represents the building's total energy demand from renewable and non-renewable sources for the building's operation.

4.7 Results

Applying the existing conditions for the base case (Table 48), the base case's energy and environmental performance is calculated using DesignBuilder (Table 51), serving as a benchmark for design improvements. It records 6703.52 hours of discomfort annually, indicating thermal inefficiency. The total LCA impact is 41033.62 kg, with embodied CO₂ at 25897.98 kg, operational CO₂ at 302.71 kg, and total primary energy use at 19.93 kWh/m², highlighting the need to balance material selection and energy efficiency.

Table 51

Base Case's Energy And Environmental Performance

Objectives		Additional Outputs		
Discomfort (All Clo)	LCA (Simple)	Embodied CO ₂	Operational CO ₂	Total Primary Energy Use
6703.52 hrs	41033.62 kg	25897.98 kg	302.71 kg	19.93 kWh/m ²

The optimization process focuses on key variables influencing thermal comfort, LCA, and energy efficiency. Fourteen plan layouts are proposed from the base case and analyzed by varying envelope materials, insulation, window-to-wall ratios, shading, and window opening rates (Table 49). As illustrated in Figure 38, among 63,154 iterations, 243 iterations are reported as optimal designs (A complete report of all optimal designs is provided in Figures F-1 to F-9 in the Appendix). As mentioned

earlier, the optimization is driven by two primary objectives, including reducing discomfort (annual hours based on ASHRAE 55 thermal comfort) and minimizing the life cycle assessment (LCA) in terms of total carbon emissions.

Figure 38 shows the performance distribution of optimal designs, highlighting trade-offs between comfort and environmental impact in shelter design. LCA values range from 11,585.84 kg (C2-6) to 16,648.08 kg (T3-12), with lower values indicating more sustainable but potentially less comfortable designs due to thermal trade-offs. Discomfort varies between 3,496.57 hours (T1-2) and 4,788.93 hours (C3-4), reflecting occupant thermal conditions. Embodied CO₂ spans 3,656.44 kg (C2-8) to 4,708.98 kg (C4-13), with lower values linked to less resource-intensive materials. Operational CO₂ emissions range from 162.71 kg (C3-4) to 253.87 kg (T3-12), showing how insulation reduces emissions but increases embodied CO₂. Total primary energy use varies from 7.22 kWh/m² (C2-15) to 11.17 kWh/m² (T3-12), with lower values achieved through balanced insulation, shading, and ventilation strategies.

Table 52 highlights the two worst optimal designs: C2-6 (row 101, Figure F-4) with the highest discomfort (4,538.31 hours) and T1-2 (row 2, Figure F-1) with the highest LCA (15,847.91 kg CO₂). In contrast, using the Pareto Front method, Li2-7 (row 239, Figure F-9) and Li1-6 (row 219, Figure F-8) are identified as Pareto optimal or ideal designs, with their improvements over the base case shown in Table 52.

Table 52

Improvements In LCA And Discomfort: Worst Vs. Pareto Optimal Layouts

Optimal Layouts	Objectives		Additional Outputs		
	Discomfort (All Clo)	LCA (Simple)	Embodied CO ₂	Operational CO ₂	Total Primary Energy Use
Base Case	6703.52 hrs	41033.62 kg	25897.98 kg	302.71 kg	19.93 kWh/m ²
C2-6	4538.31 hrs	11585.84 kg	4402.68 kg	162.83 kg	7.40 kWh/m ²
Improvement	47.85%	71.76%	83.01%	46.18%	62.85%
T1-2	3496.57 hrs	15847.91 kg	3776.91 kg	229.41 kg	10.1 kWh/m ²
Improvement	47.85%	61.38%	85.42%	24.22%	49.33%
Li2-7	3892.72 hrs	12037.74 kg	4145.15 kg	174 kg	7.7 kWh/m ²
Improvement	41.92%	70.66%	84.00%	42.51%	61.37%
Li1-6	3911.66 hrs	12042.88 kg	4192.13 kg	173.57 kg	7.67 kWh/m ²
Improvement	41.65%	70.65%	83.82%	42.66%	61.52%

The EWDM method is applied to rank the 243 optimal shelter designs using LCA and discomfort as criteria. Both metrics were normalized following the EWDM normalization formula and summed together. Subsequently, equal-weighted values are assigned to each optimal design to reflect their importance in environmental impact and user comfort. Tables 53 and 54 identify Li1-3 as the best and T3-12 as the worst optimal designs, according to EWDM scores, in which their efficiency rates and outputs against the base case are compared in these Tables. Table 53 shows that Li1-3 significantly outperforms the base case, reducing discomfort by 44.48%, LCA by 69.46%, embodied CO₂ by 84.55%, operational CO₂ by 40.44%, and total primary energy use by 60.09%. Table 54 shows that T3-12, while less efficient than Li1-3, still reduces discomfort by 43.17%, LCA by 59.43%, embodied CO₂ by 85.49%, operational CO₂ by 16.18%, and total primary energy use by 43.98%, indicating that even the worst optimal design offers significant improvements over the base case.

Table 53

EWDM Best Layout Vs. Base Case: LCA And Discomfort Improvements

Optimal Layouts	Objectives		Additional Outputs		
	Discomfort (All Clo)	LCA (Simple)	Embodied CO ₂	Operational CO ₂	Total Primary Energy use
Base Case	6703.52 hrs	41033.62 kg	25897.98 kg	302.71 kg	19.93 kWh/m ²
Li1-3	3721.32 hrs	12538.20 kg	4000.17 kg	180.29 kg	7.95 kWh/m ²
Improvement	44.48%	69.46%	84.55%	40.44%	60.09%

Table 54

EWDM Worst Layout Vs. Base Case: LCA And Discomfort Improvements

Optimal Layouts	Objectives		Additional Outputs		
	Discomfort (All Clo)	LCA (Simple)	Embodied CO ₂	Operational CO ₂	Total Primary Energy use
Base Case	6703.52 hrs	41033.62 kg	25897.98 kg	302.71 kg	19.93 kWh/m ²
T3-12	3808.99 hrs	16648.08 kg	3756.31 kg	253.87 kg	11.17 kWh/m ²
Improvement	43.17%	59.43%	85.49%	16.18%	43.98%



Figure 38. Overall comparison of discomfort and LCA of optimal designs of all layouts

