Sustainable Materials and Methods for Developing Affordable Refugee Core Shelters

A dissertation presented

by

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

In the name of Allah, the Entirely Merciful, the Especially Merciful.

Declaration

I certify that this thesis constitutes my own work/investigation, except where otherwise stated; other sources are acknowledged by explicit references.

I declare that this thesis describes original work that has not previously been presented for the award of any other degree of any institution.

Signed: Rojhat Ibrahim

Date: 2 May 2023

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From beginning to end, my gratitude is to The Lord, who blessed me with this task. Through His Strength, by His Knowledge and in His Grace are all things accomplished. O Allah, I am the needy servant at Your door, and You are the most generous of hosts.

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Abstract

Globally, natural and man-made disasters continue to force the displacement of masses of people. However, studies show that several aspects have not been integrated into constructing refugee camps and shelters to achieve sustainability, such as long lifespan, indoor thermal comfort and air quality, energy efficiency, socio-cultural aspects, integration with local planning and design systems, and environmental impact. Therefore, the research mainly aimed to design affordable and feasible core shelter prototype typologies for displaced people by adapting sustainable long-lifespan materials and methods, being culturally responsive, and achieving sufficient indoor environmental comfort with minimum energy consumption and environmental impact.

The main research question has been answered based on qualitative and quantitative analysis and using the dynamic program Indoor Climate and Energy IDA ICE 4.8 SP2 simulation and Excel sheets software. The comprehensive and concise question was, what is the current condition of shelters regarding construction techniques and performance based on conventionally used materials in Iraq and what other methods and upgrading phases could be adopted to design and propose new sustainable shelter typologies? Additionally, several sustainable construction methods and materials have been investigated then; based on the context of this research, low-impact construction (LIC) through the bottom-up approach, besides the incremental strategy, have been targeted.

Furthermore, the current condition of shelters regarding construction techniques based on conventionally used materials in Duhok City in Iraq has been analyzed. Moreover, by proposing a novel construction method through the bottom-up one, the study offered the opportunity to prolong the lifespan of shelters and enhance the indoor environment and energy performance by assessing and comparing nine different scenarios.

Later, by integrating the above six identified issues, the research designed and proposed comprehensive prototype typologies considering several variables based on the socio-cultural and local planning and design systems. Additionally, the impact of orientation on the

performance of six designed Cases through eight different cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions have been addressed.

Finally, three upgrading phases through incremental strategy proposed to prolong the lifespan of the core shelters based on the Iraqi context and allows upgrading based on time, available cost and need. Moreover, an empirical evaluation of the energy use and indoor environment performance for six designed core shelters typologies with three incremental phases in two different positions, i.e., terraced (T) and end-of-terraced (ET) has been done. The results revealed that the adopted approach leads to remarkable improvements in the prototypes' overall performance. Concerning energy use, compared to the base case scenarios built with conventional materials, the proposed prototypes show an opportunity to save energy up to 10,800 kWh per unit per year, equivalent to almost 2700 USD savings in energy bills. This is while achieving an acceptable level for nearly 89–94% of thermal comfort hours, and 74–85% predicted mean vote (PMV), respectively. However, the CO2 concentration level remains relatively low, ranging from 29 to 51%.

To sum up, the valuable novelty and main contribution study were to fill gaps by integrating the six main shortcomings in the current literature. That is through developing the energy and indoor environment performance of the six proposed core shelters typologies, designed based on the Middle Eastern cultural context using locally available sustainable construction materials and techniques and embedded in the local planning system with their three incremental phases.

Keywords

Post-disaster shelters; Affordable and upgrading strategies; Low-impact constructions; Bottom-up method; Sustainable prototypes; Energy efficiency; Indoor environment comfort; Planning and design systems; Incremental phases

Research Outcomes Publications

The following journal papers were published in support of the research.

- **Ibrahim, R.** and Baranyai, B., 2021. **Developing migrants prototypes performance through bottom-up construction method**. *Pollack Periodica*, *16*(3), pp.127-132.
  DOI: 10.1556/606.2021.00392

- **Ibrahim, R.**, Elhadad, S., Baranyai, B. and Katona, T.J., 2022. **Impact Assessment of Morphology and Layout of Zones on Refugees' Affordable Core Shelter Performance**. *Sustainability*, *14*(18), p.11452.
  DOI: 10.3390/su141811452

- **Ibrahim, R.**, Baranyai, B., Abdulkareem, H. and Katona, T.J., 2023. **Energy Use and Indoor Environment Performance in Sustainably Designed Refugee Shelters: Three Incremental Phases**. *Sustainability*, *15*(8), p.6903.
  DOI: 10.3390/su15086903

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CHAPTER 1
INTRODUCTION

1.1 Research Overview and Problem Statement

The displacement issue of a large number of people is considered one of the continuous and major global challenges that individuals, societies, states, and even international and Non-Governmental Organizations (NGOs) nowadays are facing [1-3]. Currently, most countries have suffered from migration issues due to having displaced people, hosting them from other countries, or spending too much on the subject within the international framework [3]. The last report of the global trend in 2022 for the United Nations High Commissioner for Refugees (UNHCR) stated that the number of forcibly displaced people reached 103 million, an almost 60 million increase in one decade. The 2022 figure is equivalent to one forcibly displaced person for every 77 people living on Earth. All this is due to violence, conflict, and persecution [4]. Millions of people worldwide, such as Palestinians, Sahrawi, Rohingya, Kurdish, Afghan, and Somalian, have been displaced for decades and have lived in camps [5-10]. More recently, the Russian-Ukrainian war in a relatively safe continent from wars and the recent earthquakes in Turkey and Syria indicate that the displacement issue and its causes are an unexpected challenge that could target any place [11-13].

Globally, the root causes of the continuous and increasing migration of masses of people are either natural disasters such as earthquakes, floods, tsunamis, wildfires and droughts or man-made such as conflicts and persecution, ethnic and religious discrimination, economic and political instability, and demographic factors [14-17]. Across the Middle East and North Africa (MENA), the main factor is more of a man-made rather than a naturally driven issue. Amongst the main causes of displacement in such regions is political instability driven by external intervention, internal armed conflicts, and ethnic persecution [18,19]. These factors led a country like Iraq to be one of the world’s major countries plagued with internal and external displacement. According to a 2022 report from the International Organization for Migration (IOM), the Global Peace Index (GPI) rank for Iraq in 2021 is 159, and their passport index class is 109 [20]. In addition, estimations show more than 2 million Iraqi refugees worldwide, but fewer are registered [21]. For instance, by 2022, the number of registered Iraqi migrants is around 1.125 Million in the United States of America, Germany, Turkey, Jordan and Syria, while there were more than 574000 asylum seekers by 2020 [20,22]. Also, UNHCR declared in September 2022 that there were more than one million Internally Displaced People (IDPs) besides 300 000 refugees in Iraq [23].

Although many people have been displaced for more than 70 years and live in camps[24], conventional camps with temporary and inefficient transitional shelters have been the predominant approach in many countries. Consequently, such an approach greatly burdens refugees, host countries, international organizations, and the environment. Moreover, their short lifespan costs billions of US Dollars yearly [25,26]. Their main shortcomings, according to existing literature, can be concluded as follow:

The short lifespan of the shelters compared to the displaced period: Leads to a waste of resources such as materials and energy, a waste of money, and pollution from manufacturing, transportation and landfill [26-28].

Inadequate planning and designing systems: Lack of coordination, insufficient services and shelters areas, lack of safety and security moreover to crimes because of narrow alleys, shared services, and poor quality of doors, windows, and walls, additionally to defective materials, waste of land due to isolated unit approaches and extreme horizontal expansion, lack and inadequate future expansion strategies [24,27,29,30].

Disregarding socio-cultural aspects: Ignoring social and religious needs, lack of community engagement, shared sanitation, messing privacy, gender-based violence, and conflicts [27,30-32].

Energy sources and consumption: Fossil fuel energy sources are used widely in camps due to the budgetary shortage for displaced people that lead to health risk and 20000 deaths annually due to indoor air pollution based on World Health Organization (WHO). Additionally, the emissions and their environmental impacts contribute to the global warming issue due to utilizing unrenewable sources for producing energy. Moreover, generally, sufficient power still has a shortage in many developing countries, and both displaced people and host countries are suffering [27,33,34].

Indoor environment issues: insufficient thermal comfort, improper ventilation, high moisture ratio, and high level of CO_2 concentration lead to inadequate health, poor productivity, and morale [35-38].

Environmental impact due to the abovementioned problems: Land and resources waste and degradation, pollution from unrenewable energy sources, and nonrenewable waste of materials [26,27,30,39].

Therefore, implementing different strategies and methods is recommended to mitigate the impact of mentioned issues, enhance the quality of life for displaced people, and achieve sufficient, sustainable camps and shelters. For this, several factors must be considered when aiming sustainable shelters for displaced people, for instance:

- Upgrading strategies to prolong the lifespan.
- Affordability by host countries and displaced people.
- Sufficient thermal and air quality comfort performance.
- Minimum energy consumption.
- Socio-cultural aspects.
- Integration with local planning and design system.
- Minimum impact on the environment.

Although a considerable amount of research has been devoted to the displaced issue annually, there is a gap concerning integrating all the above factors in designing camps and shelters worldwide. In Iraq, like in many other countries, such integration is lagging behind. This study's main contribution and novelty are to fill that gap by combining the above elements in the six refugees' core shelters typologies designed based on the Middle Eastern cultural context using locally available sustainable construction materials and methods. In addition, it proposes a unique approach that exploits a set of low-impact materials on every prototype wall for affordability and adaptability and examines its application performance.

1.2 Study Area

The case study is based on refugee camps in Duhok province in the Kurdistan Region of Iraq (KRI) (Figure 1-1). In the KRI, geopolitical factors and the strategic location near the border of Syria, Turkey and Iran made the people living with the displacement issue either to be displaced people or host them. For instance, more than two million Kurds from Iraq had already become refugees in Turkey and Iran due to the wars and conflicts with the Iraqi government [40]. Moreover, till 2017, around two million Kurds were displaced from their homeland in Turkey, Iran, Iraq and Syria due to persecution and conflicts and registered as refugees or asylum seekers, most of whom live in Europe [41]. Due to the relatively safe location compared to other parts of Iraq, the KRI has become the preferred destination for IDPs from Iraqi and Kurdish refugees from Turkey, Iran and Syria, and Duhok province has the lion's share.

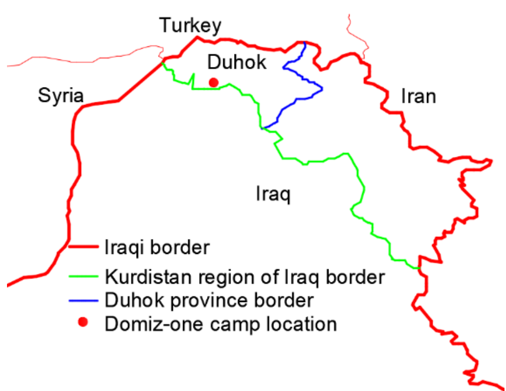

Figure 1-1 Case study location

For instance, the Directorate of Migration and Crises Response (DMCR) in Duhok [42] stated in the last updated report in February 2023 that there are 540702 individuals displaced people (449071 IDPs and 91631 refugees) in the Duhok province. Moreover, it mentioned that in the Domiz-one camp (visited case-study as the largest Syrian refugee camp in Iraq), there are 29232 refugees distributed to 6132 families while there are just 5496 shelters.

The altitude of Duhok province is around 585 m above sea level, while 36◦ 54’ 27.72” and 43◦ 3’ 47.52” are their latitude and longitude coordinates [43]. The Köppen-Geiger climate classification referred that Duhok province has a borderline semi-arid and Mediterranean climate with extremely hot dry summers and mild to cool wet winters [44]. While according to Alwan et al. (2019) [45], it has been divided into various climatic zones, from a very humid, semi-humid Mediterranean and cool semi-arid winter to warm and very warm summer. The location of the selected case (Domiz-one) camp in Duhok is characterized as a cool semi-arid winter and a very warm summer. Additionally, the mean-daily temperature is 32–36 °C in summer and 4–11 °C in winter in Duhok province [46].

Additionally, the gap in energy demand in the KRI has increased considerably during the last two decades. For example, the average daily electricity supply from the state grid is 13 hours in Duhok province, while the shared split generator provides for other hours at a relatively expensive level [46]. However, 85% of their production is from fossil fuel sources, greatly impacting the environment due to CO_2 emissions [47]. Moreover, the current conditions for the huge number of displaced people in Duhok city have accelerated the energy issue and its environmental impacts.

Concerning the shelters' construction materials, most displaced live in tents as temporary shelters, while the visit case (Domiz-one camp) has core shelters. However, the indoor living standards conditions are unbearable even in core shelters due to the extensive use of unsustainable construction materials (concrete block walls and zinc roofs) and methods (detached units) (Figure 1-2). In conclusion, the harsh weather conditions in the Kurdistan region, including Duhok, force the buildings to be designed based on both heating and cooling parameters. Consequently, thinking about more sustainable, efficient construction materials and methods for displaced shelters is an unavoidable need to enhance the indoor environment conditions of refugees shelter, reducing energy consumption and environmental impacts.


Figure 1-2 Case study (Domiz-one camp) typical construction materials

1.3 Research Questions

The thesis attempts to find solutions by finding answers to the following research questions:

1. Is the current refugee shelter lifespan compatible with the displaced period?
2. What build-environmental issues that the refugee camps and shelters currently suffer from?
3. What methods and techniques could prolong the lifespan of the displaced shelters?
4. What is the current condition of shelters regarding construction materials and techniques, thermal comfort and energy performance based on conventionally used materials in Iraq?
5. Is there any other construction method that could offer the opportunity to prolong the lifespan of shelters and enhance the indoor environment and energy performance?
6. What methods must be taken to design and propose new sustainable shelter typologies, and what layout system performs better?
7. What is the impact of orientation on the performance of six designed Cases?
8. What upgrading phases could be proposed to prolong the lifespan of shelters, gives the opportunity to upgrade based on time, available cost and need, and what is their energy and indoor environment performance?

1.4 Research Aim and Objectives

This study aimed to design affordable and applicable core shelter prototype typologies by adapting sustainable longer lifespan materials and methods, being culturally responsive, and achieving sufficient indoor environmental comfort with minimum energy consumption. To fulfil the above aim following objectives have been set:

1. Review the relevant current literature to understand the background context of the displacement, the current issues, and the common approaches in building affordable low-impact refugee shelters.
2. To understand the issue within the Iraqi context regarding factors shaping refugee camps, this includes but is not limited to the building characteristics of the existing shelters through sit visiting, reviewing governmental documents, and conducting and direct communication with key stakeholders.
3. To develop computer base models based on the data collected from earlier objectives.
4. To develop upgrading proposals based on locally available low-impact construction materials and techniques, propose a new affordable and applicable method and assess their impact on energy and thermal performance.
5. Design prototypes based on refugee and society needs using the most efficient upgrading proposal methods and assess their energy and indoor environment performances.
6. Identifying the best direction by assessing the impact of orientation on the energy and thermal comfort performance of six designed Cases through eight different cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions
7. Propose three upgrading incremental phases for the designed cases and assess their energy and indoor environment performances.

1.5 Overview of the Research Methodology

The research aims were fulfilled through three self contains published studies [48-50] and presented individually in the next chapters (Chapters Three, Four and Five), where each study has its own data collection and analysis methods, results, discussion and conclusion. The conceptual framework in below Table 1-1 refers to the research's adopted methodologies and work.

Table 1-1Conceptual framework for the research methodology

Data collection

<u>Data sources</u>

- Literature review
- Communication with stakeholders
- Review of governmental documents
- Case studies and site visit
- Observation

<u>Data types</u>

- Typologies
- Construction Methods
- Materials and Techniques
- Performance
- Documentation data

Data processing

<u>Finding study problems</u>

- Lifespan issues
- Energy consumption issues
- Indoor environment issues
- Planning and design issues
- Socio-cultural issues
- Environmental issues

<u>Processing factors</u>

- LIC and bottom-up method
- Selection of cases
- Planning and designing investigation
- Materials selection

Development of computer-based models

- Setting location and orientation
- Input parameters and Setting schedules
- Building models

Development of upgrading propositions

- Application of Low-impact construction via the bottom-up method
- Application of different design layouts ranging from compact to open to yard
- Future expansion through incremental improvement strategy

Assessment and simulations

- The impact of the Bottom-up method on energy and thermal performance
- The impact of different layouts on energy and indoor environment performance
- The impact of future expansion and incremental improvement strategy on energy and indoor environment performance

1.6 Research Structure

Besides this introductory chapter, this thesis includes five chapters outlined as follows:

Chapter 2 focuses on the general theme and reviews existing research to understand the humanitarian shelter typologies and terminologies, strategies and methods for minimizing their environmental footprint, incremental approach, and low-Impact construction (LIC) through the Bottom-Up method. This is to provide the background knowledge and the technical insight needed for developing sustainable refugee shelters presented in Chapters 3, 4 and 5 .

Chapter 3 presents the first study [48], which develops core shelters' energy and thermal comfort performance through the bottom-up construction method. Next, the chapter details the modeling process of nine different scenarios employing a few low-impact materials and methods and compares their energy use and indoor environmental performance.

Chapter 4 presents the second study [49], which provides a detailed assessment of the impact of different orientations, morphologies, sittings, and layouts on the energy and thermal performance of the designed prototypes.

Chapter 5 presents the third study [50]. Using dynamic building simulation, the chapter provides an empirical assessment of energy use and indoor environment performance of six refugee core shelters situated on two different building plots, i.e., terraced and end-of-terrace, and undergoing three development phases, known as the incremental improvement strategy.

Chapter 6 concludes the research and provides a summary of the main findings followed by a set of recommendations, limitations of the study, and future research.


DURABLE
TRANSITIONAL
EMERGENCY

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

This Chapter focuses on the general theme and reviews existing research to understand the humanitarian shelter typologies and terminologies, determining the main issues in humanitarian accommodations and concluding recommendations, strategies and methods for minimizing their environmental footprint through incremental approach and low-Impact construction (LIC) through the Bottom-Up method. Moreover, this chapter reviews the interconnection issues of energy and indoor environmental performance in shelters. This provides the background knowledge and the technical insight needed for developing sustainable refugee shelters presented in Chapters Three, Four and Five.

2.2 Displaced People, Terms and Definitions

Several terms and definitions for the various displaced groups have been widely used in field studies, such as reports by humanitarian organizations, international treaties and academic journals. However, at the same time, it has to be mentioned that there is a controversy among some international organisations about using the terminology, which has been used usually based on their new destination or circumstances to leave their habitual places. For instance, according to IOM, the term Migrant, is more general and includes any person who leaves their birthplace homeland either to live within their state or across an international border, and it stated that till 2020 there were around 281 million migrant people. However, according to the UNHCR, migrants do not include Asylum seekers or refugees and mention that there are approximately 103 million forcibly displaced people worldwide in 2022 [4,14,20,51,52] Based on those references, the following terms are some most predominant ones:

- **Migrant:** A person who moves from their habitual places to live within their states or across international borders, usually for work, education, or family reason, while IOM includes forced displacement as well.
- **Refugee:** A person forced to flee their country of origin for fear of war, violence, and persecution because of religion, nationality, political or social opinions or other threats to their freedom or life.
- **Asylum seeker:** A person seeking protection in another country, usually due to the reasons mentioned above for the refugee.
- **Internally Displaced Person (IDP):** A person forced to leave their habitual places but stay within their country's borders. Their displacement is usually due to natural disasters and persecution or wars.
- **Environmental migrant:** A person forced to leave home due to climate change (global warming) and natural disasters.
- **Stateless person:** A person who does not have a nationality or legal status in any country caused by discrimination in gender, ethnicity and religion or conflict between races.

To conclude, the current literature show generally several data concerning displaced people globally. Moreover, the terminology of some widely used words in the field could refer mostly based on the reasons and destinations. Additionally, a group of people could not be counted under each category or on more than one based on the organization or attitude. For instance, many Kurdish people from KRI have recently migrated to developed countries (mostly Europe) and seek asylum not because of conflicts but usually due to a lack of justice in the distribution of wealth or the unstable economy of the region. Consequently, those people could be counted as migrants, asylum seekers, or refugees. Therefore, addressing this subheading in the literature was important to clarify and get more understanding during picking terms and data regarding the field. Finally, as a result, more coordination seems recommended between such humanitarian organizations and stakeholders besides careful attention when investigating such a group of people.

2.3 Shelters Typologies and Terminologies

Similarly to the displaced people terminologies, various shelter typologies and terms are used for post-disaster and humanitarian accommodations. Those terms have been used in the literature and construction field based on life span, materials, and methods. The following are several common typologies and terminologies for displaced people's shelters based on several relevant literature, stakeholders and humanitarian organizations, including UNHCR [53-56].

- **Tent Shelters:** These shelters are made from canvas or synthetic materials that are easy to set up and remove. Depending on the environmental and maintenance conditions, they can protect for a short-term period (1-2 years). Therefore, they are commonly used as emergencies or temporary shelters. Their cost varies from approximately 23-40 US dollars per meter square while 10-21 US dollars per square if the walls are built from natural and earth-based materials. The construction time varies from 0.5-24 hours depending on the area, construction staff and assembled technique.
- **Container Shelters:** These types of shelters are made of converted shipping containers. They can be used as temporary or transitional shelters. Their lifespan is from 2-4 years, their cost varies from approximately 65-143 US dollars per meter square, and the construction time varies from 6-16 hours depending on the area, construction staff and assembled technique.
- **Prefabricated Shelters:** These types of shelters are built in factories and then transported to the site for installation such as Tents, Caravans or Containers. They are designed to be easily assembled but usually not considering the sociocultural aspect and environmental conditions for subjective regions due to importing.
- **Core Shelters:** Usually built from more durable materials or earth-based materials, it is considered a more permanent solution (could reach the permanent housing standards), and their lifespan reaches more than ten years. Their costs are various from approximately 78-205 US dollars per square meter depending on the materials and construction method. Additionally, the construction time varies from 7-21 days depending on the area, construction method and staff and availability of materials.

- **Emergency Shelters:** This typology of shelters is designed to provide urgent protection after a disaster and is usually intended to transport and set up easily, such as tents.
- **Temporary Shelters**: This typology is considered a more temporary (expected short stay) method until providing more suitable permanent ones. They generally share public facilities, usually prefabricated or fast self-built methods such as tents, caravans or containers.
- **Transitional Shelters:** This typology consists of semi-permanent shelters, usually developed from emergency and temporary shelters to more progressive standards for a relatively long period than previous typologies. Hence, it is named as more process than construction materials. However, this typology with Temporary ones is called T-Shelters in some literature, while transitional shelters are generally more resistant to environmental conditions with more durable strategies than temporary shelters.
- **Progressive Shelters:** This typology is designed to be upgraded later to be more durable once, and it has a higher level of resistance to environmental conditions than the above typologies.
- **Permanent (Durable) Shelters:** This typology of shelters is designed to provide long-term housing for displaced people and could reach permanently affordable housing standards, and they are also called Core-shelters in many studies. The construction of a shelter may start from one room and could be built as a part of a permanent existing shelter. However, the construction process needs more coordination with governmental authorities to meet planning development standards. They are typically made of more durable materials, such as concrete block walls or earth-based materials and are designed to resist unfavorable environmental conditions. Moreover, based on the construction materials and method, this typology is considered more comfortable and sustainable than the above typology shelters.

To conclude, these typologies and terms are several predominant examples of the various types of shelters used as post-disaster shelters for displaced people. Moreover, some terms and typologies could have interconnected definitions or be overlapped in some literature. Additionally, several factors such as duration of displacement, size of displaced people, environmental and climatical conditions, an abundance of resources and geopolitical factors could determine the type of shelter. Finally, it is recommended to utilize earth-based techniques as much as possible due to their efficient cost, durability and environmentally friendly.

2.4 Determining Issues and Considerations

The displacement issue is a continuous and major global challenge faced by individuals, societies, states, international and NGOs. Although many people have been displaced for more than 70 years and live in camps [24], conventional camps with temporary and inefficient transitional shelters have been the predominant approach in many countries. Consequently, such an approach greatly burdens refugees, host countries, international organizations, and the environment. Moreover, their short lifespan costs billions of US Dollars yearly [25,26]. Therefore, due to the constant factors (natural and man-made) that lead to aggravating displacement crises, a considerable amount of research has been devoted to the issue concerning the built environment annually. For instance, many institutions, scientific researchers and involved entities investigated how to minimize the impact of displaced issues and enhance the quality of life for humanitarian shelters and camps via different methods and strategies.

Regarding this aspect, a scientific study has discussed a proposal for reusing and rehabilitating vernacular settlements for migrants in the context of the Middle East and also mentioned that annually billions of dollars are spent on temporary refugee camps establishing [57]. Furthermore, Hendriks et al. [58] evaluated cost, time reduction, and maintenance of traditions, concentrating on expected long-term effects by analyzing self-built housing cases as a strategy for the post-disaster recovery of low-income groups. Moreover, Ibrahim et al. [59] observed the superiority of the adobe dome over other humanitarian agencies' shelters as tent caravans in northern Syria through analyzed and compared based simulated research for the assessment of energy and indoor environment performance. Additionally, by manipulating Low-Impact Construction (LIC) materials and techniques, a study produced an assessed model with low carbon emissions that was comfortable and energy-efficient by adopting passive strategies [60]. In the same way, a study evaluated the carbon impact of refugees shelters and resulted that using local materials like straw, wood, and clay can extremely decrease the carbon footprint [26]. Moreover, another study investigated the three pillars of sustainability (social, economic, and environment), focusing on existing solutions and novel designs in displaced people shelters [30].

Concerning the considering planning system, a self-built upgrading technique embodied in the staggered-based planning design strategies system has been proposed by a study [61] for internally displaced people (IDP) in Syria. Moreover, Bredenoord stated that a planning system considering the upgrading and incremental approach is a sustainable solution for long-term projects [62]. Al Ameen [56] proposed an upgrading method for the planning and designing phases of refugee's shelters in Iraq. The techniques included a wall panel composed of layers of steel mesh, tarpaulin, sand, roof canopy, and sunspace. Moreover, Wainer et al. [63] explained the significance of effective collaboration between finance and design in a scale of planning and design for low-cost housing. Additionally, Askar et al. [64] concluded that incremental strategies for post-disaster dwellings build bridges between both temporary and permanent phases and provide affordable solutions, contributing to sustainable development via different beneficial points such as saving time, materials, and a huge amount of resources. Finally, Wagemann [54] illustrated how people adapt their dwellings after disasters through different incremental phases via transforming temporary structures to permanent ones.

In conclusion, despite the continuing efforts to enhance the quality of life for the displaced people and enhance the performance of humanitarian relief camps and shelters addressed in the existing literature. However, it revealed several shortcomings that the built environment for the post-disaster shelters suffered from especially concerning integrating them, as has been mentioned in the introduction chapter as well, and the main issues are:

1. The short lifespan of the shelters compared to the displaced period.
2. Inadequate planning and designing systems.
3. Ignoring sociocultural aspects.
4. Energy use sources and consumption.
5. Indoor environmental issues (insufficient thermal comfort and indoor air quality).
6. Environmental issues.

Therefore, implementing different strategies and methods is recommended to mitigate the impact of mentioned issues, enhance the quality of life for displaced people, and achieve sufficient, sustainable camps and shelters. For this, the following factors and considerations must be addressed when aiming for sustainable shelters for displaced people, for instance:

- Upgrading and incremental strategies to prolong the lifespan and minimize carbon footprint.
- Affordability by host countries and displaced people.
- Achieving adequate thermal and air quality comfort performance.
- Minimize energy consumption by adopting passive strategies for enhancing the performance of shelters.
- Addressing Socio-cultural aspects.
- Integration with local planning and design system of the host cities.
- Minimizing footprint impact on the environment.
- Considering the cost and availability of resources.
- Considering transportation of main resources and setup time of shelters.
- Considering weather proof, quality and durability of shelters.
- Considering the size and security of units.
- Considering noise and privacy in the designing system.

2.5 Sustainable Construction Methods and Materials

Construction methods refer to the procedures and techniques used in the building construction sector, from preparation to finishing or even demolishing and dismantling. These methods could be chosen based on the building typology, the location of the building or the function of the building (intended use). Construction methods could include traditional approaches such as earth-based, timber framing and masonry or modern modular construction such as precast construction technique [65-67]. Furthermore, building construction materials could consist of natural materials from the earth, wood, hay, and stone or synthetic materials such as steel, concrete, or plastic. Moreover, selecting proper materials and methods is crucial in achieving a successful building, as it affects their function, safety, indoor environmental performance and lifespan. Likewise, Several factors could be considered when choosing construction methods and materials, such as affordability and cost, availability of materials and time management, indoor environmental and energy use performance, durability, and aesthetic or sustainability factors [65-67].

Furthermore, sustainable construction considers three fundamental pillars (environmental, social, and economic) to create a better world for present and future generations [65][68]. Consequently, this section addressed sustainable construction materials and methods to build minimal environmental impact shelters while providing occupants with a healthy and safe environment. As a result, the following sub-section has been focused on to get more understanding when targeting them for the research.

2.5.1 Incremental Strategy

One fundamental strategy for sustainable architecture is to design for longevity [64]. So regarding this, an incremental approach in the construction sector is a prominent example of prolonging the building lifespan. An incremental methodology is an approach that has been argued for, proposed, and implemented by several architects, for instance, Alejandro Aravena, to find the solution for low-income, homeless and displacement issues. Moreover, incremental strategy is usually incorporated into affordable dwelling solutions. For instance, The Quinta Monroy project in Iquique City, with 100 housing units for low-income people in Chile, has adopted the method as shown in the Figure 2-1 [63,64,69-72].

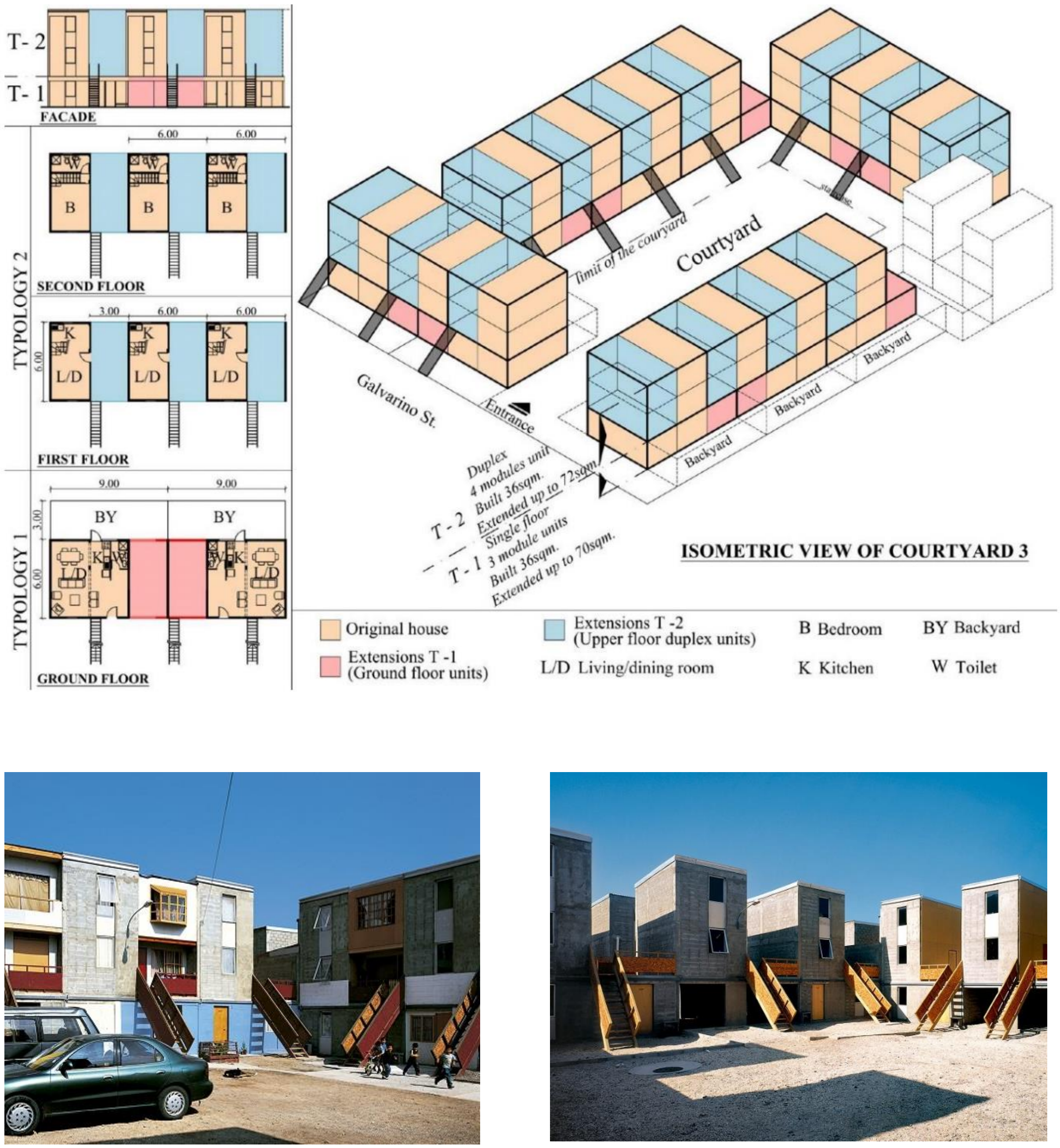

Figure 2-1 *Incremental strategy in The Quinta Monroy project in Iquique City, Chile [70]*

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Furthermore, The incremental method aims to provide the basic functional shelter phase to be upgraded and improved later through other stages due to shortages in time, finances, and construction material resources, as it has proposed by Wagemann in her study, “From Shelter to

Home: Flexibility in Post-Disaster Accommodation" (Figure 2-2). [55,63,70,73]. For these reasons, the strategy is considered a suitable approach for post-disaster accommodation, affordable housing, and displaced shelters to start with the basic phase and be upgraded to more permanent housing [64,71]. Consequently, this study concluded that the method suits their context.

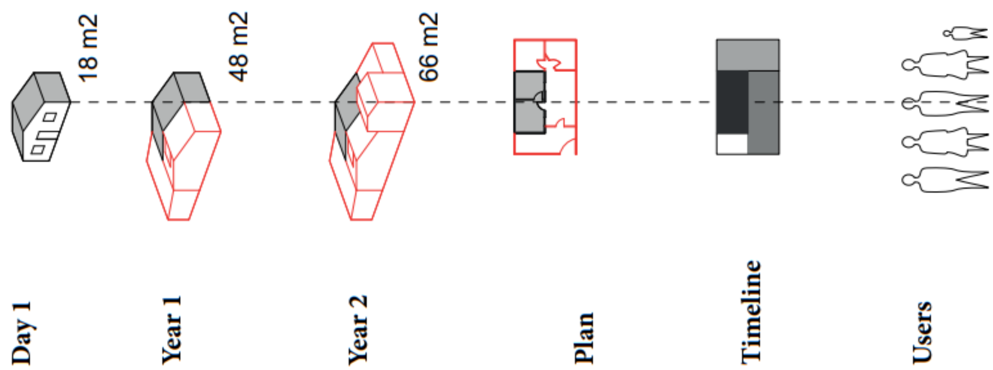

Figure 2-2 *Incremental approach, illustration for Post-Disaster Accommodation [55]*

2.5.2 Low-Impact Construction (LIC) through Bottom-Up Method

Low-Impact Construction (LIC) is a broad concept that could include top-down and bottom-up methods for sustainable construction practices when aiming to involve repair, reuse, recycling, and locally sourced materials. According to Sandy Halliday and others, LIC encompasses ecological design approaches; this can be achieved through prefabricated or modular strategies (top-down) or built on-site by local workers or displaced people in humanitarian relief cases (bottom-up). Local authorities or NGOs can manage the bottom-up construction method in the displaced people settlements projects [65,67,68,74].

Concerning post-disaster shelters, the bottom-up method is considered a more acceptable approach culturally because there is a high level of satisfaction due to locally sourced materials, building on site, and construction management. The bottom-up method is generally based on the local labours' skills and collaborative work (community involvement), the use of locally sourced, traditional and natural materials, and reuse, repair and recycling materials. Moreover, the method is considered extremely cost-effective and has a minimum impact on the site and environment. For instance, earth techniques (adobe, rammed earth, cob, wattle & daub, earthbags), straw bales, cordwood, waste materials constructions (glass & plastic bottles, car tires), earth-ship concept and so on [31,65-67,74]. Consequently, this study selected several low-impact techniques such as cob, earthbags and straw bales as more abundant and cheap materials in the Kurdistan region of Iraq (KRI) (Figure 2-3).

Figure 2-3 *Cob, earthbags and straw bales construction techniques*

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In conclusion, incremental strategy and the bottom-up construction method have been targeted for this study. The techniques and materials have been utilized based on the socio-cultural context, urban planning system and available materials in Duhok City, north of Iraq. Concerning the incremental strategy, a horizontal upgrading and adaptability strategy have been used as more feasible for the context of this study. While for the bottom-up method, an origin approach has been adopted by using three techniques (Cob, earthbags and strawbales) in one prototype wall, as referred to in the next chapter methodology.

2.6 Energy and Indoor Environment Performance

All advanced countries are currently focused on building energy problems in different ways to use energy rationally and preserve its sources [75]. Also, reducing energy consumption is critical in protecting the environment globally because 40% of the consumption is for the building sector [76,77]. However, energy and indoor environment performance are interconnected and crucial issues for displaced people's health and well-being, while providing displaced communities with clean or affordable energy is challenging. Moreover, sufficient power is generally scarce in many developing countries, and displaced people and host countries suffer [33]. For instance, the gap in energy demand, even in the KRI has increased considerably during the last two decades. For example, the average daily electricity supply from the state grid is 13 hours in Duhok province, while the shared split generator provides for other hours at a relatively expensive level [46]. Also, 85% of their production is from fossil fuel sources, greatly impacting the environment due to CO_2 emissions [47]. Moreover, the current conditions for the huge number of displaced people, besides poor construction techniques in Duhok City, have accelerated the energy issue and its environmental impacts.

Furthermore, according to UNHCR estimation, supplying diesel fuel as a primary energy source for providing electricity in displaced camps costs approximately USD 35 million annually [33]. Moreover, globally, due to the budgetary shortage for displaced people, the increased use of kerosene-based heaters and the resultant indoor air pollution leads to health risks and 20,000 deaths annually, according to the World Health Organization (WHO). Additionally, the emissions and their environmental impacts contribute to the global warming issue due to utilizing unrenewable sources for producing energy [27,33,34]. Moreover, Concerning indoor environmental issues, insufficient thermal comfort, improper ventilation and relative humidity, and high level of CO_2 concentration lead to inadequate health, poor productivity, and morale [35-38]. Consequently, energy demand and nonrenewable dependence sources and their consequences from cost and pollution can be avoided dramatically due to passively achieving thermal and indoor environment comfort through passive design strategies (building geometry, orientation and envelope) for light, ventilation, heating and cooling [78-80].

Concerning the shelters' construction materials in Iraq, most displaced live in tents as temporary shelters. However, the visit case (Domiz-one camp) has built core shelters typology. At the same time, the indoor living standards conditions are unbearable due to the extensive use of unsustainable construction materials (concrete block walls and zinc roofs) and methods (detached units). In conclusion, the harsh weather conditions in the Kurdistan region of Iraq (KRI), including Duhok City, force the buildings to be designed based on heating and cooling parameters. Consequently, thinking about more sustainable, efficient construction materials and methods for displaced shelters is an unavoidable need to enhance the indoor environment conditions of refugees shelter, reducing energy consumption and environmental impacts. Furthermore, one of the fundamental requirements of a comfortable environment is to keep thermal conditions and indoor air quality (IAQ) suitable for the residents since they directly impact their productivity, health, and morale [38]. Therefore, the following categories have been addressed to assess building indoor thermal comfort performance.

2.6.1 Fanger Comfort Model Indicators (PMV, PPD)

Fanger created a well-known comfort model based on two indices, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD), for the assessment of occupied spaces [81-83]. PMV and PPD are measurements used to estimate thermal comfort in an inhabited zone based on metabolic rate, clothing, air velocity, humidity, air temperature, and mean radiant temperature. PMV value is based on the ASHRAE thermal sensation scale, demonstrated through seven classes: 3, 2, 1 indicates hot, warm, and somewhat warm, 0 denotes neutral, while −1, −2, −3 denotes slightly cool, cool, and cold, respectively. According to ISO 7730 (2005), there are three categories for evaluating the range of PMV: [−0.2, +0.2], [−0.5, +0.5], and [−0.7, +0.7] represent categories A, B, and C, respectively [82,84,85].

According to ISO 7730, EN 15251, EN 16798-1 and ASHRAE 55 standards, Table 2-1 contain Definition and variables of the comfort categories for Fanger comfort model indices [82,85]. To conclude, due to the importance of the six variables that the Fanger model indices can assess, the module has been used in this research (Chapters Four and Five) through both accepted and good (B or II and C or III) categories.

Table 2-1 Fanger comfort model indicators (PMV, PPD) definitions of variables and categories

Category		Description	Fanger Indeces Ratios	
ISO 7730	EN 15251 and EN 16798-1		Predicted Percentage of Dissatisfied (PPD), %	Predicted Mean Vote (PMV)
A	I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons	<6	−0.2 < PMV < 0.2
B	II	Normal level of expectation, should be used for new buildings and renovations	<10	−0.5 < PMV < 0.5
C	III	An acceptable, moderate level of expectation and may be used for existing buildings	<15	−0.7 < PMV < 0.7
	IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year	<25	−1.0 < PMV < 1.0
ASHRAE 55 class		Scope	PPD (%)	Fanger PMV
90%		It shall be used when a higher standard of thermal comfort is desired	≤10	−0.5 < PMV < 0.5
80%		It is for typical applications and shall be used when other information is not available	≤20	−0.85 < PMV < 0.85

2.6.2 Carbon Dioxide Concentration Level (CO_2)

Natural ventilation minimizes the impact of sick building syndrome (SBS) symptoms, such as headaches, fatigue and eye irritation. Besides, it effectively reduces the CO_2 level and their contributions to natural cooling [86]. For investigating indoor environment performance, several categories could be addressed, such as carbon dioxide (CO_2) concentration levels could be used to measure indoor air quality (IAQ) [38]. Additionally, IAQ is affected by contaminant gases, for instance, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), radon (Rn), and sulfur dioxide (SO_2) [87]. The concentration level of CO_2 is determined mainly by the ventilation rate and the number of people [88]. European Standard EN 13779 for IAQ classification utilizes 1500 parts per million (ppm) as a maximum level of the CO_2 concentration, while it recommends keeping the level below 1000 ppm [89]. To conclude, the maximum acceptable and good level of CO2 concentration represented in 1500 and 1000 parts per million (ppm) has been addressed in this research (Chapters Four and Five).

2.7 Discussion and Conclusion

This Chapter reviewed the current literature to understand the background context of displacement and humanitarian shelter typologies driven by the following three questions:

- Is the current refugee shelter lifespan compatible with the displaced period?
- What build-environmental issues that the camps and shelters currently suffer from?
- What methods and techniques could prolong the lifespan of the displaced shelters?

The Chapter focused on the general theme to inform the study approaches and then identify the answers to the above questions. That was through addressing terminology and definitions of common displaced groups of people, their shelters typologies and common issues. Additionally, it addressed strategies and methods for minimizing their environmental footprint through incremental approach and low-Impact construction (LIC) through the Bottom-Up method. Furthermore, this Chapter reviewed the interconnection issues of energy and indoor environmental performance in shelters. Finally, reviewing the literature was more fruitfully supported by reviewing governmental documents and direct communication with key stakeholders to understand the issue within the Iraqi context regarding factors shaping refugee camps and the building characteristics of the existing shelters. The following key findings have been concluded from reviewing the literature:

Firstly, current literature show generally several numbers of data concerning displaced people globally. Moreover, the terminology of some widely used words in the field could refer mostly based on the reasons and destinations. Additionally, a group of people could not be counted under each category or on more than one based on the organization or attitude. Therefore, more specifications and accuracy for the terminologies of displaced groups of people are recommended in the literature. Consequently, addressing this subheading in the literature was important to clarify and get more understanding during picking terms and data regarding the field as for the context of this study, the term (Refugee) has been used for the displaced peoples from Syria to Iraq. Finally, as a result, more coordination seems recommended between such humanitarian organizations and stakeholders besides careful attention when investigating such a group of people.

Secondly, concerning shelter typologies and terms, several predominant examples of the various types of shelters used as post-disaster shelters for displaced people have been addressed. Moreover, the literature referred to their time to construct, cost, lifespan and general performance. Furthermore, it has been observed that some terms and typologies could have interconnected definitions or be overlapped in some literature. Additionally, several factors such as duration of displacement, size of displaced people, environmental and climatical conditions, an abundance of resources and geopolitical factors could determine the type of shelter. Also, it is recommended to adopt earth-based techniques as much as possible due to their efficient cost, durability and environmentally friendly method. Finally, based on the investigation in the available studies, the term (Core shelter) has been adopted for the shelters of this study context.

Thirdly, concerning addressing the issues in the displaced people camps and shelters, although it has to be concluded that due to their global significance, many institutions, scientific researchers, and involved entities continue investigating how to minimize the impact of displaced shelters issues and enhance the quality of life for humanitarian shelters and camps. However, current literature revealed several shortcomings that the built environment for the post-disaster shelters suffered from several important issues, especially concerning integrating them, such as:

- The short lifespan of the shelters compared to the displaced period.
- Inadequate planning and designing systems.
- Ignoring sociocultural aspects.
- Energy use sources and consumption.
- Indoor environmental issues.
- Environmental issues.

Therefore, implementing different strategies and methods is recommended to mitigate the impact of mentioned issues, enhance the quality of life for displaced people, and achieve sufficient, sustainable camps and shelters.

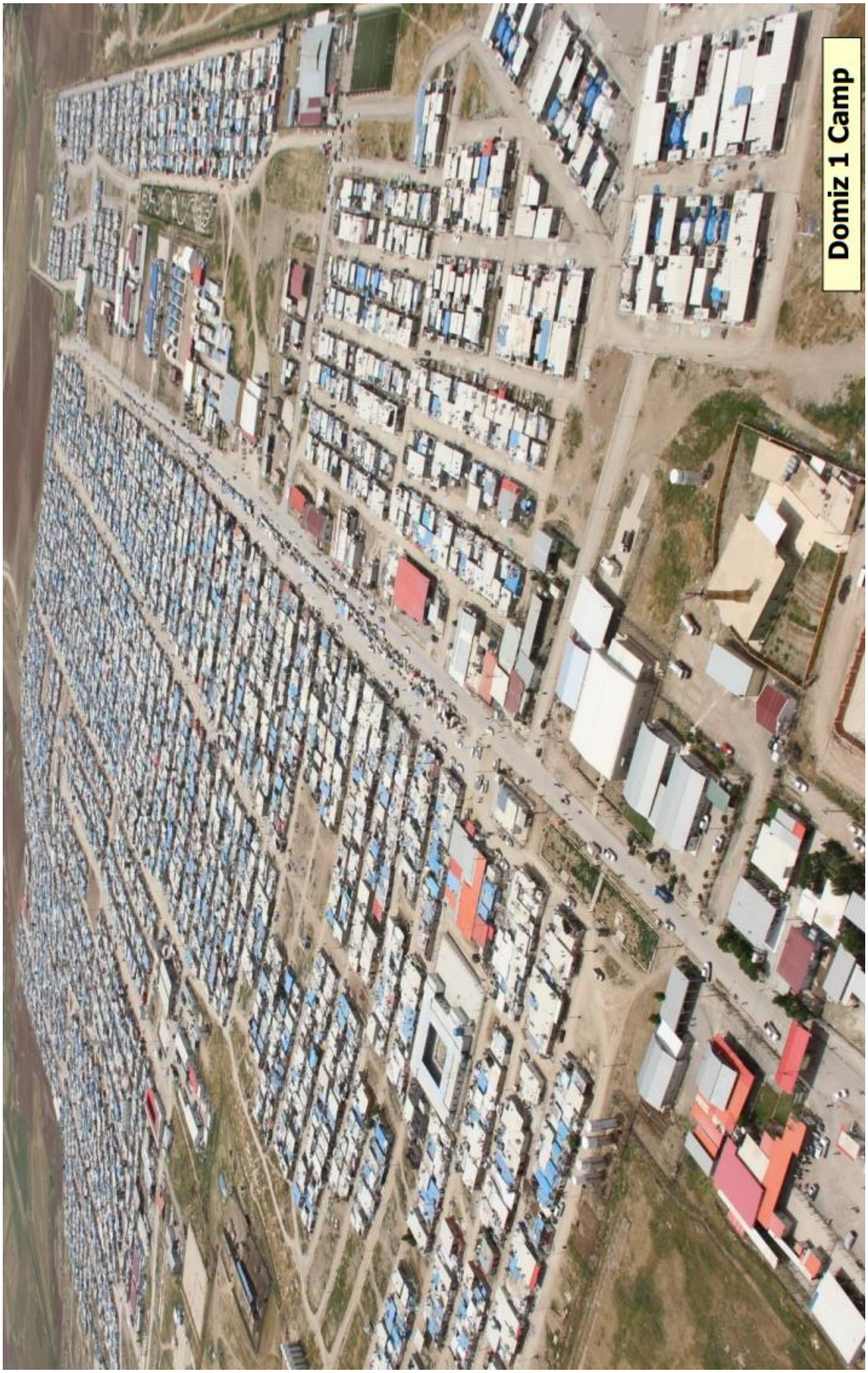
Consequently, studies concerning sustainable construction materials and methods have been addressed, focusing on several crucial factors in the post-disaster construction sector, such as longevity, affordability, and environmental performance. Moreover, two fundamental approaches have been investigated to address the three pillars of sustainability (environmental, social, and economic). At first, incremental strategy has been studied as a prominent strategy to find the solution for low-income, homeless and displacement issues. Their main aim has been identified to provide the basic functional shelter phase to be upgraded and improved later through other stages due to shortages in time, finances, and construction material resources. Therefore, this study concluded that the method suits their context while a horizontal upgrading and adaptability strategy has been targeted as more feasible for the context of this study, not as used in the case study (The Quinta Monroy project). Then, low-impact construction (LIC) in both methods has been addressed while the bottom-up approach has been targeted due to the cultural acceptance in the displaced people construction field and other advantages factors (cost, durability, and environmentally friendly). Moreover, several techniques have been identified as a bottom-up method, while an origin approach has been proposed by using three techniques (Cob, earthbags and strawbales) in one prototype wall, as referred to in the methodology of the next Chapter.

Finally, energy and indoor environmental performance as interconnected issue in the construction field has been studied and concluded that reducing energy consumption is a targeted approach even in developed countries due to their environmental impact. Moreover, it referred to the scarcity of power form in some developing countries, including KRI and Duhok city, as a targeted context, besides challenges in providing clean and sufficient power, cost, health, safety and environmental effect. Furthermore, the section concluded that energy demand and nonrenewable dependence sources and their consequences from cost and pollution could be avoided dramatically due to passively achieving thermal and indoor environment comfort through passive design strategies (building geometry, orientation and envelope) for light, ventilation, heating and cooling. Then, the section referred that the fundamental requirement of a comfortable environment is to keep thermal conditions and indoor air quality (IAQ) suitable for the residents since they directly impact their productivity, health, and morale. Finally, Fanger comfort model indicators (PMV, PPD) and carbon dioxide concentration level

(CO_2) and their important role in assessing building indoor comfort performance have been referred to be adopted in this research.

To conclude, the investigation of the existing literature found the answers to the above questions, informed the main approaches and scope to be followed besides identifying the bellow gaps for the next chapters (Chapters Three, Four and Five). The targeted strategies are to find feasible materials and methods for developing shelters' performance based on the durability (long life span through Core-shelter), affordability, and adaptability (incremental) factors considering the integration of the main above issues. Finally, the following gaps have been identified to be filled based on three self contains published studies [48][49][50] and presented individually in the next chapters (Chapters Three, Four and Five).

- Adopting the bottom-up construction method by utilizing a few sustainable low-impact materials and techniques in one prototype wall to develop the energy and thermal comfort performance for refugee core shelters in Duhok City, north of Iraq.
- Integrating the six main identified issues into the proposing new sustainable shelter typologies design and developing their energy use and indoor environmental performances.
- Propose three phases for designed typologies to prolong the lifespan, gives the opportunity to upgrade based on time, available cost, and need, and develop their energy and indoor environment performance.