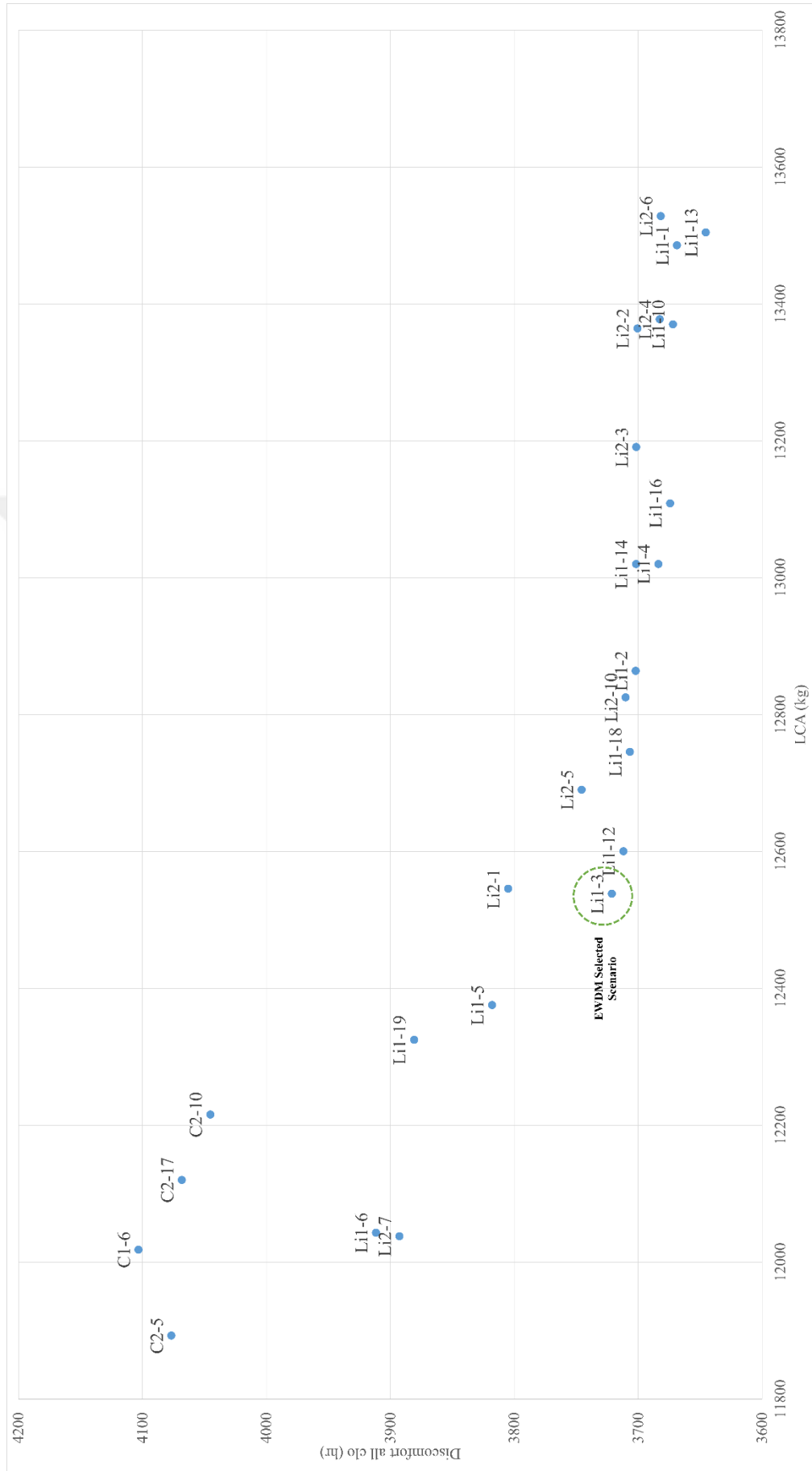


Figure 39. Overall comparison of discomfort and LCA of top 25 EWDM optimal designs

4.8 Discussion

The outcomes derived from the optimization process are discussed, emphasizing the dominant variables that significantly influence shelter performance in terms of energy efficiency, LCA, and thermal comfort. By analysing the 25 top-performing designs (Table 55) and their variables, critical insights into the relationship between construction elements and energy performance have been revealed. In general, Hardwood, paired with 9 cm XPS insulation, emerged as the most effective envelope material and insulation thickness for thermal performance. Lower WWR (10%) consistently minimized heat loss and excessive heat gain while ensuring daylighting (Figure 41). No shading and 0.5m louver shading were most common for WNW and ESE orientations (Figure 42). Window opening rates varied by orientation, as detailed in Figure 43. Figure 40 shows the distribution of optimal shelter designs across various shapes, considering all 243 optimal designs (Figure 38). T-Shape dominates with 83 optimal designs, exhibiting minimal variation among their subtypes. Among the C-shape layouts (71 in total), C-shape 3 stands out with 27 designs, making it the most frequently optimal configuration overall. L-shapes rank third, while Linear-shapes are the least selected. Li-shape layouts, though less frequent, are often the most optimal under EWDM, excelling in balancing key criteria like energy efficiency and discomfort (Table 55).

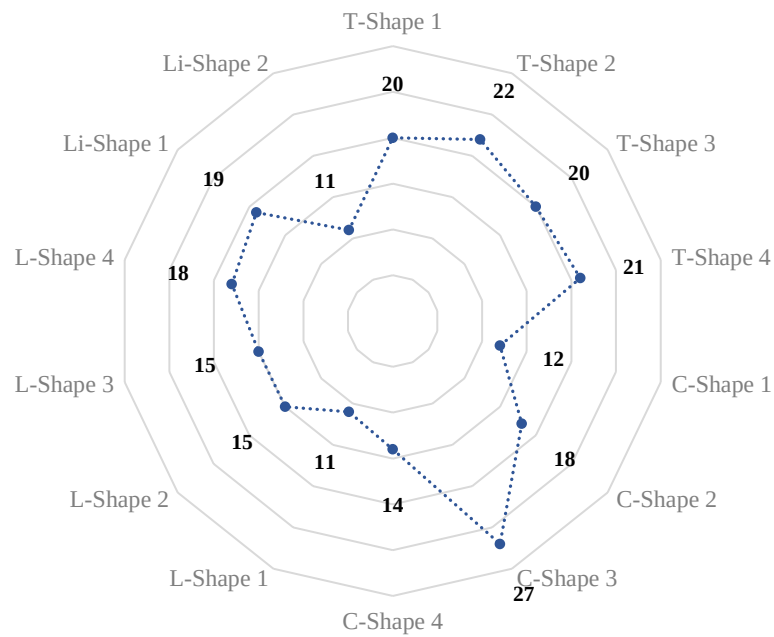


Figure 40. Proposed plan layouts distribution of 243 optimal designs

Among all evaluated materials, the combination of Hardwood + XPS 9cm dominates overwhelmingly, appearing in 230 of the 243 optimal designs (approximately 94.65%). It can be said here that this configuration offers the best balance of thermal performance, energy efficiency, and possibly environmental impact. The lesser presence of Hardwood + XPS 8cm (3.29%) and Hardwood + XPS 7cm (0.41%) reinforces the importance of insulation thickness, with thicker XPS layers contributing to enhanced outcomes.

Conversely, Zinco + XPS configurations (7cm, 8cm, and 9cm) do not appear in any optimal design, highlighting their unsuitability for the project's goals. This could be due to Zinc's inferior thermal properties and environmental drawbacks when compared to alternatives. Meanwhile, Fibercement + XPS configurations are present in only 4 designs (1.65%), with the 8cm thickness slightly outperforming others. While Fibercement shows some viability, it is not competitive enough to rival Hardwood in achieving optimal design parameters.

The analysis of Figure 41 reveals that the WNW (292°) orientation shows a higher frequency at 10% WWR, with 115 occurrences, indicating a preference for smaller window-to-wall ratios (WWR). Similarly, the NNE (22°) orientation exhibits a strong preference for 10% WWR, with 172 occurrences, significantly more pronounced than other orientations, and a sharp drop in frequency as WWR increases. The ESE (112°) orientation demonstrates a more evenly spread distribution, with 107 occurrences at 10% WWR, but also a stronger presence at higher WWR values, such as 15% (54 occurrences) and 30% (37 occurrences), indicating more flexibility in WWR selection.

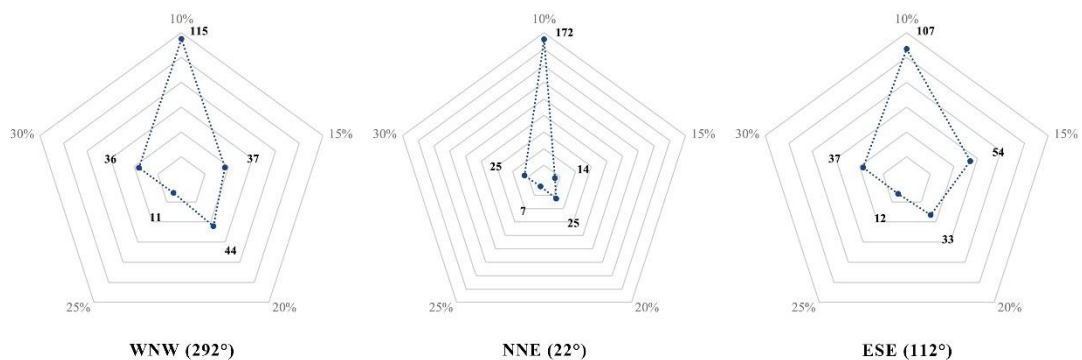


Figure 41. WWR distribution based on the analysis of 243 optimal designs

According to Figure 42, for the WNW orientation, most optimal designs (55.1%) use no shading, while 34.2% incorporate a 0.5m louver, and 10.7% use a more complex combination of shading. In contrast, for the ESE orientation, no shading is the dominant choice (87.2%), with very few designs using the 0.5m louver (9.5%) or the combination of louver and overhang (3.3%). This indicates that the WNW orientation may be more exposed to solar heat gain, making shading more beneficial, while the ESE orientation appears less affected by solar radiation, with a preference for minimal or no shading.

The majority of optimal designs used no shading, indicating the minimal effect of this variable, likely because the shelters were already highly insulated (e.g., XPS 8–9 cm), which significantly controlled indoor temperatures and reduced the relative importance of additional solar protection. The generally low window-to-wall ratios also limited solar gains through glazing, making shading less critical. Furthermore, the orientation of the shelters (along with WNW) and the climatic context of Mafrq reduced the necessity for extensive shading.

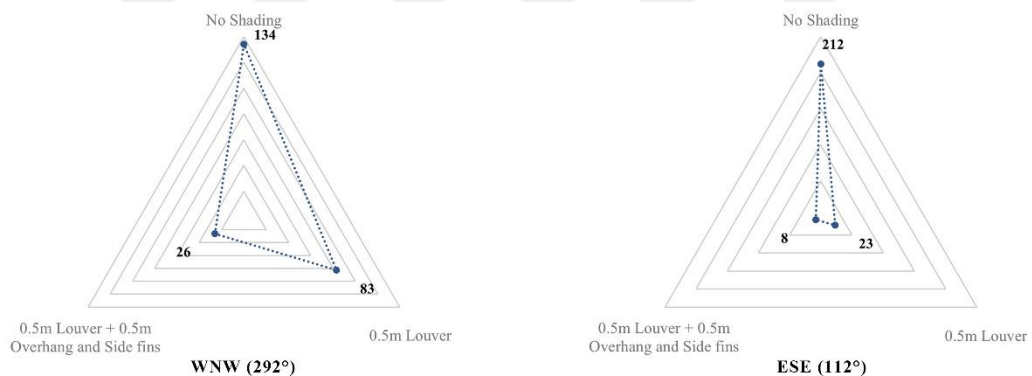


Figure 42. Shading distribution based on the analysis of 243 optimal designs

Figure 43 illustrates the frequency of window opening rates across three orientations—WNW, NNE, and ESE—revealing distinct patterns of ventilation. For WNW (292°), the most common opening rates are 50% (46 occurrences), 100% (47 occurrences), and 80% (61 occurrences), indicating a preference for larger openings to balance solar gain and ventilation. The NNE (22°) orientation shows a preference for smaller openings, with 20% (64 occurrences) being the most frequent, suggesting a focus on minimizing heat loss and optimizing insulation. The frequent 0% openings in NNE (26 occurrences) indicate a strategy to reduce energy loss during colder

periods, while 100% openings are used for ventilation in warmer seasons. For ESE (112°), the most common openings are 50% (47 occurrences), 40% (46 occurrences), 30% (33 occurrences), and 20% (29 occurrences), reflecting a preference for moderate to larger openings for balanced air flow. According to Mafraq's dominant wind direction (Figures 17 and 20), the WNW orientation, with larger window openings for air intake, might indeed lead to faster ventilation speed due to the higher volume of air entering the space and smaller exit on ESE.

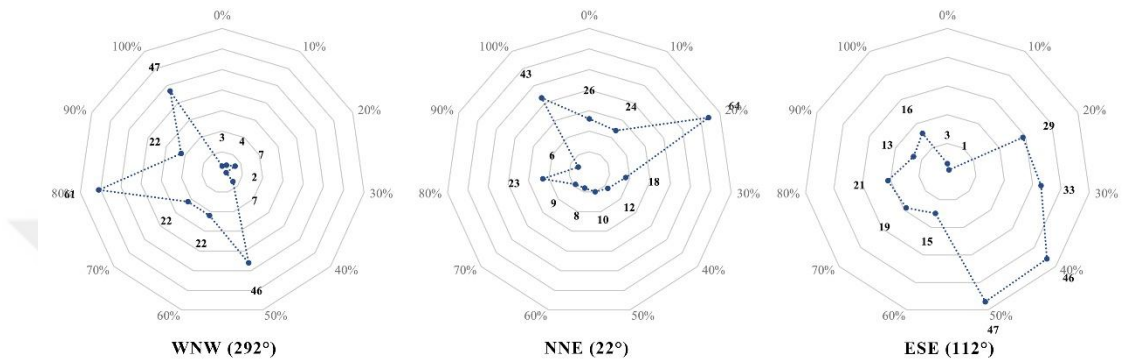


Figure 43. Windows opening percentage distribution based on the analysis of 243 optimal designs

After applying the EWDM method to the objectives, 50 optimal designs are selected from the initial 243, which are divided into two categories, including Top 25 optimal designs (Figure 39 and Table 55), representing the best-performing options, and Bottom 25 optimal designs, representing the least favourable options (Table 56) among all the optimal designs. In terms of plan layout, Linear-shape 1, with 13 selected designs, Linear-shape 2, with 8, and C-shape 2, with 3, emerge as the most favorable options among the best optimal designs (Table 55). Conversely, T-shape 4, with 7 selected designs, along with T-shape 3 and L-shape 1, each with 4, are the most frequent layouts among the worst optimal options (Table 56). Nevertheless, as previously noted, the most prevalent layout overall is C-shape, appearing 71 times in total, particularly C-shape 3, which accounts for 27 of these occurrences.

The analysis of the top 25 optimal designs (Figure 39 and Table 55), indicates how the chosen variables, including envelope material, insulation, window-to-wall ratios (WWR), shading types, and window opening percentages, influence key performance outcomes such as LCA, discomfort, and additional outputs (embodied CO₂, operational CO₂, total primary energy use).

Due to the lower embodied carbon of Hardwood among the other envelope material alternatives (Zinco and Fibercement), all Top 25 EWDM Optimal Designs have selected this material. This consistent choice highlights the role of material selection in influencing both LCA and total primary energy use. Therefore, the variations in LCA, discomfort, embodied CO₂, and other outputs are under the impact of other variables like window-to-wall ratios (WWR), shading, and window opening percentages.

The consistent choice of XPS 9 cm insulation across all optimal layouts indicates it provides the best balance between thermal comfort, energy efficiency, and overall performance. This thicker insulation significantly reduces heat transfer, improving indoor temperature stability and reducing discomfort hours. Although it comes with a slightly higher embodied CO₂ due to the increased material, this trade-off is justified by the substantial reductions in operational energy consumption and CO₂ emissions over the building's lifetime. The long-term energy savings from using XPS 9 cm offset the initial embodied carbon, making it the most efficient choice when considering comfort and sustainability.

The analysis of the window-to-wall ratios (WWR) across the optimal designs reveals their varying impacts on energy performance and comfort. For WNW-facing windows, higher WWRs (e.g., Case C2-5 at 20%) are linked to increased discomfort hours and higher total energy consumption, suggesting that excessive WNW-facing glazing contributes to thermal discomfort due to solar heat gain, especially in the late afternoon. This is supported by the observation that increased solar exposure in the late afternoon can lead to higher cooling needs.

In contrast, the NNE WWR values (ranging from 10% to 30%) exhibit less dramatic effects on LCA and CO₂, but higher NNE-facing glazing (e.g., Case Li1 -6 at 30%) can contribute to greater embodied CO₂ and LCA due to additional materials required and potential energy loss. Meanwhile, increased ESE WWR (such as in C1-6 at 30%) correlates with more discomfort and higher energy usage due to early morning solar exposure, which can raise cooling demands. The data indicates that balanced WWRs are key to maintaining comfort while managing energy consumption.

The shading type significantly impacts the thermal performance and comfort of the shelter layouts. Designs without any shading, including Li2-7, Li2-5, Li2-1, C2-5, C2-17, C2-10, and C2-6, exhibit higher discomfort levels due to increased solar heat gain, especially on the WNW side, where afternoon sunlight can cause overheating. In contrast, designs incorporating a “0.5m projection Louvre” on the ESE, such as Li1-5 and Li1-19, show reduced operational CO₂ emissions and total primary energy use, suggesting that shading helps control heat gain and energy use effectively.

Moreover, combining shading strategies, like in Li1-13 and Li2-6 with both a Louvre and overhangs, leads to even greater improvements in comfort by reducing discomfort hours to 3645 and 3681 hours, respectively. This combination blocks solar radiation while allowing natural light, reducing cooling loads and energy use. Strategically designed shading systems improve thermal comfort, lower energy consumption, and enhance building sustainability.

Higher window opening rates, such as those seen in cases Li2-3, Li2-4, Li2-2 and Li2-6, are linked to better thermal performance, with reduced discomfort hours of 3701, 3682, 3700 and 3681 hrs, respectively, and lower operational CO₂ emissions, indicating effective natural ventilation. This configuration allows for more air circulation, helping to regulate indoor temperatures and improve comfort. Conversely, lower window opening rates, like in Li1-6 (40% WNW, 20% NNE, and 40% ESE), show increased discomfort of 3911 hrs.

Figure 44 illustrates the dominance of each variable’s option in the top 25 optimal options. In terms of WWR, similarly to the overall analysis of WWR (Figure 41), the 10% WWR was most selected, particularly for WNW (292°), NNE (22°), and ESE (112°) orientations, suggesting that minimal glazing is optimal for managing solar gain and energy use. Higher WWRs were less popular, reinforcing the preference for lower glazing percentages to maintain energy efficiency.