Domiz 1 Camp

CHAPTER 3

ASSESSMENT the IMPACT of BOTTOM-UP CONSTRUCTION METHOD

3.1 Overview

As stated in the previous chapters, natural and man-made disasters are vital issues that led to the increasing number of displaced people worldwide. Similarly, these factors led a country like Iraq to be one of the world's major countries plagued with IDPs and refugees. Likewise, in the Kurdistan Region of Iraq (KRI), geopolitical factors and the strategic location near the border of Syria, Turkey and Iran made the people live displaced issue either to be refugees or hosts them. For instance, the Board of Relief and Humanitarian Affairs (BRHA) in Duhok City, north of Iraq, quantified in its annual report for 2018 [90] that 616625 IDPs and refugees live in Duhok province distributed in 66645 shelters including tents, caravans and rooms (Figure 3-1). Globally many migrants stay displaced for decades and live in inefficient and uncomfortable transitional and temporary shelters, which normally carry a high burden on the environment and host countries and displaced people and cost billions of dollars annually due to their short lifespan [25,26].

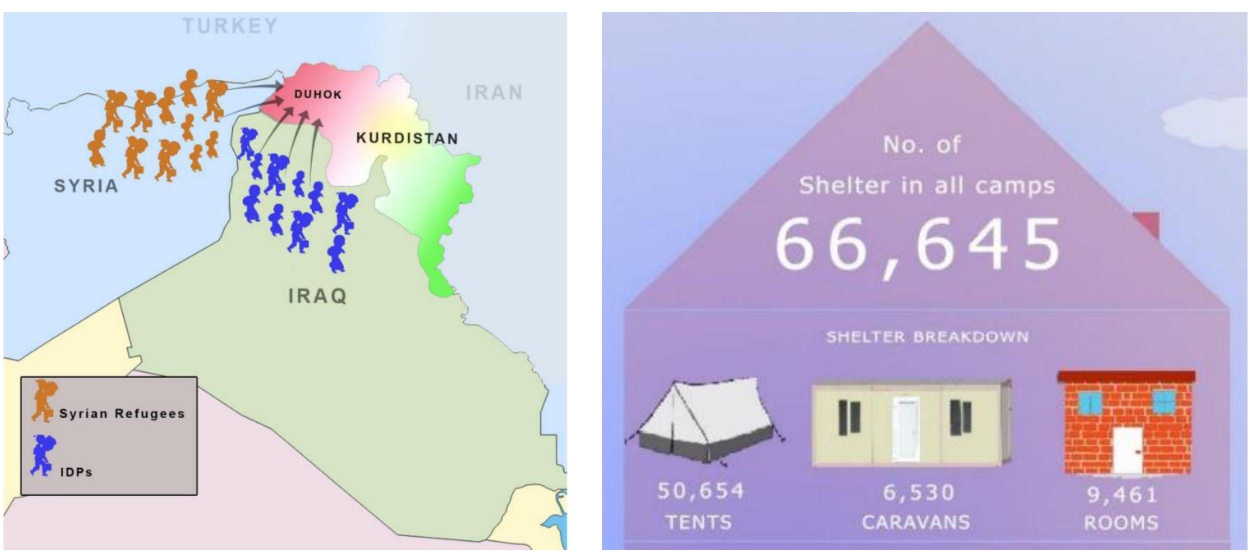


Figure 3-1 *Source of Displaced people, types and number of shelters in Duhok* [90][91]

Consequently, based on the mentioned problem findings from an increasing number of displaced people, the short lifespan of shelters, and the environmental and energy challenges. This chapter's study question was, what is the current condition performance of shelters based on conventionally used materials in Iraq, and is there any other construction method that could offer the opportunity to prolong the lifespan and enhance their energy and thermal comfort performance? The study investigated the method that comprises more comfortable, flexible and affordable permanent shelters. Therefore, this study aimed to develop the energy and thermal comfort performance for core shelters through the bottom-up construction method since such a method is culturally more acceptable due to the self-construction involvement of displaced people, locally sourced materials, durability, minimum environmental impact, and efficient cost. Furthermore, for affordability and adaptability reasons, the study adopted a novelty by exploiting a few low-impact materials and methods on one prototype.

Regardless of the overview for the problem statement, focus, question, aim, novelty and contribution of the study in this section, the next section demonstrates data collection and processing analysis methods, followed by the energy and thermal comfort assessment in the result section and finally concludes with a discussion and main findings section. Dynamic simulation tool Indoor Climate and Energy (IDA ICE 4.8) has been used to assess nine different scenarios' performance. The results quantified that the annual heating-cooling energy and thermal comfort accepted hours of proposed scenario nine (C1S9) with adopting LIC materials throgh the bottom-up method are better than base-case scenario one (C1S1) with conventional materials by 85% kWh and 4215 hours, respectively. Furthermore, the bottom-up method proposed scenario (C1S9), compared to the base case scenario (C1S1) built with conventional materials, shows an opportunity to save energy up to 10000 kWh per unit per year, equivalent to almost 2500 USD savings in energy bills. Even the chapter's context focused on Syrian refugees' core shelters in Duhok City, north of Iraq, while the methodologies and results of this study can be adopted and applied to various places of the world affected by migration issues.

3.2 Methodology

3.2.1 Methods Description and Conceptual Framework

This Chapters study question is, what is the current condition performance of shelters based on conventionally used materials in Iraq, and is there any other construction method that could offer the opportunity to prolong the lifespan and enhance their energy and thermal comfort performance? Based on the four fundamental steps to do scientific research, this study has been done as shown in the conceptual framework flow chart in Table 3-1 to answer the study question and achieve its aim. The qualitative approach was used for exploring, describing, and interpreting through a literature review, conducting and consultation with stakeholders, case studies, and observation. However, the quantitative method was applied through Excel software calculation and simulation software assessment to prepare, analyze, and assess performance. Although the investigation generally started to follow the literature regarding displaced people shelters, the study's targeted objective was exposed in the processing step. The analysis and preparation scenarios are organized for the reason of development, and the selected scenarios were simulated to assess the performance of prototypes.

Table 3-1 Conceptual framework for investigating the impact of the Bottom-up method

1-Data collection	• Literature review • BRHA (Board of Relief and Humanitarian Affairs) • Observation	
2-Data processing	Cases studies: Typologies, techniques, materials and performance Core shelters	
	Top-down method	**Bottom-up method**
3-Instrument development	Analyzing, preparing and comparing prototypes	
4-Simulation tool	Assessing performance via simulation software program (IDA-ICE)	

3.2.2 Data Collection and Processing

The study began investigating the context and literature regarding post-disaster shelter typologies, techniques, materials, and performance. The context of the study firstly has focused on the displaced people shelters in Duhok City in KRI. The collected data consisted of primary data, such as observation, and secondary data, such as conducting and consultation with stakeholders, in addition to a literature review. Furthermore, several challenges were faced regarding permission and access to the cases, such as security considerations and a strict long routine to obtain raw data and visit camps. Hence, the data regarding the case studies were gathered by conducting the BRHA in Duhok City. In addition, concerning ethical considerations, stakeholders were informed about the purpose of the study.

The main aim of this study has been exposed in the processing stage after a general and depth investigation of previous literature and the conduction with (BRHA) in Duhok City. As a result, the study tended to adopt affordable strategies, long lifespan, adaptability, weather resistance, community involvement, thermal comfort and energy consumption factors. Consequently, LIC materials and techniques through the bottom-up method have been targeted for this study as a more feasible approach [28,31] for the factors mentioned above.

Regarding the case size, it was targeted to host a family of five people, as an average household size in the Kurdistan Region of Iraq (KRI) and a more typical size in the camps [92]. Therefore, this study's selected core shelter case was Syrian refugee shelters in Domiz-one Camp with End-of terraced (ET) position in a rectilinear grid layout system with an area of 50 m^2 (5 m×10 m) and a height of 2.6 m. The selected Case (Case 1) includes few spaces, such as, a bedroom for parents, a living room to be a bedroom for three kids at night, a kitchen and a bath, including a toilet (Figure 3-2). The materials which have been used are solid concrete block with a width of 15 cm for the walls and are plastered with rendered concrete 2 cm, plastic doors and windows, concrete floor and zinc sheets or sandwich panels in some instances for the roof (Table 3-2).

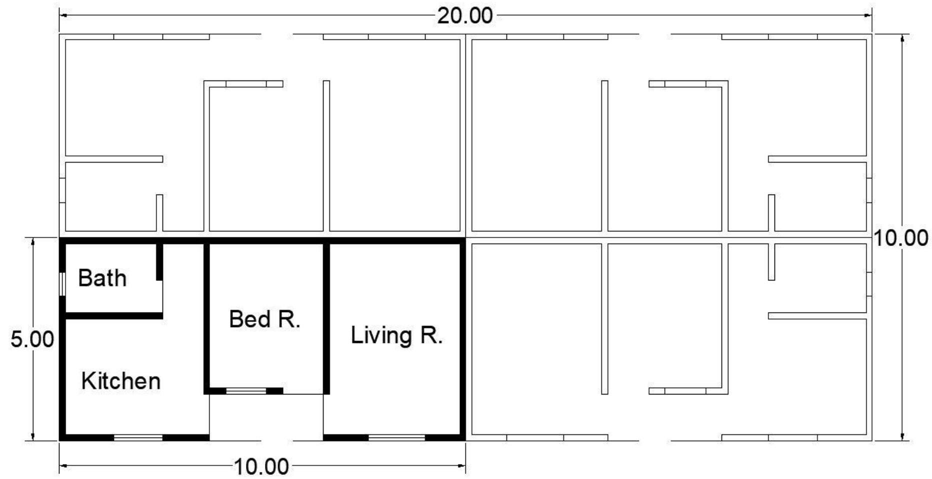


Figure 3-2 *Domiz-one refugee core shelter, Base case floor plan (Case 1)*

3.2.3 Data Analysis and Evaluation Process

Several procedures have been done to prepare for the prototype evaluation process. First, a few of LIC materials and techniques have been selected, such as straw-bales, cob, and earth-bag for walls. Then, a mixed strategy for the roof was chosen with wood, straw, and soil (WSS) as locally available and widely used by rural communities. Later, based on the database of the software and other literature, the physical properties of the selected materials were reviewed to determine the U value (thermal transmittance) [93-95]. Subsequently, nine scenarios have been prepared to assess its performance (Table 3), first and second scenarios (C1S1, C1S2) represented base model references components. Finally, for affordability and adaptability factors and to make it easy to expand shelter from 50 m^2 to 100 m^2 and prolonged life-span, a few low-impact materials have been proposed for one single prototype wall, as shown in scenario nine (C1S9) Table 3-2.

The reason behind using triple materials for one prototype wall is that it is not easy to build thousands of shelters with one material during a displacement disaster. Additionally, It allows building a shelter with more than one material in different incremental stages. Furthermore, straw and earthen materials are the most abundant low-impact materials in the region, as they are easy and fast to build with the involvement of the displaced people. Finally, the high quality of the techniques regarding the high thermal mass of the earth-bags and the high insulation factor of straw-bales was proposed for the upgrading stage.

Table 3-2 Materials thermal transmittance (U value) and scenario components

Materials	U value (w/(m².k)	Materials	U value (w/(m².k)	Materials	U value (w/(m².k)
Zinc roof	5.88	Concrete blocks wall	15 cm = 3.24	PVC door = Door 1	2.0
Sandwich panels roof	0.44	Earth-bags wall	40 cm = 0.57	Wood door = Door 2	0.54
Wood + Straw + Soil = (WSS) roof	0.26	Cob earth wall	15 cm = 1.86 30 cm = 1.17	One pane glazing = Window 1	5.8
Lightweight concrete floor = F1	0.85	Straw-bales wall	30 cm = 0.14 40 cm = 0.10	Double pane glazing = Window 2	2.9
Case one (C1) Scenarios	**Components**				
Base model scenario 1 (C1S1)	Zinc roof + Concrete blocks wall + F1 + Window 1 + Door 1				
Base model scenario 2 (C1S2)	Sandwich panels roof + Concrete blocks wall + F1 + Window 1 + Door 1				
Scenario 3 (C1S3)	Wood + Straw + Soil (WSS) roof + Concrete blocks wall + F1 + Window 1 + Door 1				
Scenario 4 (C1S4)	Cob earth wall + Zinc roof + F1 + Window 1 + Door 1				
Scenario 5 (C1S5)	Earth-bags wall + Zinc roof + F1 + Window 1 + Door 1				
Scenario 6 (C1S6)	Straw-bales wall + Zinc roof + F1 + Window 1 + Door 1				
Scenario 7 (C1S7)	Zinc roof + Concrete blocks wall + F1 + Window 2 + Door 2				
Scenario 8 (C1S8)	Best Roof (WSS) + Best Wall (Straw-bales) + F1 + Window 2 + Door 2				
Scenario 9 (C1S9)	Best Roof (WSS) + Proposed variation wall (Cob earth + Earth-bags + Straw-bales) + F1 + Window 2 + Door 2				

3.2.4 Modelling Tool and Input Parameters

For assessing the performance of the nine scenarios in Table 3-2 relating to base-case 1 (C1), the study utilized the simulation program Indoor Climate and Energy IDA ICE 4.8 (Figure 3-3). The software is licensed to the Faculty of Engineering and Information Technology, University of Pécs in Hungary and it is innovative and has a high accuracy to assess indoor comfort and energy performance [96][97]. Concerning the assessed position and orientation, south orientations with End-of Terraced (ET) were specified for all nine models. Later, the set points for the cooling and heating temperature controller levels were identified as 26 °C and 18 °C as a standard for the comfort level [28]. In contrast, the central air handling unit (AHU) for mechanical ventilation was absent (depending on the passive system). Furthermore, the set point for domestic hot water (DHW) specified 30 letters per person daily. Concerning heat gains, occupants' activity level is set at 1.0 MET and constant clothing 0.85 ± 0.25 CLO to be automatically adapted between limits to obtain comfort. Concerning occupancy time, several schedules were identified, as shown in Table 3-3. Finally, the simulations were run under annual processes (1 January–31 December) application for all nine prototypes scenarios.

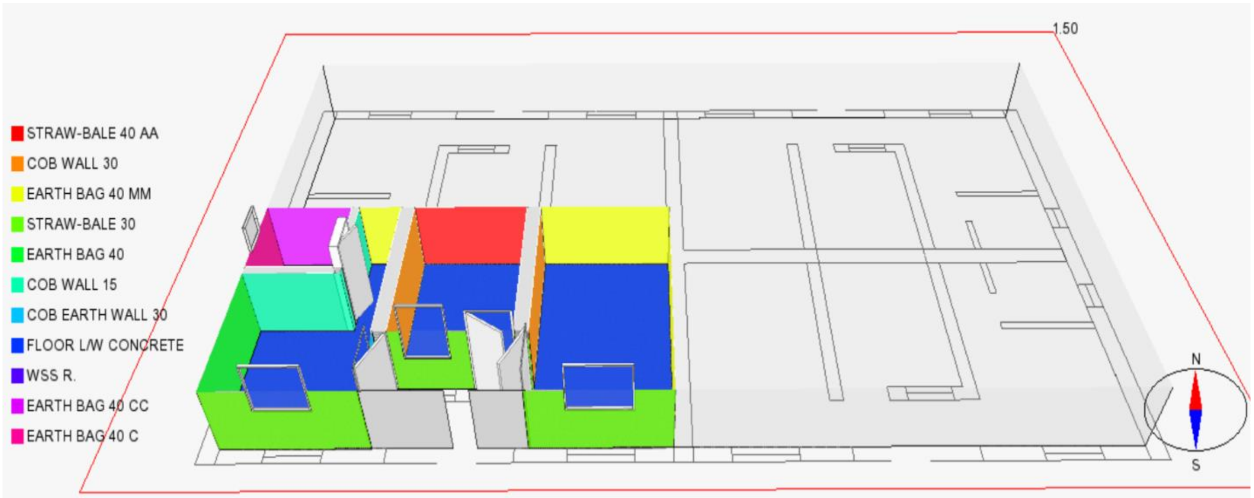


Figure 3-3 *Simulation model for the targeted proposed scenario (C1S9)*

Table 3-3 Prototypes spaces and occupancy time schedules

Spaces and Occupants	**Occupancy Time**
Bedroom for two people	No one present (7:00–13:00, 15:00–21:00), one present (13:00–15:00), otherwise fully present
Living room for three people	One present (8:00–12:00, 14:00–17:00), otherwise fully present
Living room for two people	No one present (21:00–7:00) one present (7:00–7:30, 8:00–12:00, 12:30–13:00, 15:00–18:00), fully present (7:30–8:00, 12:00–12:30, 18:00–21:00)
Kitchen for one person	No one present (18:00–7:00, 7:30–11:30, 12:00–12:30, 13:00–17:30), otherwise fully present
Bath for one person	One present (6:30–7:00, 12:30–13:00, 17:30–18:00), otherwise no one

3.3 Results

3.3.1 Energy Assessment

Delivered energy in the simulation tool comprises several categories: lighting facility, Domestic Hot Water (DHW), equipment tenant, fuel heating and electric cooling. However, to simplify the comparison of the estimated results, fuel heating and electric cooling results have been focused on separately and introduced in Figure 3-4 due to the vast similarity in the results for the other three classes. After estimating the performance of the first seven scenarios (C1S1-C1S7) consequently, the best-performed roof (WSS roof) and the best-performed wall (straw-bales wall) have been chosen for C1S8 while a set of low-impact materials for walls (Cob earth + Earth-bags + Straw-bales) with WSS roof have been selected for targeted scenario nine (C1S9).

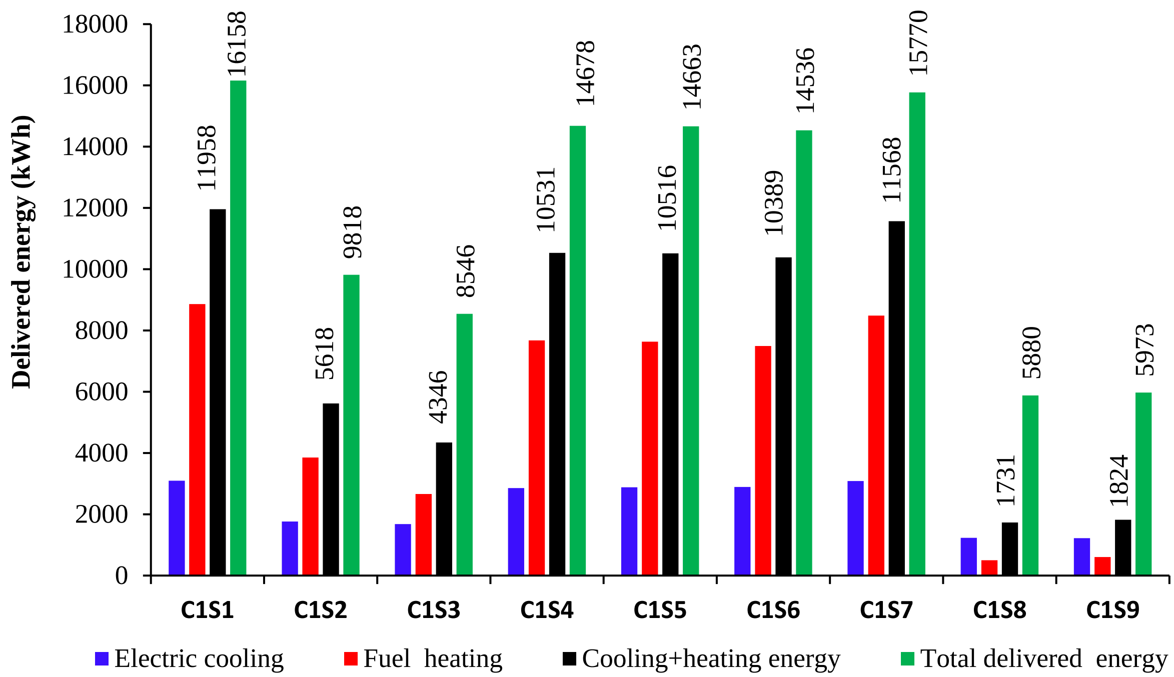


Figure 3-4 *Energy performance assessment for nine different scenarios*

Fuel heating energy demand for the first seven scenarios is almost double or more compared to cooling energy demand conversely to the last two scenarios (C1S8, C1S9). For example, the estimated heating energy ratio to the total heating-cooling energy for the first base scenario C1S1 is 74%, for the second base case C1S2 represents 68.64%, while for the C1S8 and C1S9, are 28.88% and 33.12%, respectively. Undoubtedly that is due to the high thermal insulation factor of LIC materials and specifically straw-bales material, compared to other conventional materials like concrete block walls and zinc roofs, besides the good thermal mass quality of earthen materials (cob and earth-bag).

Although the total cooling and heating energy saved compared to the first base case (C1S1) is 53% and 64% for C1S2 and C1S3, respectively. Additionally, for C1S4, C1S5 and C1S6, approximately the same ratio of 12%, 12% and 13%, respectively. However, S8 and the targeted prototype C1S9 saved about 85.5% and 85% compared to the C1S1. Furthermore, concerning the quantified energy value as 1 USD for 4 kWh based on the recent policy reform announced by the Kurdistan Regional Government (KRG) concerning energy pricing [98]. Consequently, there is a possibility to save energy by the bottom-up method proposed scenario (C1S9), compared to the base case scenarios (C1S1 and C1S2) built with conventional materials, by 10000 and 3800 kWh per unit per year, equivalent to almost 2500 and 950 USD savings in energy bills.

3.3.2 Thermal Comfort Assessment

The accepted and unaccepted hours have been focused on in Table 3-4 to compare the thermal comfort performance assessment for all scenarios. The process concentrated on three main spaces living room with a total number of occupancy hours 8760, a bedroom with 4380 hours and a kitchen with 730 hours annually, with the entire occupancy hours being 13,870. However, bathes results have not been introduced due to the big similarity in all scenarios.

Table 3-4 Estimated thermal comfort performance (accepted and unaccepted hours)

Scenarios	Living room		Bedroom		Kitchen		**Summation accepted hours**
	Accepted hours	Un accepted hours	Accepted hours	Un accepted hours	Accepted hours	Un accepted hours	
C1S1	5550	3210	2118	2262	449	281	8117
C1S2	7784	976	3412	968	444	286	11640
C1S3	7924	836	3515	865	449	281	11888
C1S4	5454	3306	1910	2470	437	293	7801
C1S5	5336	3424	1809	2571	434	296	7579
C1S6	5231	3529	1664	2716	437	293	7332
C1S7	5649	3111	2180	2200	452	278	8281
C1S8	7009	1751	4259	121	553	177	11821
C1S9	7487	1273	4299	81	546	184	12332

Results revealed that the proposed targeted scenario (C1S9) is the best, with 12,332 of the number of accepted hours, equivalent to 88.9% of annual occupancy hours, while the worst scenario is C1S6, with 7,332 hours equivalent to just 52.9%. Furthermore, regarding first and second base case scenarios C1S1 and C1S2, they performed 58.5% and 83.9%, respectively, while C1S3 and C1S8 performed almost the same with 85.7% and 85.2%, respectively. Finally, the number of accepted hours for the other three scenarios, C1S4, C1S5 and C1S7, are 56.2%, 54.6% and 59.7%, respectively, compared to the annual occupancy hours.

Although the number of unaccepted hours for the best-performed scenario (C1S9) regarding thermal performance is 1538 hours from 13870 annually, it is better than C1S1, C1S2 and C1S7 by 4215, 692 and 4051 hours annually. Moreover, it is better than C1S4, C1S5 and C1S6 by 4531, 4753 and 5000 hours annually. Finally, both scenarios C1S3 and C1S8 are performed well compared to the best scenario C1S9 while, C1S9 is still better than them by 444 and 511 hours annually due to the good thermal mass of the materials for C1S9 compared to both C1S3 and C1S8.

3.4 Discussion and Conclusion:

Globally many refugees stay displaced for decades and live in inefficient and uncomfortable transitional and temporary shelters, which normally carry a high burden on the environment and host countries and displaced people and cost billions of dollars annually due to their short lifespan. Consequently, This chapter's study question was, what is the current conditions performance of shelters based on conventionally used materials in Iraq, and is there any other construction method that could offer the opportunity to prolong the lifespan and enhance their energy and thermal comfort performance? As a result, the study investigated the method that comprises more comfortable, flexible and affordable permanent shelters. Therefore, the chapter study aimed to develop core shelters' energy and thermal comfort performance through the bottom-up construction method due to their high level of satisfaction by displaced people. Furthermore, for affordability and adaptability reasons, the study adopted a novelty technique by exploiting low-impact materials and methods on one prototype (C1S9). Dynamic simulation tool Indoor Climate and Energy (IDA ICE 4.8) has been used to assess nine different scenarios' performance.

The findings revealed firstly that the conventional construction materials and methods used in building refugee shelters in Iraq lead to high rates of indoor thermal discomfort and energy consumption, with heating demand being two to three times that of cooling demand (C1S1). At the free-running stage, the mean indoor operative temperatures remain between 32 to 35 °C and 10 to 12 °C during summer and winter periods respectively. Shelters built with corrugated metal roofing (zinc), which are the predominant shelters (C1S1), would require 220 kWh/m^2 and 77 kWh/m^2 for heating and cooling respectively, whilst those built with insulated roof sandwich panel (i.e. an 8 cm layer of the insulating board, skinned on both sides with sheet metal) (C1S2) would require 96 kWh/m2 and 44 kWh/m^2 for heating and cooling respectively.

The next finding is that, by application of the novel mixed technique (C1S9) as triple techniques in one single shelter wall from low-impact and thermally efficient materials, such as earth-based materials and straw, which are locally available and widely used by rural communities, can be remarkably reduced the energy consumption and enhance indoor thermal comfort. Conversely to conventional materials, such a technique greatly impacts reducing heating much more than cooling. For instance, it would require 17 kWh/m^2 and 34 kWh/m^2 for heating and cooling respectively. Additionally, the total cooling and heating energy that could be saved compared to the first base case C1S1 (corrugated zinc metal roofing) is 85%, and compared with the second base case C1S2 (insulated sandwich panel) is 67.5%. Moreover, the thermal comfort accepted hours ratio for the adopted technique C1S9 is about 90%. Regarding energy and cost implications and compared with the base case scenarios with conventional materials, this method can save energy by more than 10000 kWh in simply one case, equivalent to more than 2500 US dollars annually. Consequently, in a camp scale such as Domiz-one with around 5500 shelters, saving about 55 000 mWh, equivalent to 13 750 000 US dollars annually is possible.