According to Figure 44, shading strategies for the top 25 optimal options varied by orientation; WNW (292°) showed that no shading was most effective, implying minimal impact on energy performance from shading devices in this direction. Conversely, ESE (112°) favoured the use of a 0.5m louver, which was chosen 14 times, demonstrating its ability to reduce solar gain and enhance comfort. For window

opening percentages, the 50% opening was most common for WNW (292°), suggesting a balanced approach to ventilation. For NNE (22°) and ESE (112°), 20% of openings were preferred for NNE (10 selections), while ESE saw a preference for 40% and 30% of openings (11 and 6 selections, respectively), indicating a desire for moderate ventilation to optimize energy use and comfort.

According to Table 56, the analysis of the bottom 25 optimal options (worst optimal cases) highlights that the dominant insulation type is HardWood with XPS 9 cm, appearing in most cases due to its superior thermal performance. This insulation thickness offers better thermal resistance, which minimizes heat transfer, thereby reducing operational CO₂ emissions and total primary energy use. While HardWood with XPS 7 cm appeared in one layout (C3-4), it was less effective in reducing energy consumption and maintaining comfort levels (4788 hrs of Discomfort) compared to the 9 cm thickness, leading to suboptimal results. Fibercement + XPS 8 cm (with 4588 hrs of Discomfort) and Fibercement + XPS 9 cm (with 4610 hrs of Discomfort) were present in a few layouts but did not outperform the HardWood with XPS 9 cm option. Figure 45 shows that HardWood + XPS 9 cm is the most dominant insulation choice for the bottom 25 optimal options (worst optimal cases) due to its optimal balance of insulation and energy efficiency, appearing in 20 layouts. Thinner insulation options like HardWood + XPS 8 cm and 7 cm are less frequent, indicating a preference for thicker insulation for better thermal performance. Fiber Cement + XPS options are used even less, suggesting they may not match the performance of HardWood variations in this context.

The WWR data for the bottom 25 optimal options (worst optimal cases) (Figure 45) shows that 10% and 30% WWR are the most common for different orientations, particularly for WNW (292°) and NNE (22°) directions. This suggests that lower and moderate WWRs are preferred to limit heat gain while maintaining adequate natural light. It also shows higher WWR values (20% - 30%) for other orientations like ESE (112°), emphasizing that less shading and larger openings are used more in certain directions to optimize daylight penetration. Window Opening Percentages demonstrate a notable variation, with a significant preference for higher openings (100% and 80%) for WNW (292°), indicating a tendency to balance cross-ventilation and natural cooling. This is critical for optimizing airflow and controlling indoor

temperatures. However, extreme values (e.g., 0% or minimal openings) are relatively rare, implying that some degree of window opening is necessary to ensure air circulation and occupant comfort. Figure 45 highlights that no shading is a common condition in the worst optimal designs (bottom 25 EWDM optimal designs), particularly for ESE (112°) and WNW (292°) orientations. This suggests that these orientations may rely more on other variables like WWR and material selection for thermal regulation rather than shading. However, the use of 0.5m louver and egg crate (combination of 0.5m louver and 0.5m overhang + side fins) shading systems, while present, is not as widespread, indicating they may be used selectively when additional shading is needed to control solar gain and glare.

The worst-case scenarios among the Bottom 25 optimal shelter layouts (Table 56) are those characterized by high window-to-wall ratios (WWR) combined with limited or no shading strategies. Layouts such as T3-12, T3-15, and T4-18 exhibit high levels of discomfort, CO₂ emissions, and energy consumption. For example, T3-12 and T3-15, despite using shading (0.5m louvers and 0.5m overhang + side fins), suffer from excessive window openness (e.g., 80% or 90% for the ESE-facing windows), leading to significant heat gain and discomfort. T4-18 exacerbates this issue with a complete lack of shading and an even higher window opening rate (up to 100% for WNW-facing windows), resulting in poor thermal performance and increased operational CO₂ emissions.

The EWDM and Pareto optimal of the Pareto Front methods show differences in terms of improvement ratios and effectiveness. The EWDM method identified Li1-3 as the best layout, with a 44.48% improvement in discomfort and 69.46% in LCA (Table 53), outperforming the Pareto optimal layouts slightly in discomfort but similarly in LCA. The Pareto optimal method showed a more balanced performance with layouts like Li2-7 achieving 41.92% discomfort improvement and 70.66% in LCA (Table 52), along with substantial reductions in embodied CO₂ (84%) and operational energy (61%). Although in this case the results of both methods were quite close to each other, the Pareto optimal method was more effective at finding layouts that optimized across all metrics. Overall, the Pareto optimal approach is slightly more effective for achieving better overall performance, while EWDM may focus on more balanced, uniformly improved options.

Table 55

Top 25 Ideal Optimal Designs (Best Scenarios)

EWM Decision Making		Objectives		Additional Outputs		Variables									
Optimal Layouts	Best Top 25 Options	LCA (Simple) (kg)	Discomfort (All Clothing) (hr)	Embodied CO2 (kg)	Operational CO2 (kg)	Total Primary Energy consumption (kWh.m ²)	Construction Template	WNW WWR (%)	NNE WWR (%)	ESE WWR (%)	WNW Shading	ESE Shading	WNW External window opens (%)	NNE External window opens (%)	ESE External window opens (%)
L11-3	1.637961837	12538.20173	3721.324636	4000.176	180.295	7.95	HardWood + XPS 9 cm	10	30	10	No shading	0.5m projection Louvre	60	20	40
L11-12	1.632934004	12600.23608	3711.985409	3967.851	181.535	8.03	HardWood + XPS 9 cm	10	25	10	No shading	0.5m projection Louvre	80	20	40
L11-18	1.608318729	12745.38193	3706.742341	4000.176	184.438	8.13	HardWood + XPS 9 cm	10	30	10	0.5m projection Louvre	0.5m projection Louvre	50	20	40
L12-7	1.604205853	12037.715553	3892.715525	4145.154	174.004	7.70	HardWood + XPS 9 cm	15	15	15	No shading	No shading	70	100	20
L11-5	1.595331846	12275.63398	3817.920495	4063.866	177.043	7.84	HardWood + XPS 9 cm	15	25	10	No shading	0.5m projection Louvre	50	30	40
L12-10	1.58995126	12824.96565	3710.162473	3877.327	187.039	8.24	HardWood + XPS 9 cm	10	10	10	No shading	0.5m projection Louvre	80	60	30
L12-5	1.589127243	12690.17825	3745.637815	3952.858	183.559	8.09	HardWood + XPS 9 cm	10	20	10	No shading	No shading	80	100	30
L11-2	1.588557029	12863.86714	3702.033007	3967.851	181.143	7.99	HardWood + XPS 9 cm	10	25	10	No shading	0.5m projection Louvre	60	20	40
L11-6	1.588526928	12042.88317	3911.664178	4192.131	173.573	7.67	HardWood + XPS 9 cm	20	30	10	No shading	0.5m projection Louvre	40	20	40
L11-4	1.571809066	13019.87313	3683.744168	3870.859	189.928	8.37	HardWood + XPS 9 cm	10	10	10	No shading	0.5m projection Louvre	50	20	40
L12-1	1.571745969	12445.55748	3805.021488	4011.425	177.115	7.83	HardWood + XPS 9 cm	10	10	15	No shading	No shading	80	100	30
L11-16	1.561721531	13108.59038	3674.237754	3870.859	191.042	8.42	HardWood + XPS 9 cm	10	10	10	0.5m projection Louvre	No shading	50	20	50
L11-14	1.557939395	13019.78395	3701.797385	3935.545	182.978	8.06	HardWood + XPS 9 cm	10	20	10	No shading	0.5m projection Louvre	50	20	40
L11-19	1.55665629	12324.74429	3880.89506	4171.332	179.887	7.95	HardWood + XPS 9 cm	10	15	20	No shading	0.5m projection Louvre	40	70	40
L12-3	1.524290062	13190.84406	3701.613812	3877.327	186.964	8.23	HardWood + XPS 9 cm	10	10	10	No shading	0.5m projection Louvre	80	100	20
L11-10	1.511790502	13370.009	3672.028012	3870.859	189.983	8.37	HardWood + XPS 9 cm	10	10	10	No shading	0.5m projection Louvre	50	20	50
L11-13	1.505716922	13504.48193	3645.547135	3870.859	199.62	8.79	HardWood + XPS 9 cm	10	10	10	0.5m projection Louvre	Louvre, 0.5m projection + 0.5m overhangs and sidefins	60	10	40
L12-4	1.502054608	13377.48721	3682.701149	3877.327	190.697	8.40	HardWood + XPS 9 cm	10	10	10	0.5m projection Louvre	0.5m projection Louvre	80	100	30
L11-1	1.491484473	13485.50138	3668.786199	3870.859	194.291	8.56	HardWood + XPS 9 cm	10	10	10	No shading	Louvre, 0.5m projection + 0.5m overhangs and sidefins	50	20	40
L12-2	1.490823891	13364.03254	3700.650174	3877.327	187.052	8.24	HardWood + XPS 9 cm	10	10	10	No shading	0.5m projection Louvre	80	100	30
C2-5	1.490472412	11892.55778	4076.763064	4012.809	168.968	7.46	HardWood + XPS 9 cm	20	10	15	No shading	No shading	50	30	60
L12-6	1.472962742	13528.14965	3681.835095	3877.327	200.318	8.82	HardWood + XPS 9 cm	10	10	10	0.5m projection Louvre	Louvre, 0.5m projection + 0.5m overhangs and sidefins	80	100	30
C2-17	1.45206766	12120.02612	4068.324525	3961.522	174.527	7.79	HardWood + XPS 9 cm	15	10	15	No shading	No shading	70	80	100
C2-10	1.451072359	12215.44727	4045.250367	3950.386	176.435	7.77	HardWood + XPS 9 cm	20	15	10	No shading	No shading	50	30	60
C1-6	1.445153891	12018.04857	4103.293859	4014.074	170.353	7.50	HardWood + XPS 9 cm	10	10	30	No shading	No shading	80	80	20