The study has a limitation concerning calibration via in-site measurements data or another simulation program; this was due to the strict security routine to access camps and data in the real site, besides the lack of access to another free simulation program and lack of sufficient time to learn and repeat the evaluation of all scenarios. However, even the chapter's context focused on Syrian refugees' core shelters in Duhok City, north of Iraq, while the methodologies and results of this study can be adopted and applied to various places of the world affected by migration issues. The next chapter study tends to design typologies based on the socio-cultural context, then assess their layout and sitting impact on the energy and indoor environment performance. Additionally, it adopted the targeted construction method in (C1S9) as a base case (C1) to be compared with other designed layout typologies. Finally, the impact of orientation has been assessed to identfy the best orientation and be established for the last step of investigates (Chapter five).


Dawidiya Camp


Rawanga Camp (Qadya)

CHAPTER 4

DESIGNING SUSTAINABLE REFUGEES SHELTERS TYPOLOGIES

4.1 Overview

Inefficient and unsustainable construction approaches for displaced people shelters globally have resulted from improper planning and design systems regarding lifespan and socio-cultural aspects. Therefore, this Chapters study is a successive process continuing the previous chapter's investigation, and their questions are what methods must be taken to design and propose new sustainable shelter typologies, and which layout system performs better? Additionally, what is the impact of orientation on the designed refugees shelters' performance? At present, accomplishing sustainable prototypes for displaced people should involve several factors such as lifespan, socio-cultural and affordability (refugees and host countries can afford them), thermal performance and energy-efficient, local planning and designing systems, and environmental impact. However, those factors have not yet been integrated into the previous literature. Therefore, the original contribution of this chapter is integrating the above elements by proposing comprehensive prototypes typologies for the refugee's core shelters (open to yard and compact, horizontal and vertical set, separated spaced or studio layout one) and considering the socio-cultural (based on the Middle East cultural context) and local planning and design systems in Duhok City north of Iraq.

This chapter's study aim has the incentive to assess the impact of the morphological, siting, and layout of shelters for the long-term displacement prototypes considering sustainability concepts from social context, affordability, adaptability, low-impact construction materials, and techniques. Additionally, it aimed to assess the impact of orientation on the performance of designed cases. Furthermore, applying the dynamic simulation IDA ICE 4.8 tool was cardinal to justify the comprehensive reported outcomes based on the bottom-up construction method after assessing energy and indoor environmental performance in the six designed cases (Cases 2,3,4,5,6 and 7) beside the base case (C1) from the previous chapter. It likewise evaluates the impact of orientation on the performance of six designed Cases through eight different cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions. Additionally, This chapter study adopted the targeted construction method (C1S9) in the previous chapter as a base case (C1) to be compared with other designed layout typologies in this chapter.

The energy performance assessment regarding heating reveals the superiority of the compact layout plan system, while the open layout plan system is superior for the evaluation of the cooling. Concerning thermal comfort performance for the number of accepted hours category, the open layout plan system is superior. Fanger indicators for thermal comfort assessment demonstrated the superiority of the horizontal sit compact layout plan scheme. However, the carbon dioxide (CO_2) concentration level assessment shows that the open yard layout cases have better results than other systems. Finally, for identifying the impact of orientation, the results revealed the superiority of south orientation (S) above others.

In conclusion, this chapter's findings revealed that layouts have a different impact on shelters' performance, with compact forms having more superiority in energy saving and providing better indoor thermal conditions. For instance, there is a possibility to keep the heating consumption below 2.5 kWh/m^2 for the compact case (C5), a figure equivalent to almost 85% saving in heating fuel compared to the base case with an open to yard layout system (C1), this is besides keeping cooling consumption below 23 kWh/m^2. Meanwhile, open to yard layout shows more superiority in terms of air quality.

Apart from the overview of the problem statement, focus, question, aim, novelty and contribution of the study in this section, the next section demonstrates data collection and processing analysis methods, followed by the energy and indoor environment performance assessment besides assessing the impact of orientation in the result section and finally concludes with a discussion and main finding section. In conclusion, sustainable prototypes for displaced people should involve several aspects such as lifespan, socio-cultural, indoor environment and energy-efficient performance, and environmental impact. The beneficiaries from the methods and the results of this study would be firstly the Syrian refugees and low-income in the Middle

East context, then various places in the world which involved people affected by the displacement issue.

4.2 Methodology

4.2.1 Methods Description and Conceptual Framework

This Chapters study is the successive process continuing the previous chapter's investigation. The methodology processed to find an answer for this chapter study questions which is: what methods must be taken to design and propose new sustainable shelter typologies, and what layout system performs better? Additionally, what is the impact of orientation on the designed refugees shelters' performance? Varied methodological approaches were adopted to answer the study questions and achieve its aim. The qualitative method was used for exploring, describing, and interpreting through literature review, conducting authorities, case studies, site visits, and observation. However, the quantitative method was applied through Excel software calculation and simulation software assessment to prepare, analyze, and assess performance. The four essential scientific steps were considered to create the study’s conceptual framework, as shown in Table 4-1

Table 4-1 Conceptual framework for designing and assessing shelters typologies

Data collection	
<u>Data sources</u> • Literature review • Conducting stakeholders • Case studies and site visit • Observation	<u>Data types</u> • Typologies • Techniques • Materials • Performance • Documentation data

Data processing	
<u>Finding study problems</u> • Energy consumption issues • Thermal comfort issues • Lifespan issues • Planning and design issues • Socio-cultural issues • Environmental issues	<u>Processing factors</u> • LIC and bottom-up method • Selection of cases • Planning and designing investigation • Materials selection • Comparison of scenarios

Instrument (prototype) development

- Planning and designing considerations
- Designing and preparing prototypes
- Assessing case performance
- Assessing the impact of orientation

⇕

Application of simulation tool (IDA ICE)

- Setting location and orientation
- Setting points
- Setting schedules
- Running simulations

4.2.2 Data Collection

The study began by understanding the context and literature regarding post-disaster shelter typologies, techniques, materials, performance, and documentation. The collected data consisted of both primary data, such as site visits and observation, and secondary data, such as conducting and consultation with authorities, in addition to a literature review. Concerning the study sample cases, the research context selected Syrian refugee shelters in Duhok City in northern Iraq. However, several challenges were faced regarding permission and access to the Cases, such as security considerations and a strict long routine to obtain raw data and visit camps. Hence, the data regarding the first base case (Case 1) were gathered by conducting BRHA in Duhok City to investigate the impact of the bottom-up method application. While later, to explore more and understand the effect of morphology, zones sitting, typologies layout, and context of the cases, several refugee camps were studied, and one of the camps was accessed. Therefore, Domiz-one (Figures 4-1 and 4-2) was visited as Iraq's most prominent refugee camp with core shelter cases.

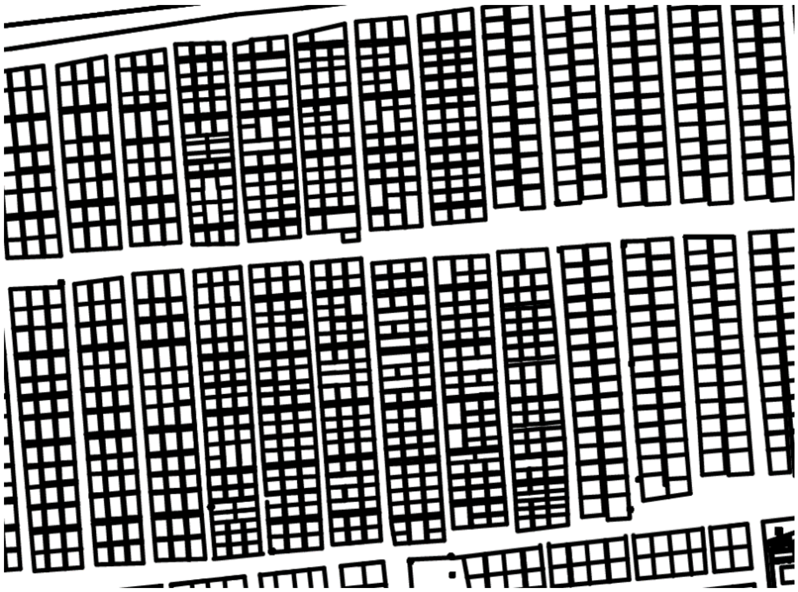


Figure 4-1 *Planning blocks layout in Domiz-one refugee camp*

Concerning ethical considerations, the identities of shelter owners remain anonymous. Likewise, photos were taken so that none of the refugees appeared as a significant consideration by authorities and camp administration, as is evident in Figure 4-2. Additionally, refugees and authorities were informed about the purpose of the study.

Figure 4-2 *Domiz-one refugee camp typical core shelters. (Source Author)*

Data associated with seven core shelter typologies were investigated and observed to answer the study question. Moreover, data relating to the urban planning system and block layout were obtained through direct conduction with the General Directorate of Urban Planning and Municipality in Duhok City. Eventually, the typical planning systems were illustrated via AutoCAD and SketchUp drawing programs, as shown in Figure 4-3.

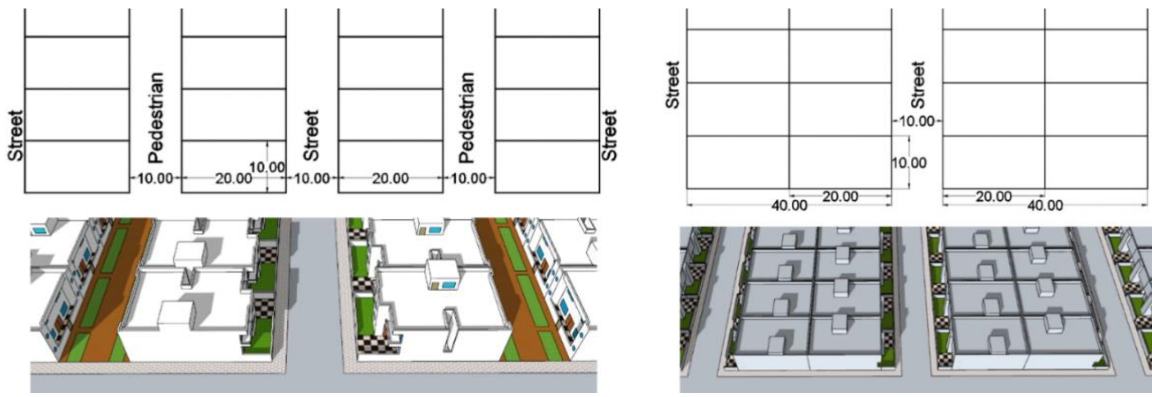


Figure 4-3 *Typical urban planning blocks layout in Duhok city.*

4.2.3 Data Processing

Several problems were detected after the critical investigation, site visit and observation, and data processing for the post-disaster shelter issues. The most prominent issues are the shelters' energy consumption and occupants' thermal comfort. Following these, the short lifespans of shelters compared with the displaced period is another critical issue regarding sustainability. Further issues include planning and designing system considerations, such as creating isolated spaces and units without an integrated option, inequality in plot sizes, irregularity, diversity, and randomization in sitting blocks, and designing shelters (Figures 4-1 and 4-2). Furthermore, the socio-cultural factor regarding privacy and behavior is a crucial issue. Subsequently, the environmental issues are the significant consequence of the mentioned issues and their consequences problems.

Following identifying problems, the procedures and analyzed process required several considerations. Firstly, the targeted scenario (C1S9) from the previous chapters as low-impact construction (LIC) technique specified in the bottom-up method was suggested as a more flexible, durable, and affordable technique for designed Cases. Then, regarding the case size, it was targeted to host a family of five people, as an average household size in the Kurdistan Region of Iraq (KRI) [92] and a more typical size in the camps. Later, cases with an area of 50 m^2 (5 m ×10 m) were targeted and prepared to follow the typical planning system in Duhok city even in the future expansion stage with 100 m^2 (10 ×10 m), as shown in Figures 4-4, 4-5 and 4-6.

4.2.4 Instrument (Prototypes) Development

Regarding planning schemes, the six assessed designed cases with proposed planning block systems were derived from the conventional typical planning system in Duhok City as a Terraced system [99]. However, the most familiar system in the Domiz-one camp for Cases 1 and 2 (Figure 4-4) was prepared to be fixed in a planning block system with dimensions 10×20 m as an end-off Terrace unit with two façade sides initially, then semi-detached after a future expansion stage. On the other hand, Cases 3, 4, and 5 (Figure 4-5) were designed to fix in the planning block system with dimensions 10 ×40 m as an attached system for the central units with a single-side façade firstly, followed by two opposite-side façades after upgrading. Furthermore, as a sustainable consideration and not to consume land concerning extreme urban sprawl, both Cases 6 and 7 (Figure 4-6) were designed to fix the planning block system with dimensions 20×40 m as an attached system for the central units with a single façade side even in a future expansion stage.

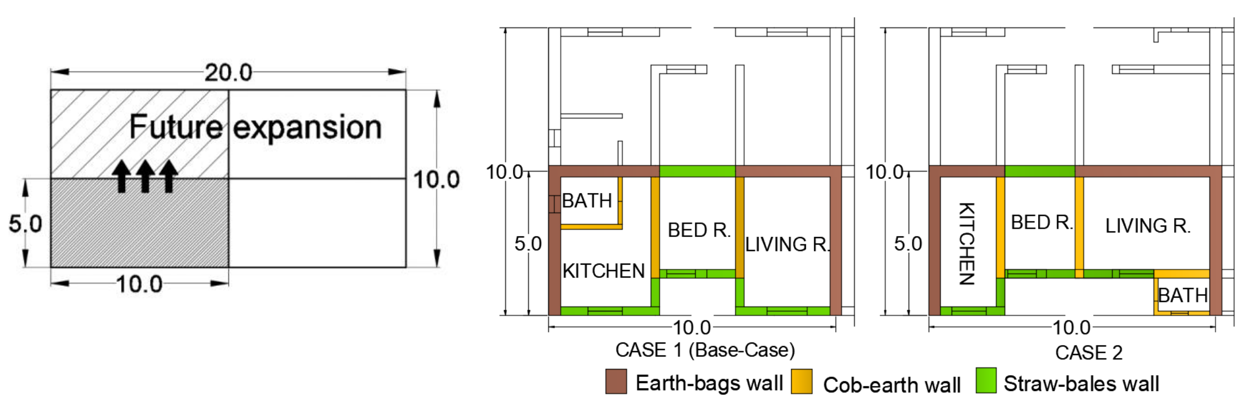


Figure 4-4 *Cases 1 and 2 with the layout-block planning system.*

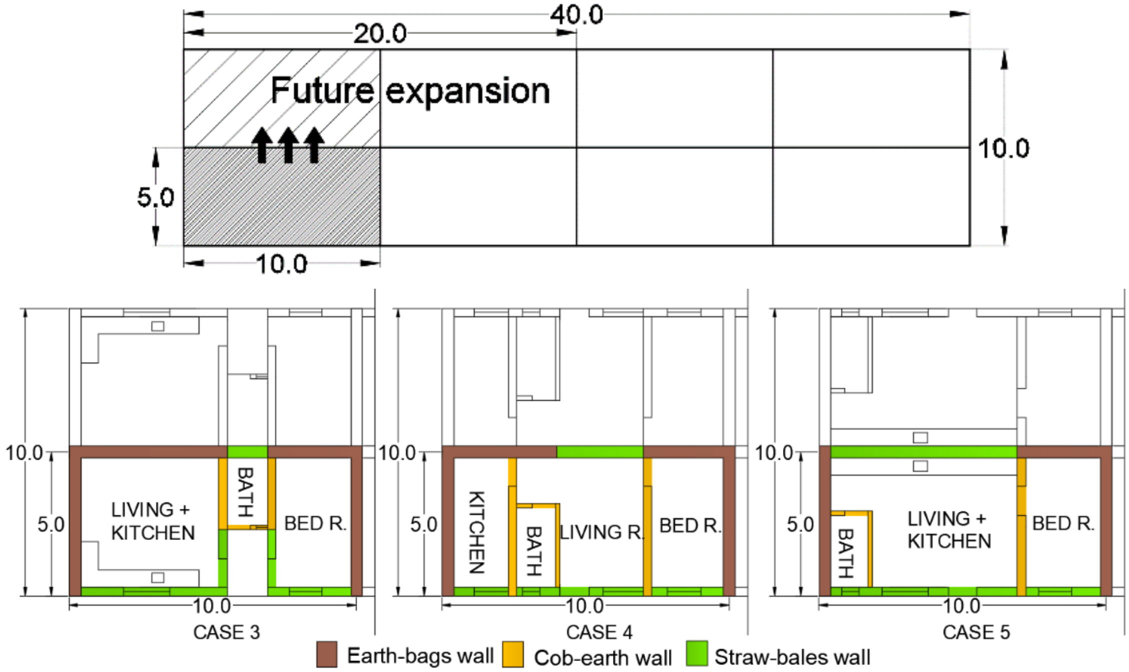


Figure 4-5 *Cases 3, 4, and 5 with the layout-block planning system.*

Concerning designing prototypes, several factors were considered after the site visit, conducting authority, and observation process.

- The first design factor is locally called the eastern or open to yard layout design system (Cases 1, 2, and 3) and the western or compact layout design system (Cases 4, 5, 6, 7).
- The second factor is an open spaces plan or studio (Cases 3, 5, 7) and a close or separate space plan (Cases 1, 2, 4, 6) pattern design.
- The other design factor is a horizontal plot layout design (Cases 1, 2, 3, 4, and 5) and a vertical plot layout design (Cases 6, 7).

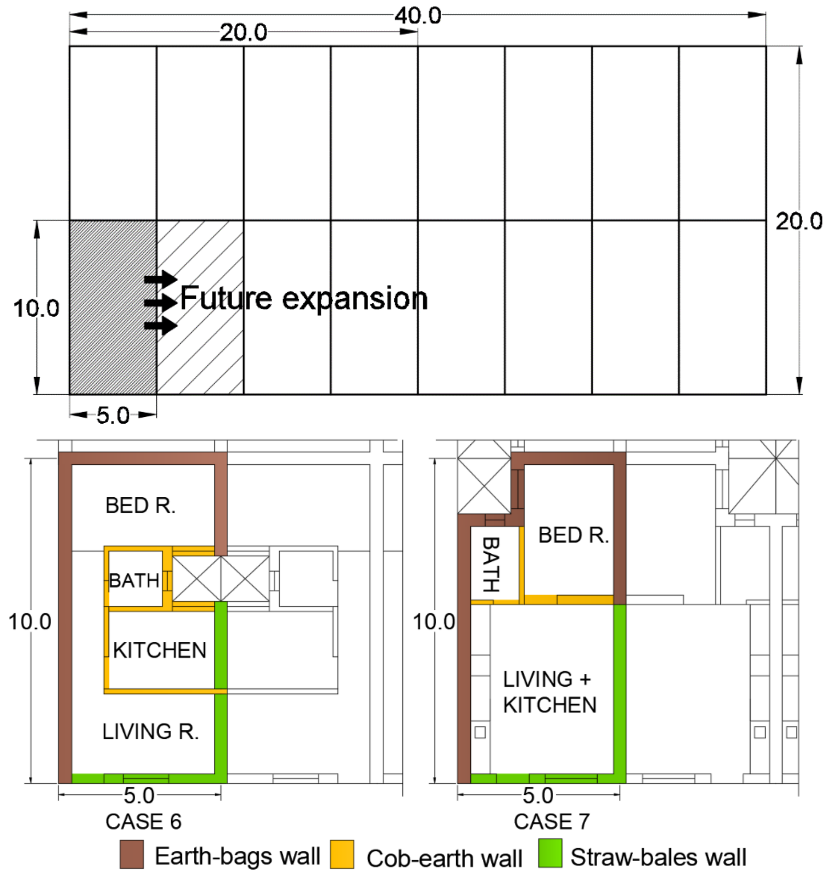


Figure 4-6 *Cases 6 and 7 with the layout-block planning system.*

In the final stage, the annual performance of the cases was simulated and assessed through energy and Indoor environment comfort. Regarding energy performance, various categories were taken under the total delivered energy assessment: electric cooling, fuel heating, equipment tenant, lighting facility, and domestic hot water (DHW). The adopted indoor environmental comfort categories were accepted hours ratio, PMV and PPD, and CO_2 concentration level.

The total categories were assessed once to reveal the entire performance concerning the energy evaluation, while this was not possible regarding thermal performance assessment due to the variety in the number of zones, areas, and occupation hours. Consequently, Equation (1) was derived from another scientific study [100] and applied via Excel software calculation to identify the representative summation ratio and average hours level.

$$\mathbf{N_{ah}} = \frac{\sum_{z=1}^{z=n} \mathbf{N_z} \times \mathbf{A_z} \times \mathbf{O_z}}{\sum_{z=1}^{z=n} \mathbf{A_z} \times \mathbf{O_z}} \qquad \text{Equation one}$$

To describe the equation, $\mathbf{N_{ah}}$ represents the average annual hours, $\mathbf{N_z}$ represents the number of annual hours, $\mathbf{A_z}$ represents the total area of each zone, $\mathbf{O_z}$ represents the occupied hours of each zone, and finally, $\mathbf{n}$ represents the total number of thermal zones of the prototype.

A representative summation ratio depending on Equation (1) was identified beside each zone's performance for assessing the accepted hour's category. Furthermore, concerning PMV assessment, a good standard of comfort Category B ±0.5 according to ISO 7730 with average annual hours was targeted. Likewise, Category B was selected to quantify average annual hours with a dissatisfaction ratio of <10 for PPD assessment [82,84]. The average number of annual hours with a CO_2 concentration of <1000 ppm was counted as a good recommended level by European Standard EN 13777 [89]. Finally, the energy and thermal comfort hours ratio have been assessed through eight different cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions to evaluate the impact of orientation on the performance of the six designed Cases typologies (Cases 2,3,4,5,6 and 7) with the End-of-Terraced (ET) position. The reason is to identify the best orientation and to be adopted for the next step of the study in the next chapter (assessment of the incremental phases).

4.2.5 Application and Simulation Tool (IDA ICE)

For assessing the performance of the seven Cases prototypes (Figures 4-4, 4-5 and 4-6) then 48 scenarios for the designed Cases (Cases 2,3,4,5,6 and 7) to identify the orientation impact, the study utilized the simulation program Indoor Climate and Energy IDA ICE 4.8. South orientations with End-of Terraced (ET) positions were specified for the seven Cases concerning the position and orientation. While concerning the evaluation of orientation impact, cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions were specified with (ET) position. Later, the set points for the cooling and heating temperature controller levels were specified as 26 °C and 18 °C as a standard for the comfort level [28]. In contrast, the central air handling unit (AHU) for mechanical ventilation was absent (depending on the passive system). Furthermore, the set point for domestic hot water (DHW) specified 30 letters per person daily. Regarding heat gains, occupants' activity level is set at 1.0 MET and constant clothing 0.85 ± 0.25 CLO to be automatically adapted between limits to obtain comfort. Concerning occupancy time, several schedules were identified, as shown in Table 3-3 in the previous chapter. Finally, the simulations were run under annual processes (1 January–31 December) application for all seven Cases.

4.3 Results

4.3.1 Energy Assessment

The assessment of total delivered energy considered comprehensive results for five categories (Figure 4-7). Significantly, the most consumed category for all cases is DHW because it is set up on 30 letters per person daily based on the observation of socio-cultural context and the crucial impact of ablution five times daily. Meanwhile, this ratio could be decreased to half based on the essential water supply ratio as guidance for displaced people [26]. Additionally, another factor that could be taken into consideration is that, usually, zinc tanks on the roof of the building have used for water in the region [101], which means that during the hot summer season, the water does not need to be warmed (it is already warm) for showers, ablution, or dishwashing. Consequently, the ratio of DHW in the study can be decreased dramatically in the summer season because, apart from washing clothes, it is not required in any other amount. The results reveal that the best-performing prototypes compared to the first base case (Case 1) are Cases 4 and 5, with saved ratios of 9.5% and 12.3%, respectively, equivalent to 567 and 736 kWh annually. Significantly, the most effective categories for giving superiority are fuel heating and electric cooling, while the performance of the other three categories is almost the same.

Concerning fuel heating, there is considerable annual energy saving compared to Case 1 from Cases 4 and 5 by 80% and 84.8%, respectively. Moreover, the fuel heating demand ratio for Cases 4 and 5 compared to the total energy demand for the same cases is dramatically low, which is simply 2.2% and 1.8% of the total cases' energy. This is due to the compact layout shape and smaller thermal bridge area than other prototypes, which results in low heat loss levels and effective heat gain in the winter season. On the other hand, Case 2 is considered the worst regarding fuel heating by consuming 52.6% more than Case 1. Consequently, this is due to the largest thermal bridges of Case 2 and its more oversized open-layout yard, high heat loss ratio, and less heat gain by the living room due to setback location.

Furthermore, concerning the electric cooling energy demand, the preference for the open-plan (studio) layout cases (Cases 3, 5, and 7) is apparent due to the sufficient air circulation in hot seasons. For instance, the ratios of the cooling energy saving for Cases 3, 5, and 7 compared to the first base case (Case 1) are 25.9%, 25.1%, and 20.7%. Although Case 2 has the worst performance regarding fuel heating, concerning cooling energy, compared to Case 1, it saves 17.5%. Consequently, this superiority is due to the layout and size of the open yard and the bath location role of Case 2 in preventing the living room from overheating. Interestingly, there is a certain level of energy consumption for electric cooling in the winter season (November, December, January, and February) due to the excellent insulation and high heat gain ratio, especially for horizontal cases. For instance, Cases 1, 4, and 5 consume 77.9, 68.8, and 49.8 kWh, respectively, and both Cases 3 and 2 consume 35.1 and 31.2 kWh, respectively. In comparison, the two vertical cases (Cases 7 and 6) consume 31.1 and 25 kWh, respectively, for cooling in the winter.

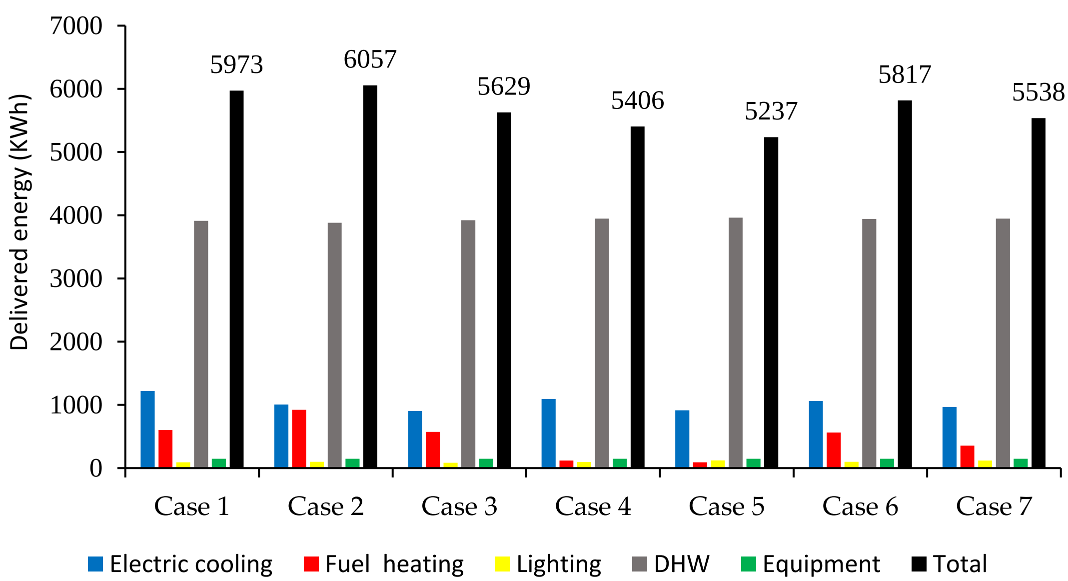


Figure 4-7 *Energy performance assessment*

4.3.2 Indoor Environment Comfort Assessment

4.3.2.1 Thermal Comfort Hours Ratio

Thermal comfort without a cooling option was specified to quantify the representative ratio of accepted level hours (Figure 4-8) based on Equation (1). The accepted hours' ratio includes good and the best hours, depending on the range temperature set points specified by the simulation software. The contribution of the occupancy hours ratio annually for the living room is the most influential and crucial class among the representative results, occupying 8760 hours (h), followed by 4380 and 730 h for the bedroom and the kitchen and then the bathroom with simply 546 h. Consequently, the simulated process revealed that the best-performing cases are Cases 7, 3, and 5 with a 1% ratio of unaccepted hours analogous to the representative number of 49, 67, and 99 h, respectively. Alternatively, Cases 1 and 4 have the lowest performance ratio with 13% and 7%, equivalent to 944 and 518 h, respectively.

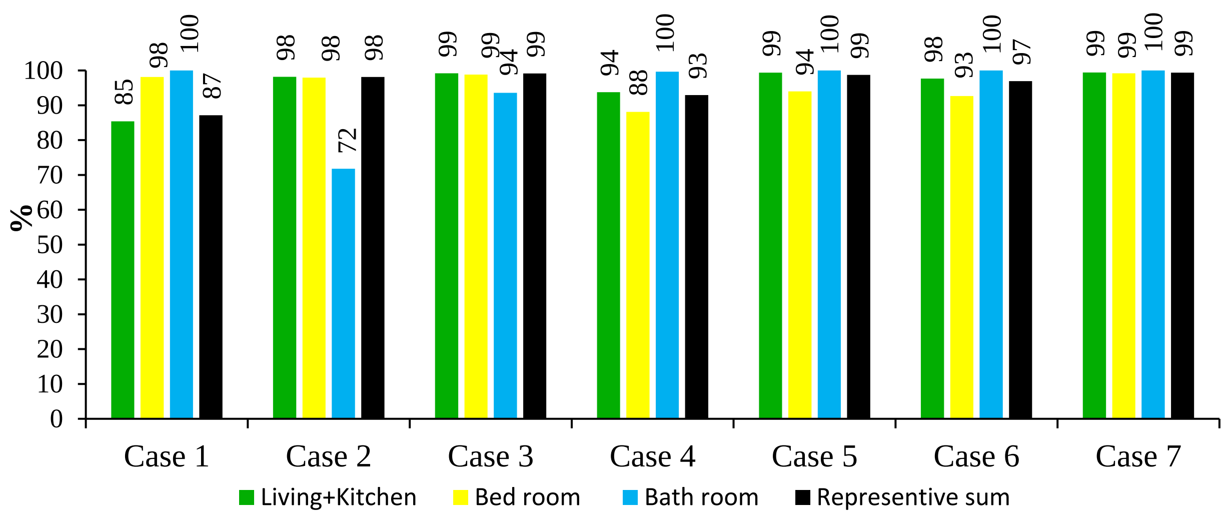


Figure 4-8 *Thermal comfort–accepted hours ratio.*

Moreover, the results quantified the good hours' level ratio in Figure 4-9 due to the vast similarity in the accepted performance for some zones. The results revealed that Case 5 still performs best with approximately the highest ratio in all zones. However, the performance of the bedroom (Case 1 with 2) and bathroom (Cases 1, 4, and 6 with 2, 3, and 7) for some lowest performing cases compared to the highest performing are better, while the superiority of the combined living plus kitchen zone is distinct due to its highest occupancy ratio. Hence, the preference for the open-plan layout over the separated zones layout is clear regarding thermal comfort–accepted hours. Furthermore, the role of the bath location in keeping main zones from heat loss and gain is another prominent factor, for instance, in Cases 2 and 5. Additionally, the well-insulated and high heat gain amount during the winter overheated some zones and led to a significant ratio of unaccepted hours, for instance, the living room for Cases 1 and 4 and the bedroom for Cases 4 and 5.

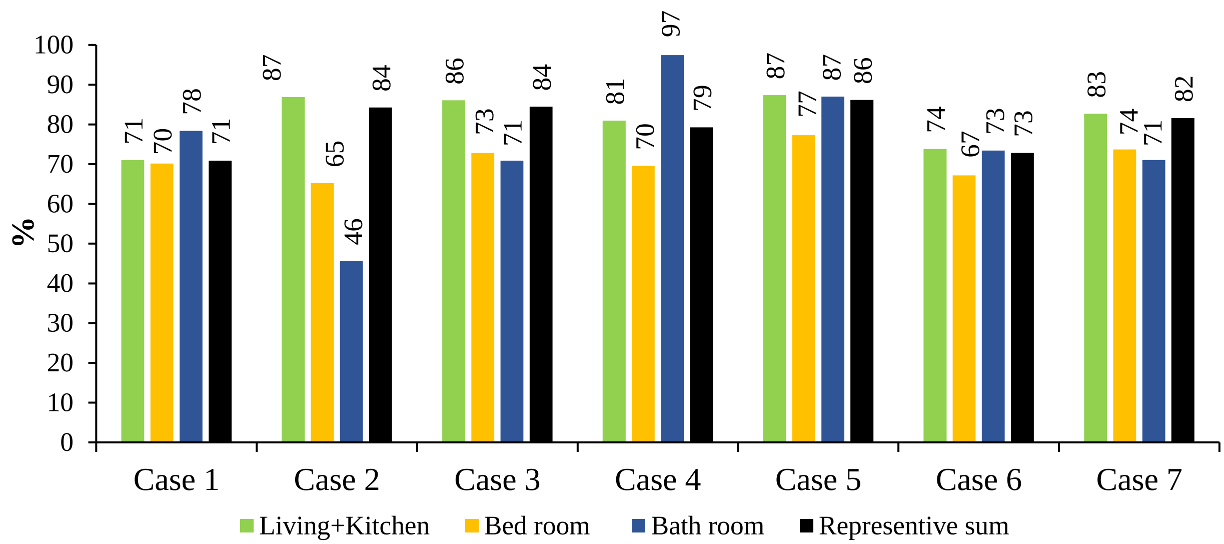


Figure 4-9 *Thermal comfort–good hours ratio.*

4.3.2.2 Fanger Comfort Model Indicators (PMV, PPD)

Concerning predicted mean vote (PMV) assessment and based on Category B as a good comfort standard with class [−0.5, +0.5], the results in Figure 10 were detected. The results revealed that the best-performing cases are Cases 4 and 5, compared to the base case (Case 1), with ratios of 15.06% and 12.58%, respectively, while the worst case is Case 6 with 6.27%. For assessing predicted percentage dissatisfaction (PPD) as a thermal comfort dissatisfaction ratio for the occupied zone, and based on ISO 7730 (2005), Category B was used, which refers to 10% of the dissatisfaction ratio [82,84]. Consequently, regarding PPD assessment, approximately the same comparison results as PMV were detected. For instance, Cases 4 and 5 performance ratios were the best, while Case 6 was still the worst.

In conclusion, both the PMV and PPD assessment results generally show the superiority of the horizontal-compact (Cases 4 and 5) layout plan compared to the verti-cal-compact (Cases 6 and 7) and horizontal-open into the yard (1, 2, and 3) layout plans. Consequently, a low circulation air ratio for the separated spaces and vertical layout plan (Case 6) is evident compared to the open-plan and vertical layout (Case 7) and the other horizontal layout plans. Additionally, the narrowest and small open-yard area beside the orientation of the doors for Case 3 is another reason compared to Cases 1 and 2.

4.3.2.3 Carbon Dioxide Level (CO_2)

For assessing IAQ performance, this study depended on the average annual hours with a CO2 concentration of <1000 ppm as a good recommended level by European EN 13777 for a safe and healthy environment (Figure 4-10) [89]. The assessment revealed that the performance of Open to yard cases (Cases 1, 2, and 3) is better than the compact layout cases (Cases 4, 5, 6, and 7). The revealed ratios for less than 1000 ppm for Cases 1, 2, and 3 are 28.65%, 27.58%, and 24.20%, respectively, while for Cases 4, 5, 6, and 7, they are 17.96%, 15.57%, 17.31%, and 15.74%, respectively. Consequently, the performance of the cases with an Open yard is better than the compact layout cases due to directly opening doors to the yard and exchanging air more efficiently. For instance, compared to other cases, the superior performance of the bedroom (Cases 1, 2, and 3) and the kitchen (Cases 1 and 2) is a crucial factor of superiority. Hence, it is recommended to set a special opening schedule for compact layout cases compared to the one open to yard to enhance IAQ and eliminate the unaccepted overheated hours in the winter season.

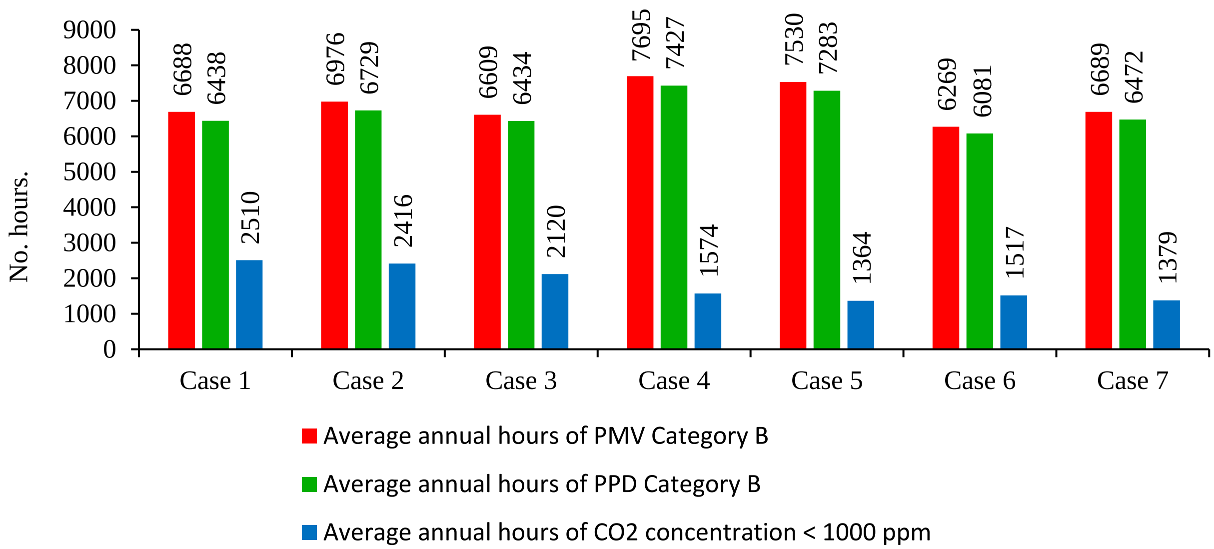


***Figure 4-10** Fanger's indicators (PMV, PPD) and carbon dioxide concentration (CO_2) performance.*

4.3.3 Assessment Impact of Orientation

4.3.3.1 Energy and Orientation

For assessing the impact of orientation on the energy performance, simply heating, cooling, and lighting parameters were focused on annually in Figure 4-11, while DHW and equipment were not considered due to the similarity in the results in all scenarios. The results revealed the superiority of the south (S) orientation in the first five cases, while the worst orientation was generally northwest (NW) or west (W) in both horizontal compact cases (Cases 4 and 5). However, concerning the last case (Case 7), the east (E) orientation has slightly the best result. Consequently, that was due to the different geometrical shape of case 7 (windows in S and E directions), which gave the east direction to have better results in winter for both heating and lighting categories (88 kWh), while in summer, the south was slightly better in cooling (41 kWh). The best-performed scenario was the south (S) orientation for Case 5 (28 kWh/m2 equivalent to 1128 kWh), while the worst scenario was the northwest (NW) orientation for Case 2 (75.8 kWh/m2 equivalent to 2481 kWh). It is worth mentioning that the largest difference in the result between the best and worst scenarios of the same case was in the Open to ard layout systems cases (Cases 2 and 3) by 453 kWh and 342 kWh, respectively, between S and NW directions.

Consequently, that was usually due to the relatively extreme heat loss in the winter for both cases when it was oriented to the prevailing wind in the (NW) direction.

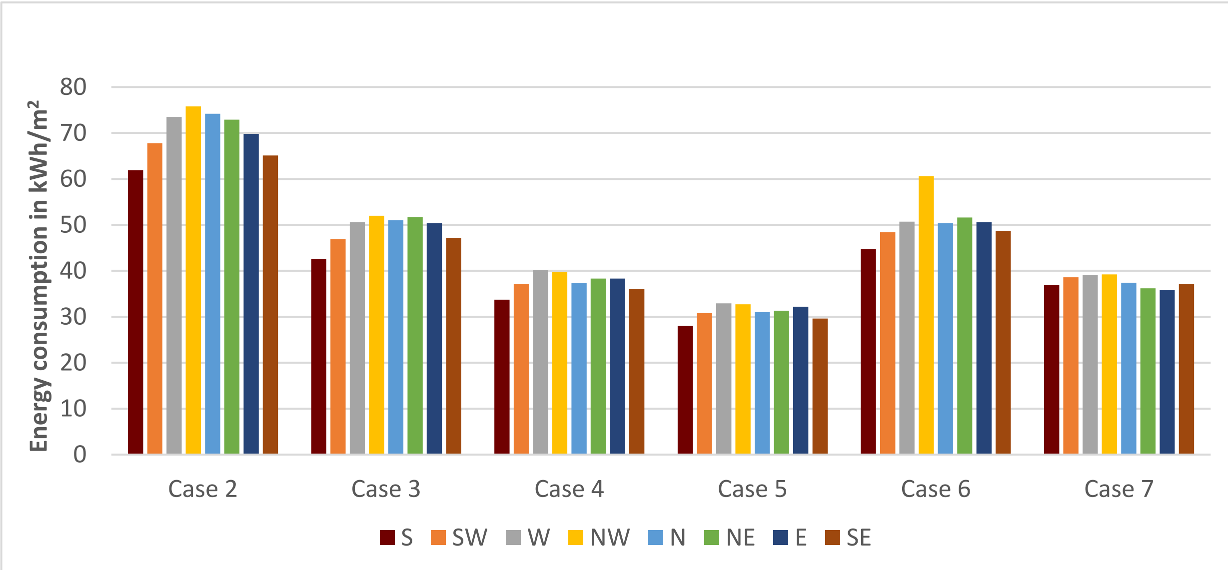


Figure 4-11 *Assessment of orientation impact on energy performance*

4.3.3.2 Thermal Comfort Hours and Orientation

The good hour's level ratio has been focused on to identify the impact of orientation concerning the thermal comfort hour's ratio. The representative good hours' ratios in (Fig 4-12) have been revealed based on Equation one after assessing zones with their different occupancy hours annually (Living 8760, Bed 4380, Kitchen 730, and Bath 546) in all Cases scenarios. Results show the superiority of the south (S) orientation for all cases (excluding Case 4) over the other direction and especially on the open space (studio) layout design (Cases 3, 5, and 7). The best-performed scenario was the south orientation for Case 5 with 88%, equivalent to 6814 hours, while the worst scenario was the NW orientation for Case 6 with 65% equal to 4756 hours. Consequently, the high occupation hour's ratio of the mixed zone (Living+Kitchen) and Living in the separated cases zones (Cases 2, 4, and 6) was a crucial factor in the resulting effect. It is justified that the slightly worst result of the south orientation for Case 4 compared to other Cases is from the overheating hours in the winter for Living and Bedroom spaces due to the superinsulation and high heat gain of this compact separated space design case.

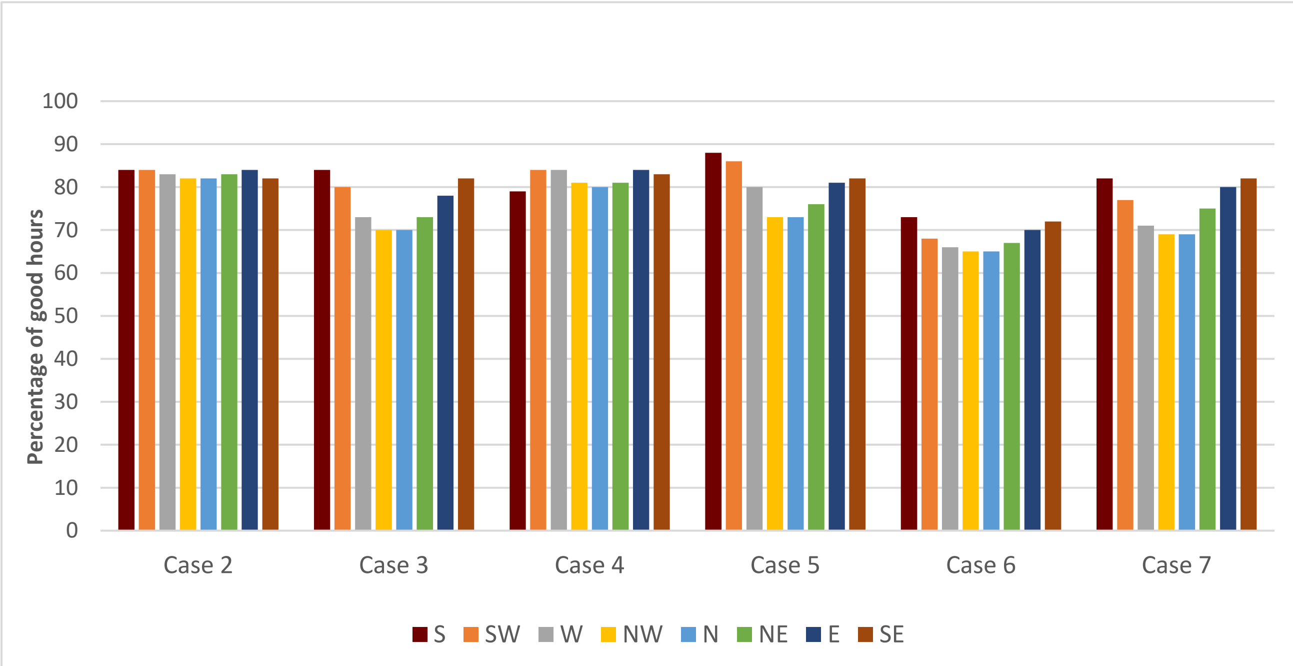


Figure 4-12 *The orientation impact on thermal comfort performance*

4.4 Discussion and Conclusion:

Due to the permanent reasons (natural disasters and conflicts) globally, the continuing issue and the increasing number of displaced people are prominent. Therefore, this Chapters study is a successive process continuing the previous chapter's investigation, and their questions were what methods must be taken to design and propose new sustainable shelter typologies for displaced people, and which layout system performs better? Additionally, what is the impact of orientation on the performance of six designed Cases through eight different cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions? Improper planning and designing systems regarding lifespan, materials, techniques, and socio-cultural aspects lead to unsustainable and inefficient construction shelters. Therefore, the study aims to assess the impact of the morphological, siting, and layout of zones and shelters for the long-term displacement prototypes. Additionally, it aimed to evaluate the effect of orientation on the performance of the designed prototypes.

Consequently, mixed methodology revealed comprehensive outcomes based on the bottom-up construction method and critical investigation of the planning and designing systems and socio-cultural context. The study outcome proposes new prototypes derived from the local planning and designing systems considering sustainability concepts from socio-cultural context, affordability, LIC materials, and techniques. As a result, the planning system of dwelling blocks would be embedded into the public planning system in Duhok City, even in a future expansion in the next chapter. The study utilized the simulation program Indoor Climate and Energy IDA ICE 4.8 for assessing the energy and indoor environment performance assessment of seven Cases firstly, then the impact of orientation on the performance of 48 scenarios. Firstly, the energy results generally revealed the superiority of the compact layout plan regarding fuel heating; for instance, Cases 4 and 5 save 80% and 84.8% compared to the first base (Case 1). Undoubtedly, that is due to the compact layout shape and smaller thermal bridge area than other prototypes, which results in low heat loss levels and effective heat gain in the winter season. However, concerning electric cooling, there is a superiority of the open-plan (studio) layout; for instance, Cases 3, 5, and 7 save 25.9%, 25.1%, and 20.7% compared to Case 1 due to the proper adequate circulation of air ratio in hot seasons and less heat gain compared to others.

Concerning the indoor environment performance, there is a difference between the thermal comfort hours ratio and Fanger indicators (PMV, PPD) categories compared to the carbon dioxide level (CO2) concentration category. Therefore, regarding the thermal comfort hours category, there is a superiority of the open-plan (studio) layout (Cases 3, 5, and 7) due to the proper adequate air circulation and the bath location's role in preventing main zones from heat loss and gain. Additionally, regarding PMV and PPD, the assessment revealed the superiority of the horizontal-compact (Cases 4 and 5) sited layout plan due to the good heat loss and gain performance compared to (Cases 1, 2, and 3) and more efficient air circulation compared to (Cases 6 and 7). Conversely, to other categories regarding CO2 concentration performance assessment, the results revealed that the Open to yard layout cases (Cases 1, 2, and 3) have better results than the compact layout cases due to opening doors to the yard directly and exchanging air more efficiently. Meanwhile, it is recommended to set schedules for openings to be open more frequently for compact layout cases to enhance indoor air quality (IAQ) and eliminate the unaccepted overheated hours in the winter season for the next chapter study.

To conclude the main finding, different layouts have a different impact on shelters' performance, with compact forms having more superiority in energy saving and providing better indoor thermal conditions. Given its nature which provides much less opportunity for heat exchange between indoor and outdoor and thereby less opportunity for heat loss, with the compact layout, there is a possibility to keep the heating consumption below 2.5 kWh/m^2, a figure that is equivalent to almost 85% saving in heating fuel. This is besides keeping cooling consumption below 23 kWh/m^2. Given its nature and the more openings that it has to the yard, which promote natural ventilation across the shelter, meanwhile, open to yard layout shows more superiority in terms of air quality, with more occupied hours below 1000 ppm.

Furthermore, the energy and thermal comfort results concerning the study regarding orientation indicate that the best-performed orientation models were generally the ones on the south (S). Thus, the next step of the study in the next chapter (assessment of the incremental phases) prototypes were established based on these results. Also, these results can be considered when considering orientation impact in both theoretical and practical implications. Moreover, the results show that models can be affected based on the geometric shapes and the opening direction. Moreover, it is recommended to have special opening schedules for avoiding overheating in the winter for the compact-layout models especially in S, SW, and W orientations. Comparing with the other study [99] taken the impact of orientation on energy assessment of housing units in Duhok City, this study is more comprehensive by taking both cardinal and ordinal directions additionally to the thermal comfort assessment while, concerning the superiority of south direction both studied are consistent.

This chapter study has a limitation to calibrating cases performance through in-site measurements data or another simulation program, and this was due to the strict security routine to access camps and data in the real site besides the lack of access to another free simulation program and lack of sufficient time to learn and repeat the evaluation of all scenarios. Based on these conclusions, the next chapter has considered a more critical investigation of shelter planning, designing systems, and affordable and adaptable strategies. In addition, adopting various positions, i.e. terraced (T) and end-of-terrace (ET), besides the incremental phase approach to better understand the comprehensive prototype’s performance has been assessed. Concerning the practical implication of this chapter's study, their designed techniques and typologies would benefit the displaced people and low-income people in the Middle East cultural context, especially Syrian refugees and Duhok city in the north of Iraq. Moreover, various places of the world could adopt the methodologies and construction techniques of the prototypes and study concerning displaced issues and affordable housing. Additionally, concerning theoretical implications, the study methodologies and the recommendations mentioned above could add valuable tips in the field.

Shekhan Camp

CHAPTER 5
ASSESSMENT of DIFFERENT INCREMENTAL PHASES

5.1 Overview

Globally, natural and man-made disasters continue to force the displacement of masses of people. As a result, this Chapters study is the successive process continuing the previous chapter's investigation. Since existing studies show that several aspects have not been integrated into constructing refugee camps and shelters to achieve sustainability, such as long lifespan, indoor thermal comfort and air quality, energy efficiency, socio-cultural aspects, integration with local planning and design systems, and environmental impact. This study integrates the above factors in six refugee core shelters, designed based on the Middle Eastern cultural context using locally available sustainable construction materials and techniques, paying more attention to prolonging strategies for shelters' lifespan. Furthermore, this chapter's study question states, What upgrading phases could be proposed to extend the lifespan of the displaced housing, gives the opportunity to upgrade based on time, available cost and need, and what is their energy and indoor environment performance?

Consequently, the prototypes are situated on two different building plots, i.e., terraced and end-of-terrace, and undergo three development phases, known as the incremental improvement strategy. The study focuses on their energy and indoor environment performance and provides empirical assessments undertaken using dynamic building simulations. It shows that the adopted approach to design and construction leads to remarkable improvements in their overall performance. Concerning energy use, compared to the base case scenarios built with conventional materials, the proposed prototypes show an opportunity to save energy up to 10,800 kWh per unit per year, equivalent to almost 2700 USD savings in energy bills. This is while achieving an acceptable level for nearly 89–94% of thermal comfort hours and 74–85% predicted mean vote (PMV), respectively. However, the CO_2 concentration level remains relatively low, ranging from 29 to 51%.