Table 56

Bottom 25 Ideal Optimal Designs (Worst Scenarios)

EWM Decision Making			Objectives		Additional Outputs			Variables							
Optimal Layouts	Worst Bottom 25 Options	LCA (Simple) (kg)	Discomfort (All Clothing) (hr)	Embodied CO2 (kg)	Operational CO2 (kg)	Total Primary Energy consumption (kWh m ⁻²)	Construction Template	WNW WWR (%)	NNE WWR (%)	ESE WWR (%)	WNW Shading	ESE Shading	WNW External window opens (%)	NNE External window opens (%)	ESE External window opens (%)
L3-7	1.0448619	14177.64015	4069.284424	3805.855	207.436	9.13	HardWood + XPS 9 cm	10	10	10	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	60	80	20
T4-3	1.04146091	15276.27769	3793.233322	3921.027	226.35	9.96	HardWood + XPS 9 cm	30	10	15	No shading	No shading	100	30	50
T4-2	1.039688733	15286.15	3792.974122	3822.133	234.693	10.33	HardWood + XPS 9 cm	30	10	10	No shading	No shading	100	70	50
C4-10	1.03401017	12236.788	4578.796641	4554.188	172.473	7.62	HardWood + XPS 9 cm	30	10	30	0.5m projection Louvre	No shading	100	10	40
T4-19	1.021170055	15545.75516	3750.631281	3855.177	231.833	10.20	HardWood + XPS 9 cm	20	10	15	No shading	No shading	100	30	40
T4-4	1.018150302	15524.48237	3759.964706	3888.094	234.047	10.30	HardWood + XPS 9 cm	25	10	15	0.5m projection Louvre	No shading	100	40	50
L4-10	1.015923118	14153.49876	4112.846897	3900.163	193.291	8.53	HardWood + XPS 9 cm	10	10	15	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	80	0	40
L3-10	1.015335313	12000.36224	4663.289351	4175.191	174.919	7.71	HardWood + XPS 9 cm	30	10	10	No shading	Louvre, 0.5m projection + 0.5m overhangs and sidefus	100	80	40
L4-4	1.010099502	12099.90253	4644.643866	4083.455	172.873	7.63	HardWood + XPS 8 cm	30	10	10	No shading	No shading	10	80	80
L4-10	1.007756223	14347.72909	4073.815627	3809.039	205.285	9.04	HardWood + XPS 9 cm	10	10	10	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	70	90	20
C4-13	0.997118332	12171.06797	4643.252101	4708.98	172.464	7.64	HardWood + XPS 9 cm	30	30	30	0.5m projection Louvre	No shading	100	0	30
L4-1	0.991638855	12414.36235	4588.221966	3739.824	178.463	7.91	Fiber Cement + XPS 8 cm	10	10	30	0.5m projection Louvre	No shading	100	50	20
T3-11	0.987590317	15371.82839	3838.430844	3756.31	233.627	10.28	HardWood + XPS 9 cm	10	10	20	0.5m projection Louvre	No shading	80	20	90
T4-20	0.984896855	15729.58732	3750.578065	3855.177	231.83	10.20	HardWood + XPS 9 cm	20	10	15	No shading	No shading	100	30	50
L4-15	0.979531778	12030.60836	4701.838751	4332.235	173.474	7.66	HardWood + XPS 9 cm	30	30	10	No shading	Louvre, 0.5m projection + 0.5m overhangs and sidefus	80	80	20
L1-6	0.978878697	12225.90806	4652.833928	4279.82	177.454	7.82	HardWood + XPS 9 cm	15	10	30	0.5m projection Louvre	No shading	0	10	50
L2-7	0.97429206	12342.45883	4628.996803	4557.428	177.724	7.88	HardWood + XPS 9 cm	25	20	30	No shading	No shading	20	20	50
L1-5	0.973652627	14416.67732	4100.287677	3807.211	200.414	8.84	HardWood + XPS 9 cm	10	10	10	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	100	10	60
L2-5	0.973254365	12419.1886	4610.74923	3833.732	179.65	8.01	Fiber Cement + XPS 9 cm	10	10	30	0.5m projection Louvre	No shading	90	0	80
T3-20	0.960455635	12763.95577	4539.27281	4210.837	189.228	8.34	HardWood + XPS 8 cm	30	30	20	No shading	No shading	80	20	70
T4-9	0.95731531	15877.88469	3748.363922	3888.094	240.754	10.59	HardWood + XPS 9 cm	25	10	15	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	100	30	40
T4-18	0.944116976	15964.41496	3743.33026	3756.283	240.206	10.57	HardWood + XPS 9 cm	20	10	10	No shading	No shading	100	60	70
C3-4	0.939353388	11892.85009	4788.932547	4370.162	162.711	7.24	HardWood + XPS 7 cm	25	20	30	No shading	No shading	20	20	20
T3-15	0.86578924	16028.74271	3828.139679	3756.31	253.877	11.17	HardWood + XPS 9 cm	10	10	20	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	60	20	90
T3-12	0.758254015	16648.08403	3808.99549	3756.31	253.879	11.17	HardWood + XPS 9 cm	10	10	20	Louvre, 0.5m projection + 0.5m overhangs and sidefus	No shading	80	20	90

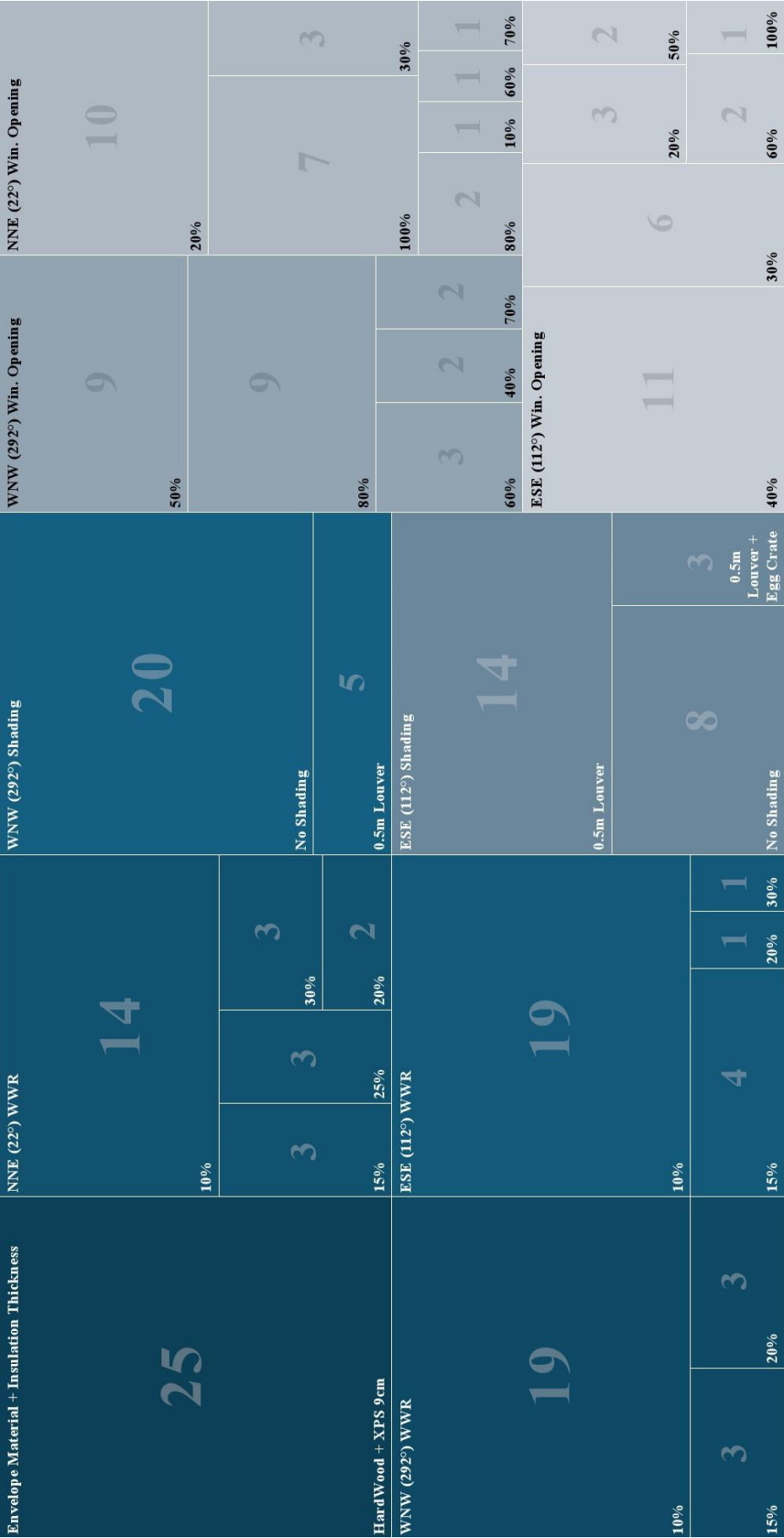


Figure 44. Variables preferences ratio among top 25 EWDM selected optimal designs

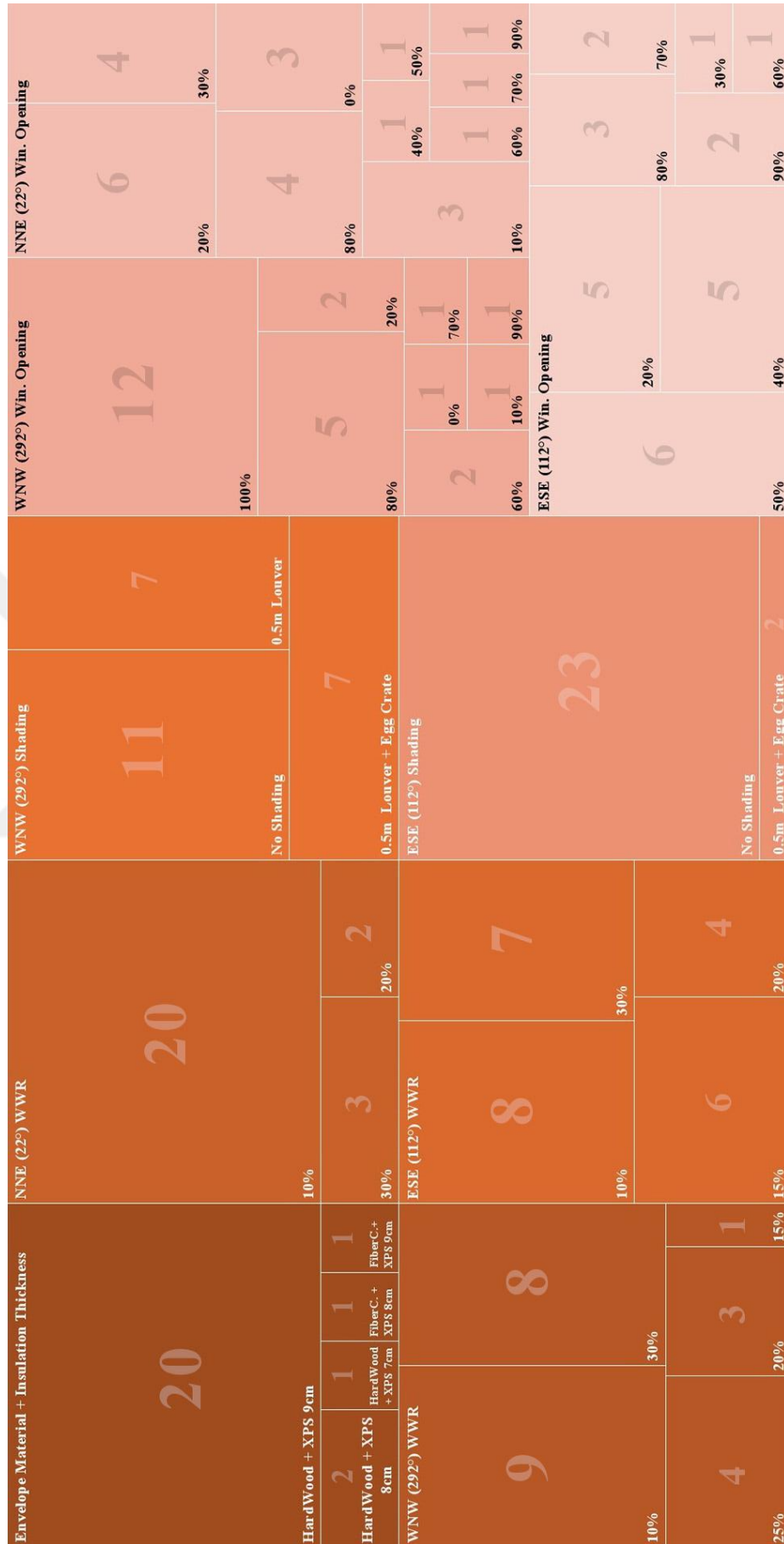


Figure 45. Variables preferences ratio among bottom 25 EWDM selected optimal designs

Analysing the overall data of 243 optimal designs, Figure 46 presents a correlation heatmap that offers insights into the relationships between the optimization objectives (Min. LCA and Min. discomfort) and additional outputs (embodied CO₂, operational CO₂, and total primary energy use). The analysis shows strong positive correlations between LCA, operational CO₂, and total primary energy use, highlighting the importance of operational efficiency in lifecycle sustainability. Discomfort has weak or negative correlations with embodied and operational CO₂, suggesting thermal comfort can improve without increasing emissions, especially using passive strategies. The minimal link between embodied and operational CO₂ indicates limited mutual impact. Overall, operational CO₂ dominates LCA, while embodied CO₂ plays a secondary role, underscoring the need to balance energy efficiency, material use, and comfort in sustainable design.