In conclusion, to minimize the environmental footprint, there is a high possibility of prolonging shelters' life span, which can later be reused by low-income local communities when refugees return to their homelands. To accommodate their needs, however, the upgraded base shelters could be expanded through an incremental improvement strategy while keeping affordability and the energy and thermal efficiency of the shelters a top priority. Doubling the overall area by adopting materials and techniques mentioned earlier would require somewhere between 16 to 40 kWh/m^2 to provide acceptable indoor temperatures throughout the year. The variation depends mainly on the layout used, with compact layouts showing the lowest heating and cooling consumption.

The overview of the problem statement, focus, question, aim and contribution of the chapters study is stated in this section, while the next section demonstrates the data collection and processing analysis methods, followed by the energy and indoor environment performance assessment for 36 incremental phases scenarios in the result section and finally concludes with a discussion and main finding section. In conclusion, sustainable prototypes for displaced people should pay more attention to the lifespan aspect through adaptability and incremental strategy based on the time, financial situation and available materials. The beneficiaries from the methods and the results of this study would be refugees, low-income people and the governmental stakeholders in the Middle East context, then various places in the world which involved people affected by the displacement issue and affordable housing for low-income people.

5.2 Methodology

This chapter's study question is what upgrading phases and methods could be proposed to prolong the lifespan of the core shelters based on the Iraqi context, allows upgrading based on time, available cost and need, and what is their energy and indoor environment performance? The following presented methodologies have been adopted to find the answer to this question.

5.2.1 Theoretical Models:

The assessed models represent those six Cases (Figures 5-3,5-4 and 5-5 in their phase 2) designed and developed based on the previous studies' data in Chapters Three and Four (Table 5-1). The six Cases were designed considering several variables, which have been identified based on the observations during the site visits conducted by the authorities and investigating the local planning and design systems in the north of Iraq. The variables were:

- Open to a yard (Cases 2 and 3) and compact (Cases 4,5,6, and 7) layout design scheme.
- Separated spaced (Cases 2,4, and 6) or studio (Cases 3,5 and 7) layout design.
- Horizontal (Cases 2,3,4, and 5) and vertical (Cases 6 and 7) plot sited layout design system .

Regarding this chapter's study's scenarios, 36 scenarios resulted from the six designed Cases (Cases 2,3,4,5,6 and 7) with three incremental phases for each case and two different positions for each model, i.e. terraced (T) and end-of-terraced (ET), were assessed to have comprehensive scenarios data.

Table 5-1 Conceptual framework for incremental prototypes

Chapter Three and [48]	**Data:** Literature review, conducting stakeholders in Duhok, north of Iraq, and observation.
	Aim: To investigate the impact of low-impact construction (LIC) through the bottom-up method on developing shelter performance.
	Models' numbers: Nine different scenarios (S) for one base-case model (Case 1).
Chapter Four and [49]	**Data:** Literature review and conducting the Authorities, site visit, and observation.
	Aim: To design prototypes and assess the impact of the morphological, siting, and layout of zones considering sustainability and evaluate the effect of orientation.
	Models' numbers: Six designed prototypes (Cases) + the base case model one C1 (C1S9). And 48 scenarios for assessing orientation impact.
Current study (Chapter Five) and [50]	**Data:** Chapters Three and Four, Literature review, and observation.
	Aim: Evaluate the prototypes' energy and indoor comfort performance in three incremental phases with two locations, i.e. terraced (T) and end-of-terrace (ET).
	Models' numbers: 36 scenarios from six cases, three phases and two positions (ET and T)

5.2.2 Data Analysis and Evaluation Process:

Regarding construction techniques, materials, and prototype parameters, the scenario nine (C1S9) method from Chapter Three has been selected for this study for affordability and adaptability reasons. Other identified parameters are shown in Table 5-2.

Table 5-2 Construction parameters of the prototypes

Construction parameters	Construction parameters U values
Area: Phase 1 and Phase 2 = 50 $m^{2,}$ Phase 3= 100 m^2	External earth-bags wall = 0.57
Dimensions: 5*10 m for Phase 1 and Phase 2, 10*10 m for Phases 3	External straw-bales wall = 0.14
Technique: The bottom-up method	Roof = 0.26
Materials: Wood + Straw + Soil (WSS) roof, straw-bales + cob + earth-bag for the walls, lightweight concrete floor, double pane glazing windows and wood doors	Floor = 0.85
Ceiling height = 2.6 m	Door = 0.54
Air tightness = 0.5	Window = 2.9

Next, based on the local urban planning systems in Duhok City, the attached planning block systems have been modified and designed to consist of the plot layout for the prototypes in their various plans systems (horizontal and vertical sited forms) and phases (Phases 1, 2, and 3). Additionally, pedestrians, gardens, and vegetation areas between the units were designed. The planning block system in Figure 5-1 was designed To Include horizontal-sited layout plot prototypes (Cases 2,3,4 and 5). However, to avoid extreme sprawl planning, the vertical-sited layout in Figure 5-2 was designed for Cases 6 and 7 typologies.

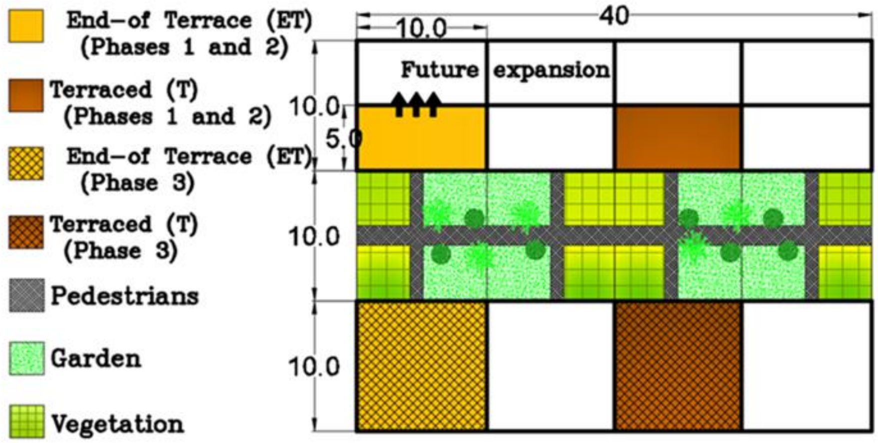


Figure 5-1 *Planning system for horizontal sited layout plot Cases (Cases 2,3,4 and 5)*

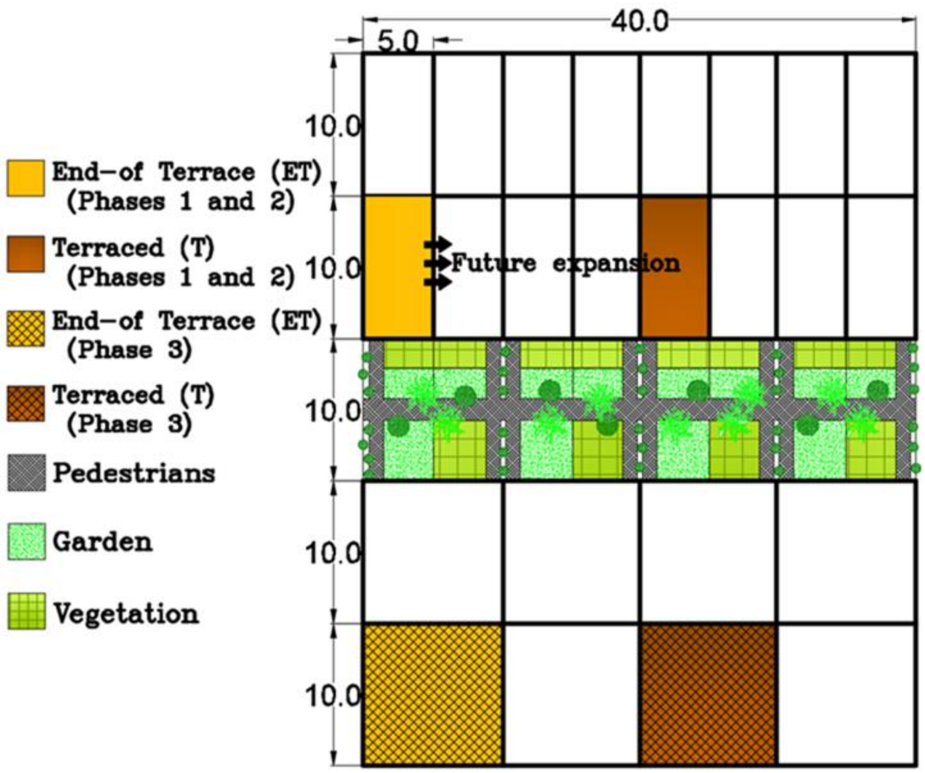


Figure 5-2 *Planning system for vertical sited layout plot Cases (Cases 6 and 7)*

Concerning prototype design, the six Cases with an area of 50 m^2 designed in Chapter Four were considered phase Two for this Chapter's Cases design (Figures 5-3, 5-4 and 5-5). Regarding the incremental phases study and after observation of the critical investigation of the previous literature and the cultural context, two other phases have been modified from each of the six Cases. Phase One, with the same area as phase two (50 m^2), is considered the initial and temporary design phase, with simply one general zone for cooking, living, and sleeping, excluding a bath in the prototype. The last design phase is Three, as an upgrade of phase Two with an area of 100 m^2 (Figures 5-3, 5-4 and 5-5), and to host six people instead of 5 people in the other two phases. This decision update has been taken based on the study of the cultural context after the site visit, where it has been observed that many newly married couples stay with their parents after the marriage process for a few years. Consequently, phase Three has been designed to host this type of family, newly married couples, or even to host low-income people when there is a chance for refugees to go back to their original homes. AutoCAD drawing programs were used to draw and illustrate the planning and designing of prototype systems.

Figure 5-3 *Open to the yard Cases (Cases 2 and 3) with their three phases*

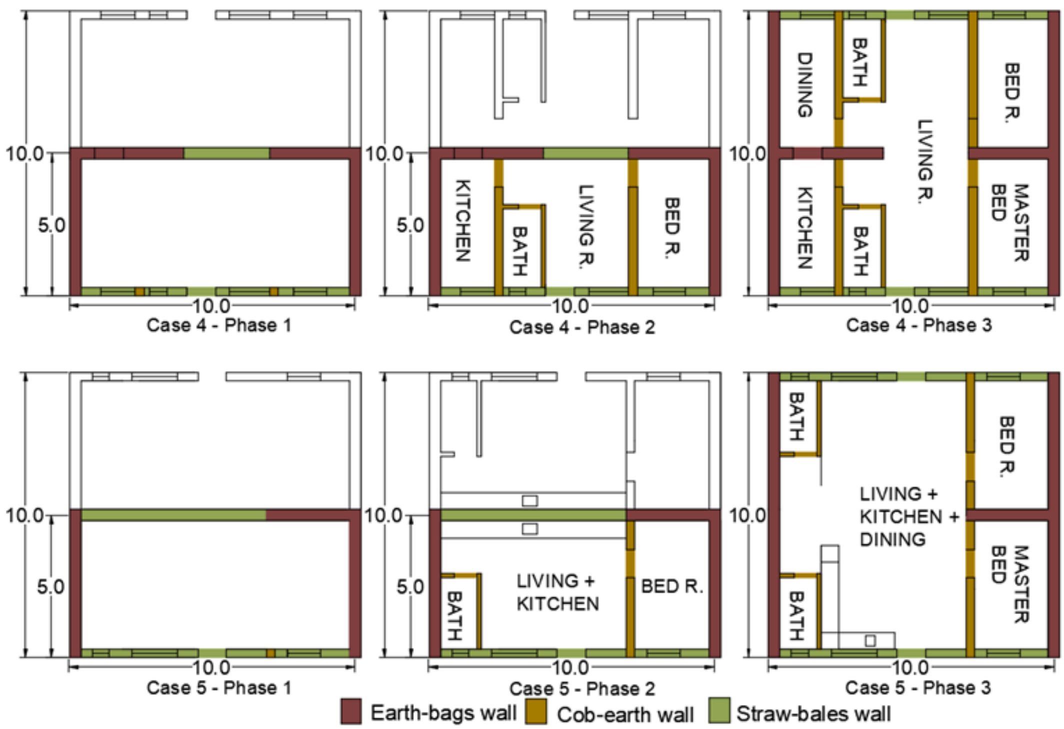


Figure 5-4 *Compact horizontal sited plot layout design Cases (Cases 4 and 5) with their three phases*

Figure 5-5 *Compact vertical sited plot layout design Cases (Cases 6 and 7) with their three phases*

It is worth mentioning that several parameters have been reviewed in phase two before the evaluation process for the last incremental phases of prototypes. For instance, due to the observation of overheating in some cases in the winter because of superinsulation that is parallel to the CO2 concentration weak result, the opening schedules have been tested and relatively modified to obtain better results. Furthermore, the input data regarding domestic hot water (DHW) has also been revised. For instance, 15 Liters (L)/Person (P) daily has been specified based on the essential water supply ratio as guidance for displaced people [26]. However, based on the cultural context of the Middle Eastern region, five other litres have been added for the ablution process so that it would be 20 L/P. While according to [101], using a zinc water tank on the top of the buildings consequently, in the four months of summer apart from the washing machine, there is no need for DHW for dishwashing, showers, or ablution. Consequently, the DHW demand would be 15L/P concluded from 20L/P in eight months while just 5L/P for other summer months (8 months *20 L + 4 months *5 L). Finally, the location of several materials has been replaced with some others, for instance, the place of the straw bales with the earthbags technique in Case 3 and straw bales with the cob technique in Case 6 to be compatible with phase three of the incremental phases.

Ultimately, the assessing and evaluation process has been done for 36 scenarios resulting from the six designed Cases (Cases 2,3,4,5,6 and 7) with three incremental phases (Phases 1,2 and 3) and two different positions, i.e. terraced (T) and end-of-terraced (ET) for each Case (6*3*2) based on the best orientation (South) assessed and identified in Chapter Four. IDA-ICE simulation and Excel sheets software have been used to evaluate and calculate the performance of models. The assessment involves energy and indoor comfort performance for each scenario. Firstly, the total energy demand has been quantified in its five categories (DHW, equipment, lighting, electric cooling, and fuel heating). Then due to the similarity in the other three classes, heating and cooling energy demand has been counted separately. Finally, the cost-effectiveness of total heating-cooling energy has been calculated and compared with the two base case scenarios models (C1S1 and C1S2) in Chapter Three.

While concerning indoor environment performance assessment, three categories have been considered, and their results are presented in one representative number based on Equation One. To come up with one representative number instead of a different one for each scenario, and due to the variations in the occupation hours, the number of zones, and their areas, consequently, from a scientific study [100], Equation One was applied.

$$\mathbf{N_{ah}} = \frac{\sum_{z=1}^{z=n} \mathbf{N_z} \times \mathbf{A_z} \times \mathbf{O_z}}{\sum_{z=1}^{z=n} \mathbf{A_z} \times \mathbf{O_z}} \qquad \text{Equation One}$$

The parameters in equation one can be defined as follow, $\mathbf{N_{ah}}$ denotes the average annual hours, $\mathbf{N_z}$ represents the number of annual hours, $\mathbf{n}$ is the total number of thermal zones of the model, while $\mathbf{A_z}$ means the total area of each zone, and finally $\mathbf{O_z}$ represents the occupied hours of each zone. Firstly, the thermal comfort hour's ratios have been quantified in accepted and good-level categories. Then categories C and B as an accepted and good comfort level standard concerning predicted mean vote (PMV) assessment have been determined [82,84]. Finally, the maximum acceptable and good level of the CO_2 concentration represented in 1500 and 1000 parts per million (ppm) has been simulated [89].

5.2.3 Modelling Tool and Input Parameters:

Simulation program Indoor Climate and Energy IDA ICE 4.8 SP2 has been applied in this Chapter study to assess the energy and indoor environment performance of 36 scenarios (6*3*2), including six designed Cases at three incremental phases (Phases 1,2 and 3) and two different positions, i.e. terraced (T) and end-of-terrace (ET). Simulating all the modules was under an annual situation from the 1^{st} of January till the 31^{st} of December. While before running simulations, the comfort level setpoint for cooling and heating controller level besides parameters in Table 5-3 were specified. Concerning DHW for the modules of phase three, based on the middle eastern context [102] 25 L/P has been identified, resulting from 5 litres for the summer months and 35 litres for others (8 months *35 L + 4 months *5 L).

Table 5-3 Set points and input parameter

Parameters	Phase 1	Phase 2	Phase 3
Number of occupants	5 persons	5 persons	6 persons
Heating set point	18 °C	18 °C	18 °C
Cooling set point	26 °C	26 °C	26 °C
DHW, daily litres	5 L /Person	15 L /Person	25 L /Person
Equipment	Oven and Washing machine	Oven, Washing machine, Refrigerator, and TV	Oven, Washing machine, Refrigerator, Iron, and 2 TV
Orientation	South	South	South
Central air handling unit (AHU) for mechanical ventilation	Absent (passively dependent)	Absent (passively dependent)	Absent (passively dependent)
The level of activity	1.0 MET	1.0 MET	1.0 MET
Constant clothing	0.85 ± 0.25 CLO	0.85 ± 0.25 CLO	0.85 ± 0.25 CLO

5.3 Results

5.3.1 Energy Assessment

5.3.1.1 *Total Energy*

For assessing the total energy performance, the energy demand was quantified in five categories (fuel heating, electric cooling, lighting, DHW, and equipment) Figure 5-6. The revealed results show that the compact horizontal cases (Cases 4 and 5) have generally better results in their three phases and two different positions, while open-to-the-yard cases (Cases 2 and 3) have the worst. The best results were for Case 5 in it is Terrace (T) location and three phases as revealed respectively 59.8 kWh/m2, 105.7 kWh/m2, and 83 kWh/m2, equivalent to 2528 kWh, 4267 kWh, and 6911 kWh annually. However, the worst results were for Case 2 in it is End-of-terrace (ET) location and three phases as revealed respectively 78.7 kWh/m2, 150.2 kWh/m2, and 123.2 kWh/m2, equivalent to 2771 kWh, 4920 kWh, and 8234 kWh annually.

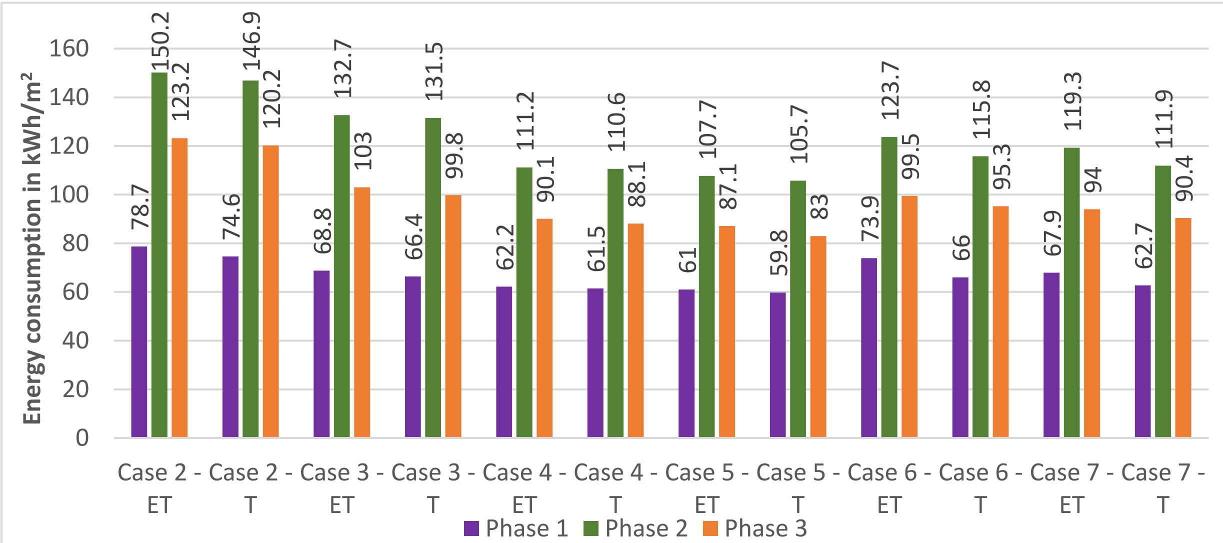


Figure 5-6 *Total energy assessment for Cases scenarios*

5.3.1.2 *Heating and Cooling Energy*

Heating and cooling energy has been quantified separately in this subsection due to the similarity in the other three categories (DHW, equipment, and lighting) between the six case phases and locations. Surprisingly, heating was the most significant effective category between the fifth for giving superior performance concerning energy (Figure 5-7). Although, the revealed results show dramatically that the compact horizontal sited cases (Cases 4 and 5) have better results in all scenarios while the worst cases were open to yard cases (Cases 2 and 3). Furthermore, the vertical-sited plot cases (Cases 6 and 7) show the biggest difference between the performance of the same scenarios concerning the impact of position, i.e., Terrace and End-of Terrace (T and ET). For instance, the heating results of the three phases for case 6 in the (ET) location were (10.3, 12.4, and 9.8) kWh/$m^{2,}$ equivalent to (419, 480, and 769) kW, respectively, while in the (T) position were (3.7, 5.9 and 6.4) kWh/m^2 equivalent to (151, 228 and 501) kW respectively. Moreover, the best results for Phases 1 and 2 were for Case 4, while for Phase 3 was for Case 5, both in (T) position and revealed (0.3,0.2 and 0.7) kWh/m^2 equivalent to (12, 7, and 62) kW respectively while the worst result for phase 1 was for Case 6 while for phases 2 and 3 were for Case 2 both in (ET) position and revealed (10.3,23.3 and 22.6) kWh/m^2 equivalent to (419, 763 and 1510) kW respectively.

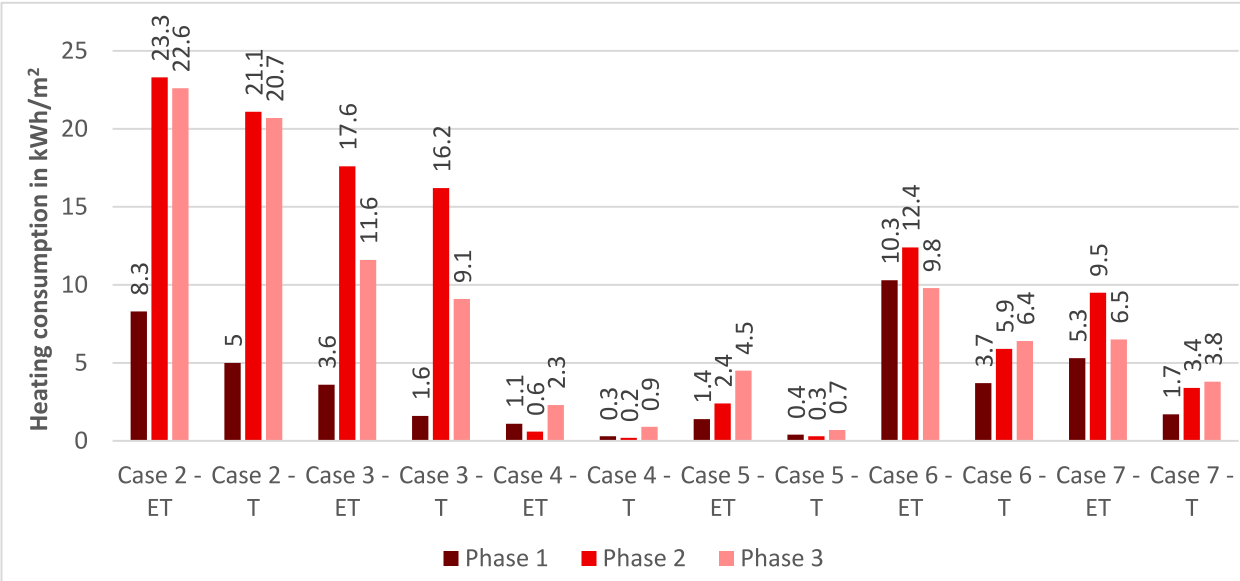


Figure 5-7 *Heating energy assessment for Cases scenarios*

Concerning cooling energy demand, even though it has the biggest portion regarding heating-cooling consumption while conversely to the heating demand energy, there is a slight difference in the cooling demand results between the cases (Figure 5-8). For instance, the worst results for the three phases were for Case 2 in (ET) position and revealed (28.8,32.4 and 20.9) kWh/m^2 equivalent to (1013, 1161 and 1399) kW, respectively, while the best results for phases 1 and 3 were for Case 5 in (T) position interestingly for phase 2 was in Case 5 (ET) position as revealed (22.9, 26.1 and 15.9) kWh/m^2 equivalent to (970, 1053 and 1325) kW respectively. This slight superiority for (ET) position over (T) one in Case 5 (Phase 2) was due to the overheating in winter, which results from their compact shape, heat emissions from equipment in the open (studio) layout design system, and superinsulation technique.