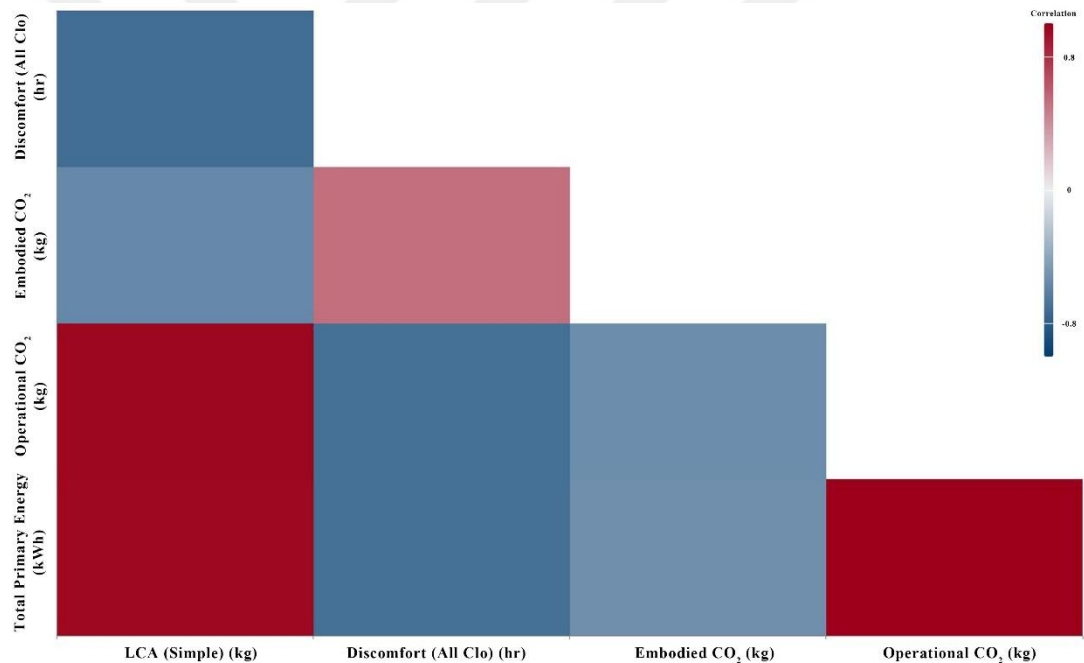


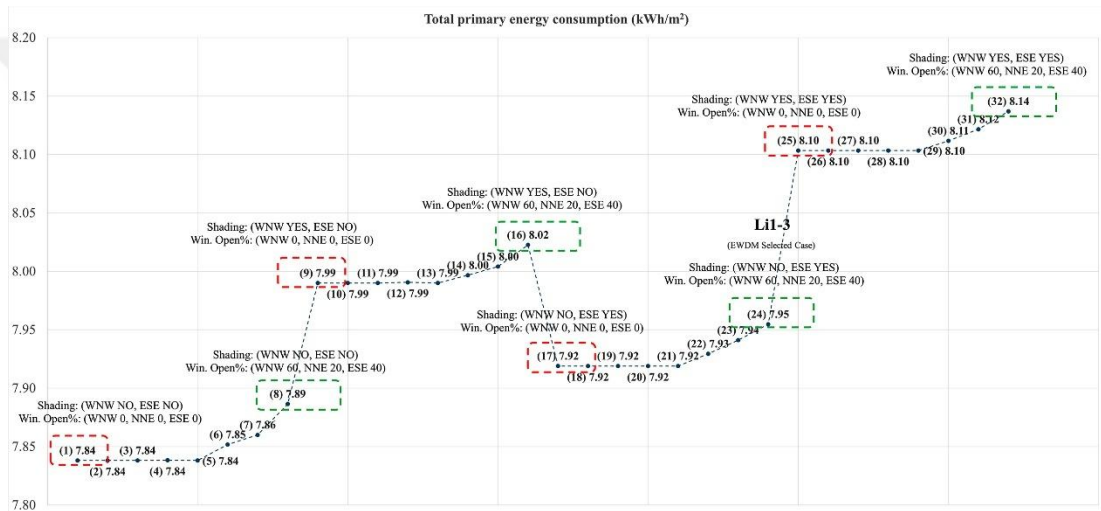
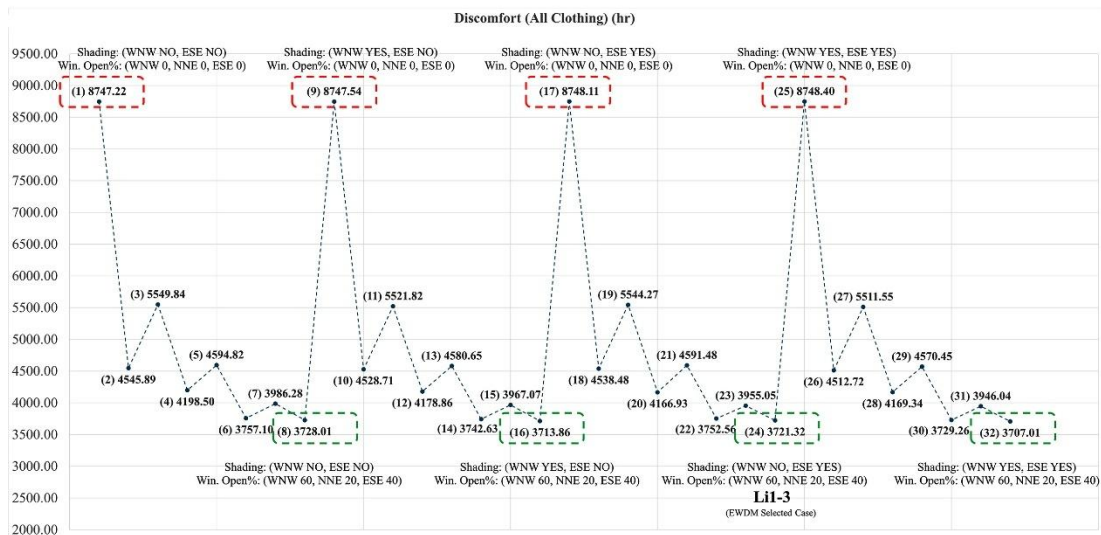
Figure 46. Correlation of objectives and outputs for 243 optimal designs

Figure 47 presents the sensitivity analysis of shading and window opening rates on discomfort hours and total primary energy use for the Li1-3 layout. Stabilizing all other variables, the original features of Li1-3 (listed in Table 55) were applied to set up the sensitivity simulations in DesignBuilder. For shading, two alternatives were tested for both WNW and ESE orientations: no shading and a 0.5 m louver. For window opening rates, two alternatives were applied for each façade: 0% and 60% for

WNW, 0% and 20% for NNE, and 0% and 40% for ESE. This setup resulted in 32 different modes for Li1-3, as shown in Figure 47. Among these, case 24 matches the original Li1-3 design and is used as the baseline for comparison.

As listed in Table 55, Li1-3 features window opening rates of 60% on the WNW, 20% on NNE and 40% on ESE facades. If these openings are closed (case 1, 9, 17 and 25: 0% opening on the WNW, NNE, and ESE façades), the discomfort rises to 8748 hours per year (58% increase in discomfort). When applying the original window opening rates compared to the case with no openings, discomfort hours were significantly reduced (case 8). Opening the WNW windows alone reduced discomfort by about 4,152 hours per year, which is approximately a 47% decrease (case 5). Opening the ESE windows at 40% yielded a 4,201-hour reduction (48% - case 2), and opening the NNE windows at 20% resulted in a 3,197-hour reduction (around 37% - case 3). In contrast, adding shading (0.5m louvers) to either the WNW or ESE façades produced minimal reductions in discomfort. Considering all windows open, applying shading on the WNW side decreased discomfort by only 14 hours annually (0.4% - case 16), shading on the ESE side by about 7 hours (0.2% - case 24), and adding shading to both façades together resulted in a 21-hour decrease (0.6% - case 32). This demonstrates that the convective cooling effect of natural ventilation far outperforms the benefits of shading in mitigating occupant discomfort under this climatic condition. Ventilation through window openings flushes out internal heat gains from occupants and equipment effectively, reducing indoor temperatures and discomfort substantially. On the other hand, shading devices like louvers primarily block direct and some diffuse solar radiation but cannot eliminate internal heat gains, therefore their impact on discomfort is negligible.

On the other hand, by applying various alternatives of window opening rate, installing louvers on the WNW and/or ESE façades slightly increases the annual total primary energy use. Considering no shading (cases 1–8), the total primary energy use increased by about 0.05 kWh/m² (0.6%). In contrast, adding a louver on the WNW side (cases 9–16) increased energy consumption by 0.13 kWh/m² (1.6%), and a louver on the ESE side (case 17–24) added 0.06 kWh/m² (0.8%). If louvers were added to both façades (cases 25–32), the energy penalty reached 0.25 kWh/m² (3.2%).



1	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 0, NNE 0, ESE 0)	9	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 0, NNE 0, ESE 0)	17	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 0, NNE 0, ESE 0)	25	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 0, NNE 0, ESE 0)
2	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 0, NNE 0, ESE 40)	10	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 0, NNE 0, ESE 40)	18	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 0, NNE 0, ESE 40)	26	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 0, NNE 0, ESE 40)
3	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 0, NNE 20, ESE 0)	11	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 0, NNE 20, ESE 0)	19	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 0, NNE 20, ESE 0)	27	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 0, NNE 20, ESE 0)
4	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 60, NNE 0, ESE 40)	12	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 60, NNE 0, ESE 40)	20	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 60, NNE 0, ESE 40)	28	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 60, NNE 0, ESE 40)
5	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 60, NNE 0, ESE 0)	13	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 60, NNE 0, ESE 0)	21	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 60, NNE 0, ESE 0)	29	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 60, NNE 0, ESE 0)
6	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 60, NNE 20, ESE 40)	14	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 60, NNE 20, ESE 40)	22	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 60, NNE 20, ESE 40)	30	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 60, NNE 20, ESE 40)
7	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 60, NNE 20, ESE 0)	15	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 60, NNE 20, ESE 0)	23	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 60, NNE 20, ESE 0)	31	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 60, NNE 20, ESE 0)
8	Shading: (WNW NO, ESE NO) Win. Open%: (WNW 60, NNE 20, ESE 40)	16	Shading: (WNW YES, ESE NO) Win. Open%: (WNW 60, NNE 20, ESE 40)	24	Shading: (WNW NO, ESE YES) Win. Open%: (WNW 60, NNE 20, ESE 40)	32	Shading: (WNW YES, ESE YES) Win. Open%: (WNW 60, NNE 20, ESE 40)

Figure 47. Sensitivity analysis of shading and window opening on discomfort hours and total primary energy use for Li1-3 layout

The reasons for these results are tied to the interaction between solar gains and heating demands. In this climate, passive solar gains during winter and shoulder seasons (spring and autumn in Mafrq, Jordan) provide a critical “free heating” contribution. Fixed shading devices, while reducing cooling needs by blocking direct

solar radiation, simultaneously cut down winter solar gains. This loss means that more mechanical heating is required, leading to an overall rise in primary energy use. In contrast, window opening has only a minor impact on total primary energy use, altering it by up to 0.05 kWh/m² within any given shading scenario. While ventilation helps remove excess heat during warmer periods, it has slight effect on the building's overall heating and cooling energy balance across the year.