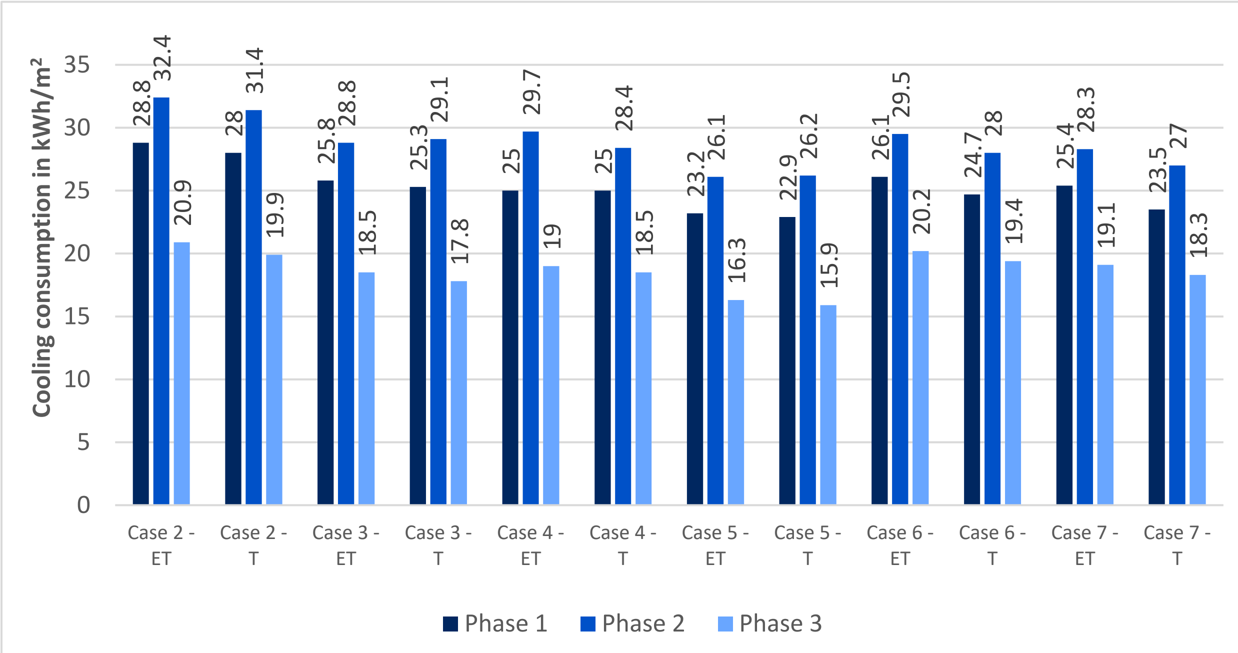


Figure 5-8 *Cooling energy assessment for Cases scenarios*

5.3.1.3 *Cost Implications*

To realize more effect of applying low-impact construction (LIC) materials and techniques through the bottom-up method, besides the impact of the designed prototypes on saving energy, the cost of heating-cooling energy has been countified (Figure 5-9). The assessment focused on Phase Two and End-of Terraced (ET) position for all the six designed Cases and base Case one (C1) in Chapter Three with it is targeted bottom-up method (C1S9) to be compared with both base case scenarios (C1S1 with zinc sheets roof and concrete blocks wall and C1S2 with sandwich panels roof and concrete blocks wall). Furthermore, the energy value has been quantified as 1 USD for 4 kWh based on the recent policy reform announced by the Kurdistan Regional Government (KRG) concerning energy pricing [98]. In conclusion, the assessment revealed that the best and worst results for designed cases were Cases 5 and 2, respectively, compared to (C1S1) can save 10809 and 10133 kWh equivalent to 2703 and 2534 US Dollars annually, additionally comparing to (C1S2) both cases can save 4469 and 3793 kWh equivalent to 1118 and 949 USD annually.

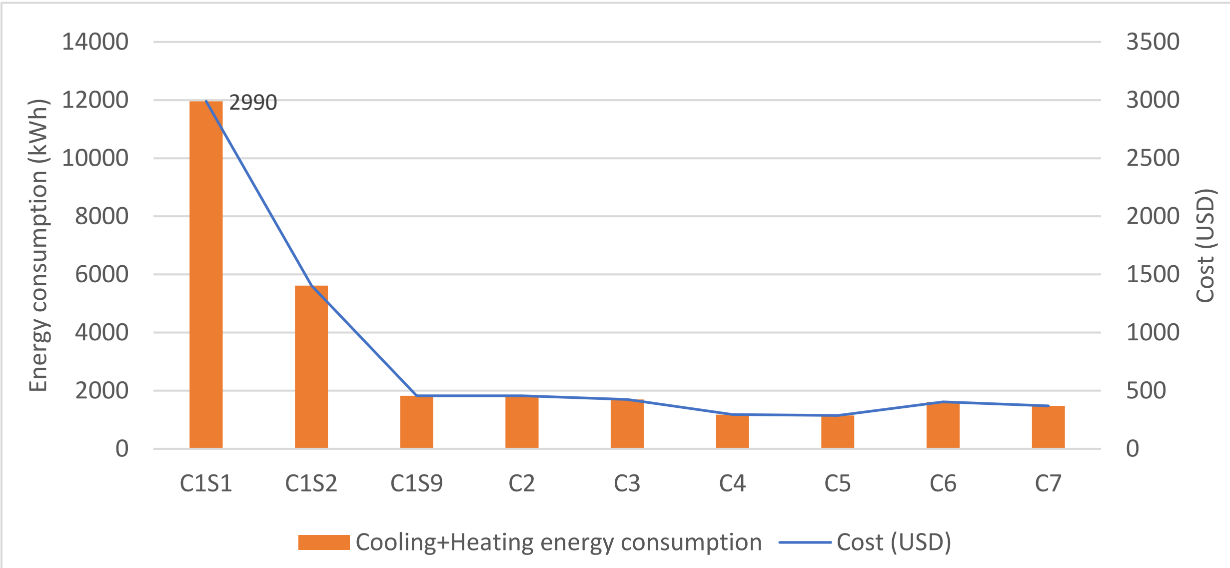


Figure 5-9 *Cost assessment for energy*

5.3.2 Indoor Environment Assessment

5.3.2.1 *Thermal Comfort Hours Ratio*

The representative accepted and good levels hours' percentage ratios in (Figures 5-10 and 5-11) have been quantified based on Equation One after assessing different zones with different occupancy hours annually. Depending on the range of specified setpoint temperatures in the modelling software (IDA ICE), the accepted level hours (including both good and best hours) and good hours (including best hours) were simulated. Concerning the accepted hours' ratio assessment for Phase One at the End of Terrace (ET) position, the best and worst performed cases are (Cases 5 and 6) with unaccepted ratios of 0.74% and 11%, equivalent to 65 and 964 hours while in Terrace (T) position were (Cases 7 and 4) with unaccepted ratios 0.10% and 5.60% equivalent to 9 and 491 hours annually. Moreover, concerning Phase Two in (ET) position, the best and worst performed cases are (Cases 7 and 4) with unaccepted ratios of 0.10% and 4.85%, equivalent to 8 and 355 hours, while in the (T) position were (Cases 6 and 3) with unaccepted ratios 0.09% and 7.87% equivalent to 7 and 610 hours ratio annually. Likewise, regarding Phase Three in (ET) position, the best and worst performed cases are (Cases 4 and 3) with unaccepted ratios of 0.63% and 6.41%, equivalent to 41 and 500 hours, while in the (T) position were (Cases

4 and 7) with unaccepted ratios 0.38% and 2.12% equivalent to 25 and 167 hours ratio annually. The best and worst Cases performance results when changing position from (ET to T) revealed that Case 6 (+771 hours) and Case 4 (-323 h) for Phase One, also Case 6 (+192 h) and Case 3 (-580 h) for Phase Two while, for Phase Three, Case 3 (+463 h) and Case 7 (-60 h).

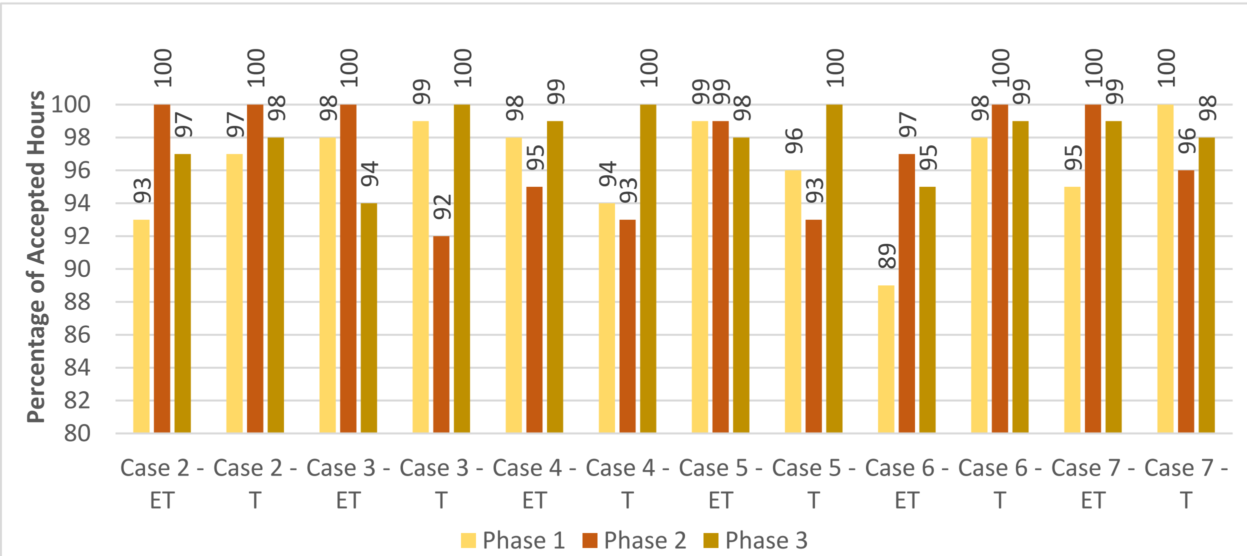


Figure 5-10 *Thermal comfort – "accepted" level of hours ratio*

Additionally, the assessment quantified the good level hour's ratio, as revealed in Figure 5-11, to better understand the scenarios' performance. The results concerning Phase one showed that, however, in the (ET) position, the horizontal-sited compact Cases (Cases 4 and 5) perform better than others. While surprisingly, in the (T) position, both cases performed worse than it is (ET) location due to the overheating in winter, while all other Cases (Cases 2, 3, 6 and 7) had better results than it is (ET) position. Moreover, concerning Phase Two, the overheating issue in winter due to well-insulated made Cases 3, 4, 5, and 7 have worst results in the (T) position than their results in the (ET) position, while both Cases 2 and 6 have better results in (T) position than it is (ET) position. Finally, concerning Phase Three, interestingly, all six cases have a better result in the (T) position than their results in the (ET) position. The best and worst Cases performance for good level hours ratios when changing location from the (ET to T) position are Case 7 (+702 hours) and Case 4 (-368 h) for Phase One, also Case 6 (+647 h) and Case 3 (-590 h) for Phase Two while, for Phase Three, are Case 3 (+833 h) and Case 7 (-32 h).

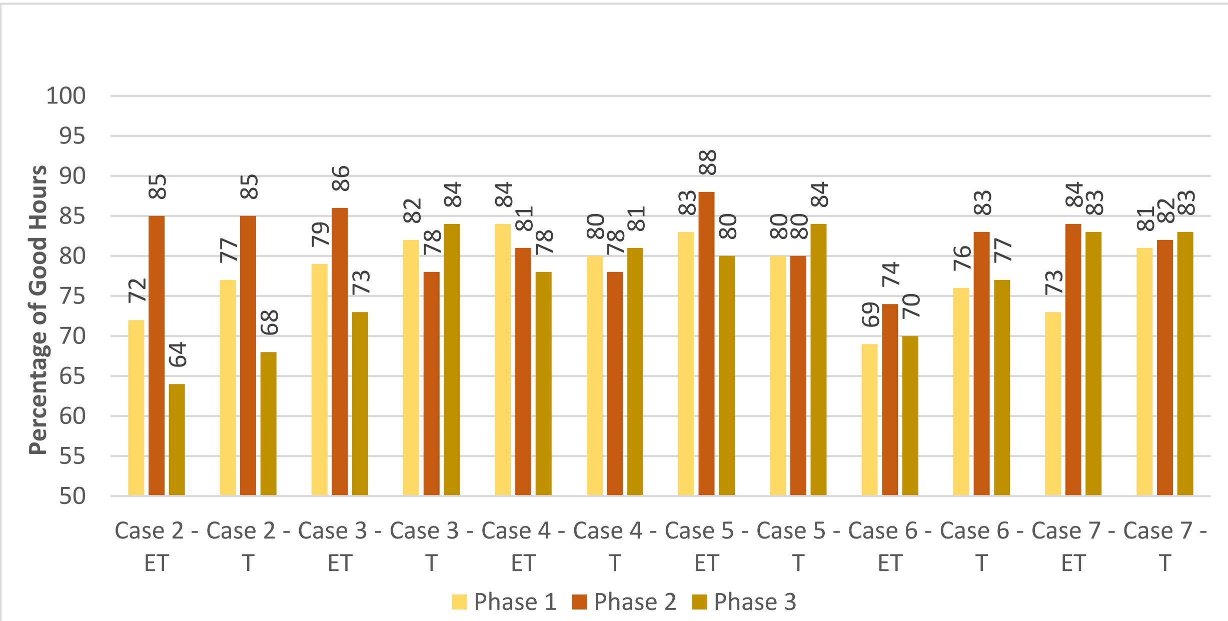


Figure 5-11 *Thermal comfort–"good" level of hours ratio.*

5.3.2.2 *Evaluation of Predicted Mean Vote (PMV)*

Predicted mean vote (PMV) is an essential index of the Fanger comfort model, which has been measured in this study in it is both good (B ±0.5) and accepted (C ±0.7) categories according to ISO 7730 (2005). MPV measurement estimates air temperature, mean radiant temperature, air velocity, humidity, metabolic rate, and clothing variables in occupied zones [82,84]. The revealed results in (Figures 5-12 and 5-13) are both accepted (C) and good (B) categories hours respectively, which have been quantified based on Equation one, after assessing different zones with it is different occupancy hours annually.

Concerning the accepted hours' percentages assessment for Phase One at the End of Terrace (ET) position revealed that the best and worst performed cases are Case 4 (93%) and Case 6 (74%) likewise, in Terrace (T) position Cases 4 has (96%) and Case 6 has (83%) annually. Similarly, in the

Phase Two (ET) position, still the best and worst performed cases are Case 4 (98%) and Case 6 (85%) likewise in Terrace (T) position Case 4 (99%) and Case 6 have (94%) accepted hours annually. Interestingly, for Phase Three in both (ET and T) positions Case 7 has the best results of 93% and 97% respectively, however, in (ET) position still Case 6 has the worst result of 83%, while in the (T) position Case 2 has the worst accepted hours percentage annually by 87%.

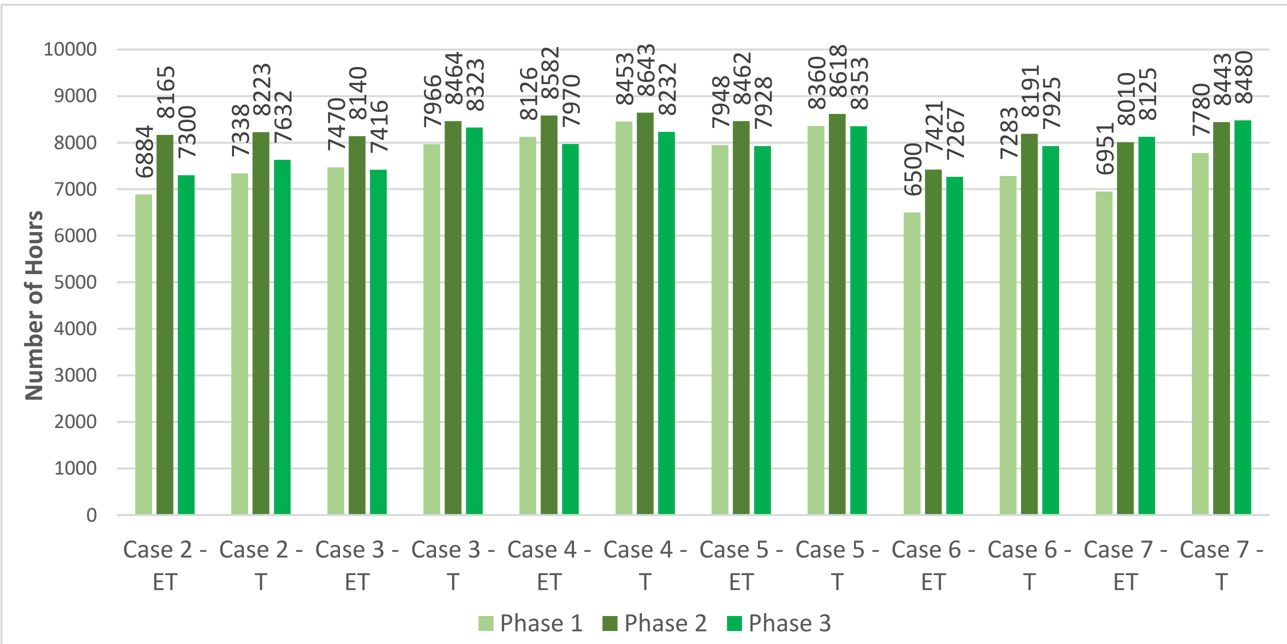


Figure 5-12 *Accepted annual hours (category C) for PMV*

On the other hand, there is some change in the best and worst cases performance concerning the good level hours' (category B) percentages assessment compared to the accepted hours above. For instance, assessment results for Phase One at the (ET) position revealed that the best and worst performed cases are Case 5 (80%) and Case 6 (58%) while in the (T) position, Case 5 has (88%) and Case 2 has (68%) from good hours annually. Similarly, in Phase Two (ET) position, still the best and worst-performed cases are Case 5 (89%) and Case 6 (72%) likewise in Terrace (T) position still Cases 5 has (93%) and Case 2 has (79%) good hours annually. Interestingly, for Phase Three in (ET) position Case 4 has the best results by 81% while Case 3 is the worst by 68%, surprisingly, in (T) position Case 7 has the best result by 86% and Case 2 has the worst result by 76% from good hour's percentage annually.

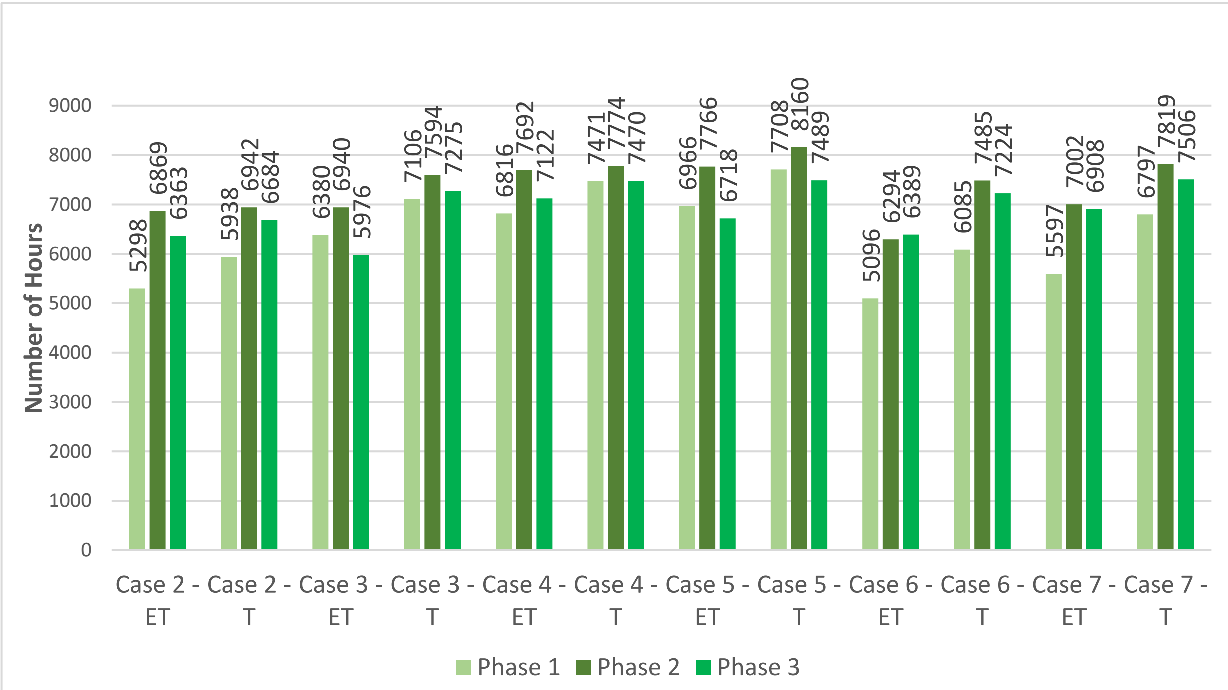


Figure 5-13 *Good annual hours (category B) for PMV*

5.3.2.3 *Carbon Dioxide Level (CO2)*

To assess indoor air quality performance, CO_2 concentration level in it is both accepted as the maximum level (<1500 ppm) and good as the recommended level (<1000 ppm) by European standard EN 13777 [89]have been measured. The revealed results concerning accepted level (CO_2 concentration <1500 ppm) in Figure 5-14 show that in both Phases One and Two and in both End of Terrace (ET) and Terrace (T) positions, the studio (Kitchen open to Living) layout design (Cases 3, 5 and 7) have better results than the separated zones Cases (Case 2, 4, and 6). However, in Phase Three and in both (ET and T) positions, separated zones layout design cases (Cases 2, 4, and 6) have better results.

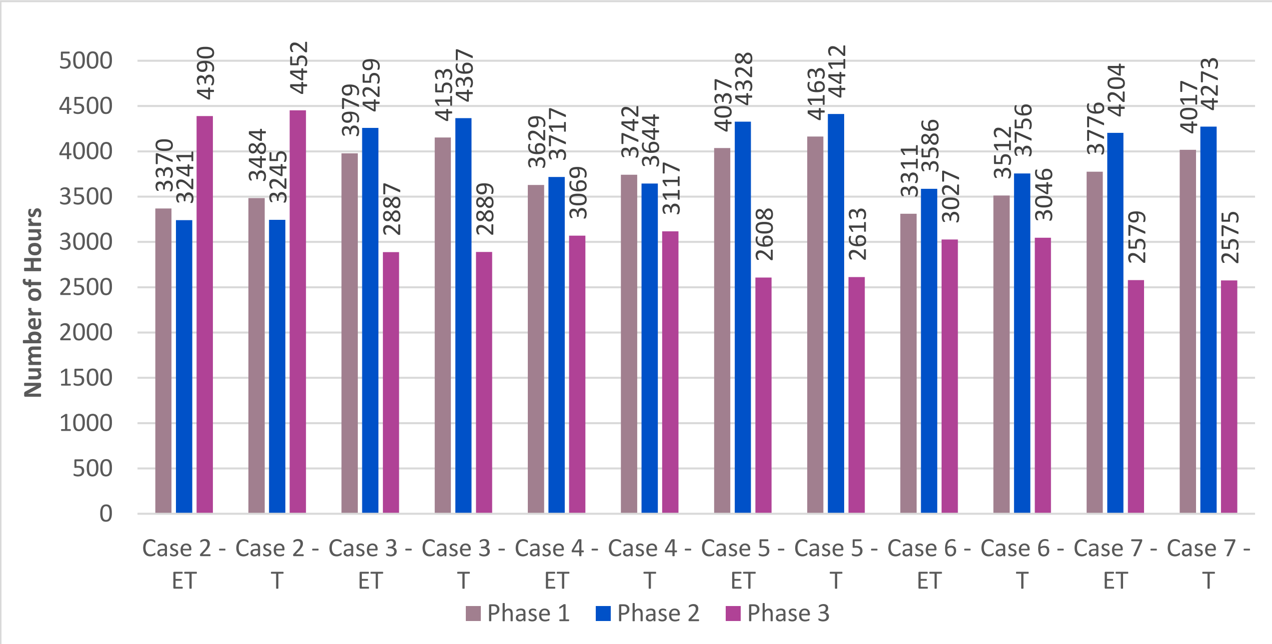


Figure 5-14 *Average annual hours of CO2 concentration <1500 ppm*

Concerning the good level of CO_2 concentration <1000 ppm, the results of Phase Two and (ET) location in Figure 5-15 show that the performance of all the cases after reviewing the opening schedules has been improved slightly compared with their results in Chapter Four. Moreover, the open zones (studio) layout cases have slightly better results than separated zones cases for instance Cases 3, 5, and 7 achieved plus 165, 256, and 254 hours respectively better than it is results in Chapter Four, while Cases 2, 4, and 6 have simply plus 122, 88, and 132 hours better. Similarly, to the accepted hours, the good hours category results show as well that in both Phases One and Two and in both (ET and T) positions, the open studio layout design (Cases 3, 5 and 7) have better results than the separated zones Cases (Case 2, 4, and 6). Likewise, conversely to both Phases One and Two and similarly to the accepted hours CO_2 concentration in Phase Three and in both (ET and T) positions, separated zones layout design cases (Cases 2, 4, and 6) have better results.

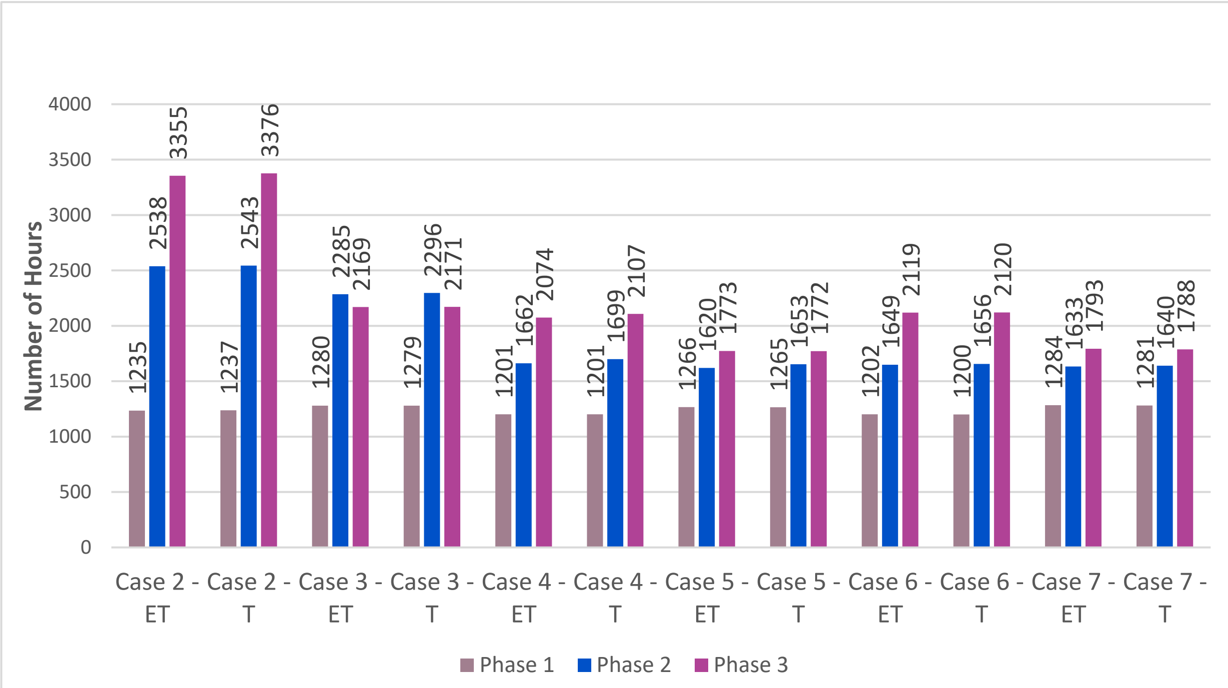


Figure 5-15 *Average annual hours of CO_2 concentration <1000 ppm*

5.4 Discussion and Conclusion

The continuous root causes (natural and man-made) are the reasons for increasing and continuing the displaced issue for masses of people globally. However, existing studies show that several aspects have not yet been incorporated into constructing displaced camps and shelters to achieve more sustainable shelters. For instance, lifespan and incremental strategies, affordability, thermal and air quality comfort, sufficient energy, Socio-cultural aspects, integration with local planning and design system, and environmental impact. Thus, the valuable contribution and real novelty of this chapters study is to fill that gap by integrating the above factors in the six refugees' core shelters prototypes designed based on the Middle Eastern cultural context using locally available sustainable construction materials and techniques and embedded in the local planning system with it is three incremental phases. Subsequently, This study question is what upgrading phases and methods could be proposed to prolong the lifespan of the core shelters based on the Iraqi context, allows upgrading based on time, available cost and need, and what is their energy and indoor environment performance? Moreover, this study aimed to empirically evaluate the prototype typologies' energy and indoor environment performance for six refugees' core shelters through three incremental phases with two different positions, i.e., terraced (T) and end-of-terraced (ET). The study used the dynamic program Indoor Climate and Energy IDA ICE 4.8 SP2 for simulation assessment of energy and indoor environment performance .