These findings reveal a clear trade-off: operable windows are the most effective means of reducing occupant discomfort, while fixed exterior shading, particularly on the WNW façade, has a more significant impact on annual energy use by reducing winter solar gains and increasing heating demand. Therefore, planners and designers should prioritize window-driven ventilation strategies when occupant comfort is the primary concern and carefully weigh the energy implications of permanent shading devices when aiming to minimize annual primary energy consumption.

Chapter 5

Conclusions

This study aimed to address the urgent need for sustainable temporary accommodations for migrants by analyzing and optimizing the dominant shelter designs in the Zaatari refugee camp. It explored sustainable design methods to enhance indoor comfort and reduce the environmental impact of such accommodations. Using DesignBuilder simulations, a comprehensive optimization process was undertaken with a total of 63,154 iterations, analyzing variables such as plan layout, envelope materials, insulation types, window-to-wall ratios (WWR), shading, and window opening rates. Implementing a six-step methodology, the research successfully identified 243 optimal designs (Figure 38 and Figures F-1 to F-9 in the Appendix) to improve the sustainability and livability of selected shelters in Zaatari refugee camp.

After the determination of the climatic region and migrant camps, the region's climate (temperature, humidity, wind, etc.) and camp-specific conditions were analyzed. Thirdly, the existing shelter (base case) is determined and studied to analyze its design, materials, and operation. In the design stage, based on the findings, alternative design scenarios were developed to analyse thermal comfort, carbon emissions, and energy efficiency changes against the base case. Applying six main variables and their alternatives including fourteen plan layouts, three envelope materials, three XPS insulation thicknesses, five WWRs, three shading configurations, and eleven values for window opening rate alongside fixed proposed parameters including orientation, and double-glazing windows, proposals are then optimized separately using DesignBuilder to compare their LCA, thermal comfort, total primary energy use, embodied CO₂ and operational CO₂ against the base case. Finally, two-step decision-making, including Pareto optimal and EWDM, is applied to conclude the most optimal design among 243 design scenarios. The selection of the ideal case among 243 optimal designs needed a two-step decision-making process. The Pareto Front optimization was first applied separately to each of the fourteen plan layouts to identify locally optimal solutions based on objectives. This step ensured layout-specific optimization but resulted in multiple fragmented Pareto Fronts. Second, the optimal designs from all layouts were combined into a dataset (Figure 38), and the

EWDM method was used to rank and select the best overall design. This hierarchical approach was necessary due to the computational limitations of applying Pareto Front optimization to all designs simultaneously, ensuring both complexity and feasibility in the evaluation process. The following items are the main findings:

- The use of Hardwood as an envelope material, replacing Zinc, proved to be the most effective variable due to its significantly lower embodied CO₂. When combined with 9 cm of XPS insulation, this material configuration appeared in more than 94% of the optimal designs
- Although T-shapes and C-shapes were common among the 243 optimal designs, the Linear-shape layout was the most common according to both the Pareto optimal (knee-point) and EWDM methods. Specifically, Li1-3, selected by EWDM, showed improvements of 44.48% in discomfort, 69.46% in LCA, 84.55% in embodied CO₂, 40.44% in operational CO₂, and 60.09% in total primary energy compared to the base case.
- The dominant WWR for all orientations of WNW, NNE, and ESE is 10%, with ESE showing greater flexibility for higher ratios of 10% and 15%. This ratio can minimize heat gain and loss, reducing cooling and heating demands while providing sufficient natural light without excessive solar radiation. The ESE orientation allows flexibility for higher ratios (10%–15%) due to its milder morning sunlight, optimizing daylighting and thermal comfort. Consequently, this approach better balances energy efficiency and occupant comfort in hot-arid climates compared to other alternatives.
- Due to the Mafrq's dominant wind direction, larger openings on WNW and smaller exits on ESE likely enhance ventilation speed through the shelter. Therefore, WNW (292°) favours larger openings (80–100%) for airflow, while ESE (112°) balances airflow with moderate openings (20–50%), and NNE (22°) prefers smaller ones (20%) to minimize heat loss.
- Shading appears to have a limited impact on optimization, as most ESE (112°) designs (87.2%) prefer no shading, suggesting minimal benefit. For WNW (292°), while 34.2% use a 0.5m louver, the majority (55.1%) opt for no shading, indicating its secondary role compared to other variables.

- The correlation chart (Figure 46) shows strong correlations between LCA, operational CO₂, and total primary energy use, emphasizing the importance of operational efficiency for sustainability because the operational phase often accounts for the largest share of a building's environmental impact over its lifespan. Inefficiencies in energy use during operations, particularly for heating, cooling, and lighting, accumulate over time, driving up total primary energy demand and CO₂ emissions, which are primary contributors to climate change. Discomfort has weak or negative correlations with embodied CO₂ emissions, indicating that thermal comfort can improve without increasing emissions, particularly with passive strategies.
- The EWDM and Pareto optimal methods slightly differed in the selection of optimal cases. EWDM highlighted Li1-3 with 44.48% discomfort and 69.46% LCA improvement, while Pareto optimal's Li2-7 achieved 41.92% discomfort and 70.66% LCA. While both methods showed close decisions, the Pareto optimal method was more effective in deciding the final optimal case across all metrics, whereas EWDM provided a more balanced decision.

The findings of this study highlight critical evidence that can alert governments and responsible authorities to the significant environmental impacts and occupant discomfort resulting from unoptimized refugee accommodations, emphasizing the urgent need for more sustainable and human-centered design approaches. The analysis confirmed that all the proposed design variables played a considerable role in enhancing the performance of the current shelter (base case). Therefore, optimizing materials and design configurations in temporary shelters can enhance indoor thermal comfort, minimize total primary energy use, and reduce environmental impact over a 30-year life cycle in migrant camps like Zaatari.

The current shelters, constructed with zinc panels and 4 cm polyurethane insulation, exhibited high embodied CO₂ emissions (exceeding 41,033 kg), inadequate thermal performance with over 6,703 annual discomfort hours, and a reliance on external energy for heating and cooling in Mafraq's extreme climate. Their uniform rectangular, and separate layouts also limited adaptability, ventilation, and comfort, underscoring the need for sustainable improvements.

The optimization process showed that replacing zinc panels with hardwood combined with XPS insulation reduced energy demand and CO₂ emissions. Linear-shape layouts improved ventilation and thermal zoning, while adjustments to WWR, shading, and window opening rate enhanced thermal comfort and reduced environmental impact and energy use, supporting long-term sustainability goals.

Although the optimization improved thermal performance by 44.48% (Li1-3 layout), discomfort hours remain high, particularly due to the lack of a cooling system in the base case, exacerbated by Mafraq's extreme heat. Incorporating energy-efficient cooling systems for migrant shelters is recommended, though it would affect LCA and total primary energy use, requiring evaluation. Solar-powered cooling systems could help manage energy demand while supporting sustainability goals.

Additionally, airflow and thermal comfort could be better optimized by examining window position placement and furniture layouts using CFD. Future studies may also consider incorporating phase-change materials and natural elements like tree shading to further enhance shelter performance, addressing both immediate and long-term sustainability challenges. As mentioned above, shadings resulted in minimal impact on the optimization. Although double clear glazing replaced the single glazing in all design scenarios, improving optimization may contribute to excessive solar absorption. As the study didn't explore various glazing options, future improvements could include evaluating innovative technologies like Low-E coatings, thermochromic glass, and tinted options, compared to standard glazing.

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