The findings of this study concerning energy performance revealed that more than 1000 kW could be saved between the cases typologies (Cases 2 and 5) with the same phase and under the same variables. Concerning positioning, similarly, more than 300 kW can be saved in prototypes by simply changing the position from end-of-terraced (ET) to terraced (T). Furthermore, however, the smallest thermal bridges additionally to high heat gain in the winter season compared to the open to the yard cases (Cases 2 and 3) and vertical plot layout cases (Cases 6 and 7) gives superiority to the horizontal compact shapes layout cases (Cases 4 and 5) regarding heating energy. While on the other hand regarding cooling the same reasons and overheating in winter are evidence for the revealed approximately equal results for instance the superior result of cooling for Phase Three compared to One and Two. Regarding cost implications and compared with the base case scenarios with conventional materials, the bottom-up method in this study prototypes have the superiority to save energy by more than 10,800 kWh in simply one case, equivalent to more than 2700 US dollars annually. Furthermore, compared with other research which has assessed the superiority of the earth technique for detached shelter over other humanitarian shelters [59], the three phases of this study have significantly more energy saving regarding kWh/m2 duo the attached zones pattern for a single dwelling, planning block scheme, and adopted technique (variation wall materials).

Moreover, concerning indoor environment comfort, even the performance of cases after reviewing opening schedule have been improved slightly compared with Chapter Four results as Phase Two of designed cases while there is still some overheating in some cases in both Phases

One and Two especially in the (T) position. For instance, the superiority in the thermal comfort performance for horizontal compact cases (Cases 4 and 5) in Phases One and Cases 3 and 7 in Phase Two when changing position from (T to ET) and conversely result for Phase Three is evidence of the issue of overheating in the two other phases because in Phase Three the spaces are bigger to get overheated in winter. Furthermore, it is important to calculate the good ratios of indoor environment parameters sometimes to get more understanding for the real performance of prototypes. For instance, the results of thermal comfort are almost the same (99% and 97% respectively) for the accepted hours ratio in Case 5 and 6 with the (ET) position while with assessment of good hours ratio their performane are (89% and 74%).

This study data and recommendations, contribute a clear understanding to the performance of indoor environment through assessing more than variable otherwise it is easy to enhance simply energy or thermal comfort performance. For instance, the results of PMV are slightly inconsistent with the thermal comfort indicator due to the various measurements variables of PMV. Concerning CO2 concentration, the volume of the air in separated zones layout design cases (Cases 2, 4, and 6) seems not enough to have sufficient fresh air based on the opening schedules in phase one and two. Conversely, the huge size of air volume in phase 3 for studio layout design cases (Cases 3, 5, and 7) were not sufficiently changed based on the opening schedules, while separated zones cases were most sufficient.

the findings for indoor environment comfort compared with above mentioned reference revealed that this study still has significantly better results as the worst result of the percentage ratio for the thermal comfort accepted hours are 89%, 92%, and 94%, and for the predicted mean vote (PMV) are 74%, 85%, and 83% in three incremental phases respectively. However, concerning CO2 concentration, the open to yard cases (Cases 2 and 3) have better results and other Cases have performed almost the same, while generally, the accepted performances of all scenarios are between 29 to 51%. Therefore, it is recommended that each design case typology must have it is special opening schedule to have even better results regarding avoiding overheating in winter to improve thermal comfort and PMV even better beside enhancing CO_2 concentration level.

To summarize, this study has made an original and relevant contribution compared to the results of the research already carried out. For instance, to minimize the environmental footprint, there is a high possibility of prolonging shelters' life span, which can later be reused by low-income local communities when refugees return to their homelands. To accommodate their needs, however, the upgraded base shelters could be expanded through an incremental improvement strategy while keeping affordability and the energy and thermal efficiency of the shelters a top priority. Doubling the overall area by adopting materials and techniques mentioned earlier would require somewhere between 16 to 40 kWh/m2 to provide acceptable indoor temperatures throughout the year. The variation depends mainly on the layout used, with compact layouts showing the lowest heating and cooling consumption.

The study has a few limitations, such as calibration via in-site measurements data or another simulation program while this was due to the strict security routine to access camps and data in the real site besides the lack of access to another free simulation program and lack of sufficient time to learn and repeat the evaluation of all scenarios. Another limitation is that the utilized simulation software cannot simulate the effect of vegetation and greenery outside on the performance of the prototypes. The last limitation was both phases 1 and 3 have not been compared with it is scenarios with conventional materials since simply Phase Two has been designed with conventional materials and established in chapters Three and Four however, Phase Two is the real phase in the sample case and it is the most reasonable phase for the situation now in Duhok City.

Despite those limitations, this study concludes with important suggestions and recommendations for future research. For instance, it is recommended that each design case typology must have a special opening schedule to have even better results regarding avoiding overheating in winter to improve thermal comfort and PMV besides enhancing CO_2 concentration level. Furthermore, to better understand the effect implications of the study results, future studies could parallelly utilize simulation software that can assess the effect of vegetation and greenery outside the shelters on the performance of the prototypes. Additionally, future studies could address the possibility of vertical incremental phases for shelters. Another recommendation is to investigate the impact of several passive factors such as double roof, the height of the roof, utilizing carpet in winter, and the effect of the upper floor on the performance of the ground floor. The final recommendation for future works is to assess the impact of several other low-impact construction (LIC) materials and techniques for instance, stones, cordwood, waste materials such as car tires, and recycled bottles. Concerning the practical implication of this study, it is designed techniques and typologies would benefit the displaced people in the Middle East cultural context, especially Syrian refugees and Duhok city in the north of Iraq. Moreover, various places of the world could adopt the methodologies and construction techniques of the prototypes and study concerning displaced issues and affordable housing. Additionally, concerning theoretical implications, the study methodologies and the recommendations mentioned above could add valuable tips in the field.


Nirgezliya 2 Camp


Darkar Camp

CHAPTER 6

GENERAL CONCLUSION, FINDINGS and RECOMMENDATIONS

6.1 Overview

The research aimed to develop affordable refugee core shelters' performance and minimize their environmental impact by adopting sustainable materials and methods. Based on a qualitative and quantitative analysis, the process has answered those eight questions in the introduction chapter and filled the three main gaps identified in the existing literature. First, the investigation found that the lifespan for the current displaced people shelters is generally incompatible with the displaced period. Additionally, the integration of some other main issues has been noticed, such as affordability, thermal and air quality comfort, sufficient energy, Socio-cultural aspects, integration with local planning and design systems, and environmental impact. Consequently, several sustainable construction methods and materials have been investigated then; based on the context of this research, low-impact construction (LIC) through the bottom-up approach, besides the incremental strategy, have been targeted.

Furthermore, the current condition of shelters regarding construction materials and techniques, thermal comfort and energy performance based on conventionally used materials in Duhok City in Iraq have been analyzed. Moreover, by proposing a novel construction method, the study offered the opportunity to prolong the lifespan of shelters and enhance the indoor environment and energy performance by assessing and comparing nine different scenarios.

Later, by integrating the above six identified issues, the research designed and proposed comprehensive prototypes typologies for the refugee's core shelters considering several variables (open to the yard and compact, horizontal and vertical plot sited and separated spaced or studio layout design systems) based on the socio-cultural (Middle East cultural context) and local planning and design systems in Duhok City north of Iraq. Additionally, the impact of orientation on the performance of six designed Cases through eight different cardinal (S, W, N and E) and ordinal (SW, NW, NE and SE) directions have been addressed. The results revealed that the compact with horizontal plot sited layout forms have more superiority in energy saving and providing better indoor thermal conditions. Moreover, the impact assessment of orientation indicated that the best-performed models were generally the ones in the south (S).

Finally, based on the results of previous steps from the impact of the bottom-up construction method, designing sustainable typologies and identifying the best orientation, the last stage of this research has been established. Consequently, three upgrading phases through incremental strategy proposed to prolong the lifespan of the core shelters based on the Iraqi context and allows upgrading based on time, available cost and need. Moreover, empirical evaluation for the energy use and indoor environment performance for six designed core shelters typologies with three incremental phases in two different positions, i.e., terraced (T) and end-of-terraced (ET) has been done.

To sum up, the valuable, novelty and main contribution study is to fill gaps by integrating the six main shortcomings in the current literature. That is through developing the energy and indoor environment performance of the six proposed core shelters typologies, designed based on the Middle Eastern cultural context using locally available sustainable construction materials and techniques and embedded in the local planning system with their three incremental phases). The study used the dynamic program Indoor Climate and Energy IDA ICE 4.8 SP2 for simulation and Excel sheets software to evaluate and calculate the performance of models.

6.2 Key Findings

This research has found several findings through investigating and addressing the three main gaps which have been founded in the previous literature while the following are the main key findings:

- The findings revealed firstly that the conventional construction materials and methods used in building refugee shelters in Iraq lead to high rates of indoor thermal discomfort and energy consumption, with heating demand being two to three times that of cooling demand (C1S1). At the free-running stage, the mean indoor operative temperatures remain between 32 to 35 °C and 10 to 12 °C (Apendix) during summer and winter, respectively. Shelters built with corrugated metal roofing (zinc), which are the predominant shelters (C1S1), would require 220 kWh/m^2 and 77 kWh/m^2 for heating and cooling, respectively, whilst those built with insulated roof sandwich panel (i.e. an 8 cm layer of the insulating board, skinned on both sides with sheet metal) (C1S2) would require 96 kWh/m2 and 44 kWh/m^2 for heating and cooling respectively.

- The next finding is that, by application of the novel mixed technique (C1S9) as triple techniques in one single shelter wall from low-impact and thermally efficient materials, such as earth-based materials and straw, which are locally available and widely used by rural communities, can be remarkably reduced the energy consumption and enhance indoor thermal comfort. Conversely to conventional materials, such a technique greatly impacts reducing heating much more than cooling. For instance, it would require 17 kWh/m^2 and 34 kWh/m^2 for heating and cooling, respectively. Additionally, the total cooling and heating energy that could be saved compared to the first base case C1S1 (corrugated zinc metal roofing), is 85%, and compared with the second base case C1S2 (insulated sandwich panel) is 67.5%. Moreover, the thermal comfort accepted hours ratio for the adopted technique C1S9 is about 90%. Regarding energy and cost implications and compared with the base case scenarios with conventional materials, this method can save energy by more than 10000 kWh in simply one case, equivalent to more than 2500 US dollars annually. Consequently, there is a possibility in a camp scale such as Domiz-one with around 5500 shelters to save about 55 000 mWh, equivalent to 13 750 000 US dollars annually.
- Another finding of this research is that, different layouts have a different impact on shelters' performance, with compact forms having more superiority in energy saving and providing better indoor thermal conditions. Given its nature which provides much less opportunity for heat exchange between indoor and outdoor and thereby less opportunity for heat loss, with the compact layout, there is a possibility to keep the heating consumption below 2.5 kWh/m^2, a figure that is equivalent to almost 85% saving in

heating fuel compared with base case typology (C1S9). This is besides keeping cooling consumption below 23 kWh/m^2. Given its nature and the more openings that it has to the yard, which promote natural ventilation across the shelter, meanwhile, open to yard layout shows more superiority in terms of air quality, with more occupied hours below 1000 ppm.

- ❖ Moreover, the study found that the performance concerning energy revealed that more than 1000 kW (48% from heating-cooling) could be saved between the designed cases typologies (Cases 2 and 5) with the same phase and under the same variables. Concerning positioning, similarly, more than 300 kW (19% from heating-cooling) can be saved in prototypes by simply changing the position from end-of-terraced (ET) to terraced (T). Likewise, concerning the impact of orientation, there is a possibility of saving more than 450 kW from heating-cooling energy use by simply changing orientation from northwest (NW) to south (S) direction.
- ❖ Finally, this study has made an original and relevant contribution compared to the results of the research already carried out. For instance, to minimize the environmental footprint, there is a high possibility of prolonging shelters' life span, which can later be reused by low-income local communities when refugees return to their homelands. To accommodate their needs, however, the upgraded base shelters could be expanded through an incremental improvement strategy while keeping affordability and the energy and thermal efficiency of the shelters a top priority. Doubling the overall area by adopting materials and techniques mentioned earlier would require somewhere between 16 to 40 kWh/m2 to provide acceptable indoor temperatures throughout the year. The variation depends mainly on the layout used, with compact layouts showing the lowest heating and cooling consumption.

6.3 Recommendation and Future Work

Firstly, it has to be mentioned that the study has a few limitations, such as calibration via in-site measurement data or another simulation program. This was due to the strict security routine to access camps and data in the real site besides the lack of access to another free simulation program and insufficient time to learn and repeat the evaluation of all scenarios. Another limitation is that the utilized simulation software cannot simulate the effect of vegetation and greenery outside on the performance of the prototypes. Besides those limitations, this research concluded with the following recommendations for future investigations:

- It is recommended that each design case typology must have a special opening schedule to have even better results regarding avoiding overheating in winter to improve thermal comfort and PMV besides enhancing CO_2 concentration level.
- Furthermore, to better understand the effect implications of the study results, future studies could parallelly utilize simulation software that can assess the effect of vegetation and greenery outside the shelters on the performance of the prototypes. Similarly, it can also take site measurements for the calibration process.
- Additionally, future studies could address the possibility of vertical incremental phases for shelters.
- Another recommendation is to investigate the impact of several passive factors, such as the double roof, the height of the ceiling, utilizing carpet in winter, and the upper floor's effect on the ground floor's performance.
- Also, it is recommended for future works to assess the impact of several other low-impact constructions (LIC) materials and techniques, for instance, stones, cordwood, waste materials such as car tires, and recycled bottles.
- Concerning the practical implication of this study, it is recommended for the displaced people in the Middle East cultural context, especially Syrian refugees and Duhok city in the north of Iraq, and the stakeholders to adopt the designed methods and techniques for this study into consideration when aiming for sustainable shelters typologies or accommodate low-income people.
- Finally, it is recommended for various places of the world to consider and adopt the methodologies and construction techniques of designed prototypes of this research when aiming for displaced issues and affordable housing.

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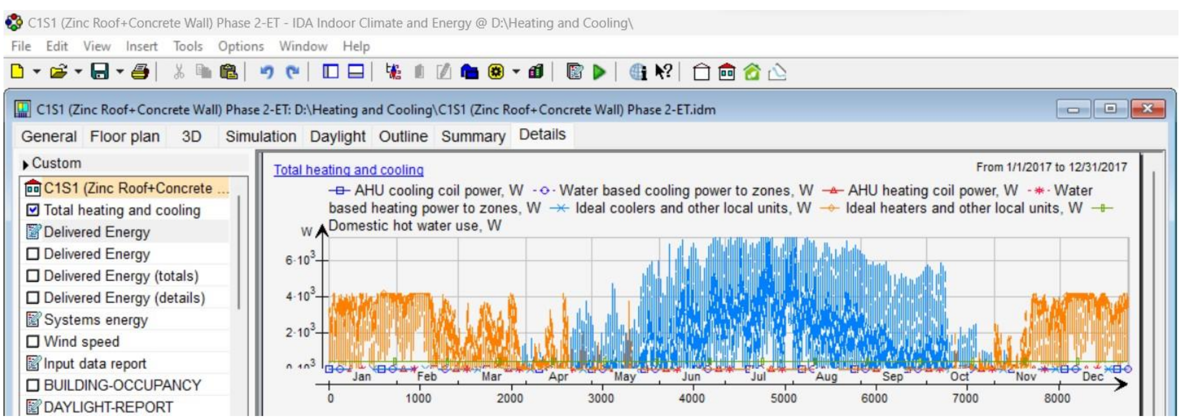
Appendix

A1- C1S1- Energy

Delivered Energy: output object in C1S1 (Zinc Roof+Concrete Wall) Phase 2-ET

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	91	2.3	0.06
Electric cooling	3097	76.8	2.43
HVAC aux	0	0.0	0.0
Total, Facility electric	3188	79.0	
Fuel heating	8861	219.6	4.63
Domestic hot water	3962	98.2	0.45
Total, Facility fuel*	12823	317.8	
Total	16011	396.9	
Equipment, tenant	147	3.6	0.1
Total, Tenant electric	147	3.6	
Grand total	16158	400.5	

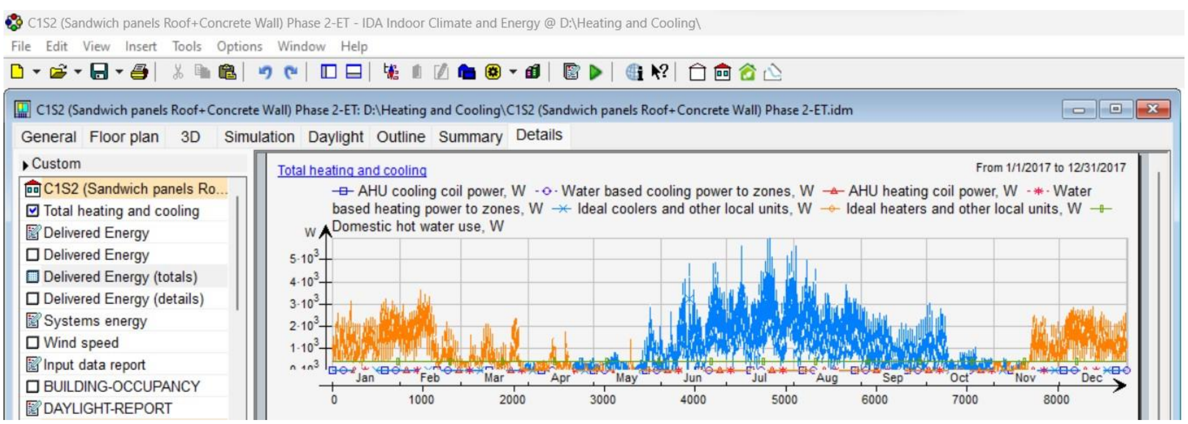


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility (kWh)	Electric cooling (kWh)	HVAC aux (kWh)	Fuel heating (kWh)	Domestic hot water (kWh)	Equipment, tenant (kWh)
1	8.3	5.2	0.0	2336.0	336.5	12.4
2	7.4	4.7	0.0	1900.0	303.9	11.3
3	8.0	8.8	0.0	867.3	336.5	12.4
4	7.8	53.8	0.0	205.9	325.6	12.2
5	7.1	211.3	0.0	40.2	336.5	12.4
6	6.3	608.0	0.0	0.0	325.6	12.0
7	6.8	921.9	0.0	0.0	336.5	12.6
8	7.6	733.8	0.0	0.0	336.5	12.4
9	7.8	378.6	0.0	0.0	325.6	12.2
10	8.1	157.9	0.0	24.8	336.5	12.4
11	7.4	7.8	0.0	1011.0	325.6	12.0
12	8.1	5.2	0.0	2476.0	336.5	12.6
Total	90.8	3096.9	0.0	8861.2	3961.8	147.2

A2- C1S2- Energy

Delivered Energy: output object in C1S2 (Sandwich panels Roof+Concrete Wall) Phase 2-ET

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	91	2.3	0.06
Electric cooling	1762	43.7	1.99
HVAC aux	0	0.0	0.0
Total, Facility electric	1853	45.9	
Fuel heating	3856	95.6	4.01
Domestic hot water	3962	98.2	0.45
Total, Facility fuel*	7818	193.8	
Total	9671	239.7	
Equipment, tenant	147	3.6	0.1
Total, Tenant electric	147	3.6	
Grand total	9818	243.4	

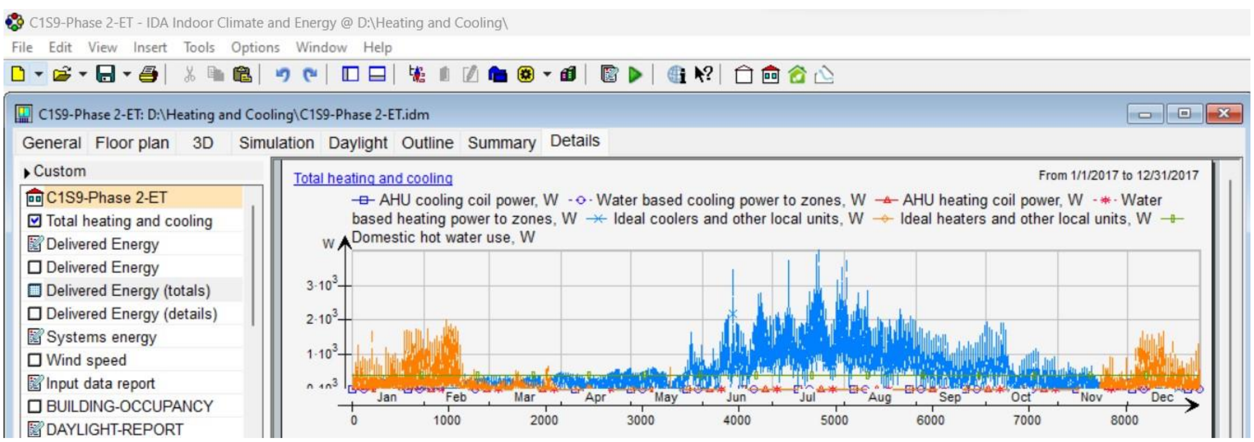


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	8.3	5.2	0.0	1006.0	336.5	12.4
2	7.4	4.7	0.0	948.9	303.9	11.3
3	8.0	6.1	0.0	364.8	336.5	12.4
4	7.8	16.2	0.0	107.1	325.6	12.2
5	7.1	72.3	0.0	14.5	336.5	12.4
6	6.4	321.4	0.0	0.0	325.6	12.0
7	6.8	533.2	0.0	0.0	336.5	12.6
8	7.6	438.3	0.0	0.0	336.5	12.4
9	7.8	223.8	0.0	0.0	325.6	12.2
10	8.1	123.9	0.0	2.4	336.5	12.4
11	7.4	11.7	0.0	363.4	325.6	12.0
12	8.1	5.2	0.0	1049.0	336.5	12.6
Total	90.7	1762.0	0.0	3856.2	3961.8	147.1

A3- C1S9- Energy

Delivered Energy: output object in C1S9-Phase 2-ET

		Purchased energy		Peak demand
		kWh	kWh/m²	kW
■	Lighting, facility	91	2.6	0.06
■	Electric cooling	1220	34.3	1.34
■	HVAC aux	0	0.0	0.0
	Total, Facility electric	1311	36.8	
■	Fuel heating	604	17.0	2.22
■	Domestic hot water	3911	109.9	0.45
	Total, Facility fuel*	4515	126.9	
	Total	5826	163.7	
□	Equipment, tenant	147	4.1	0.1
	Total, Tenant electric	147	4.1	
	Grand total	5973	167.8	

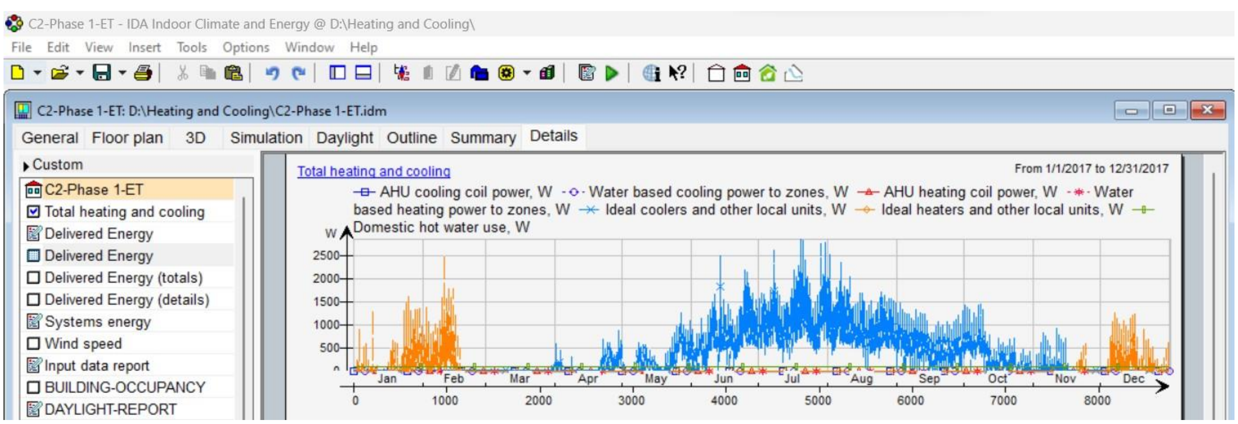


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	8.3	13.8	0.0	170.6	332.2	12.4
2	7.4	13.3	0.0	193.4	300.1	11.3
3	8.0	33.6	0.0	30.3	332.2	12.4
4	7.8	48.4	0.0	0.5	321.5	12.2
5	7.1	65.9	0.0	1.8	332.2	12.4
6	6.4	181.3	0.0	0.0	321.5	12.0
7	6.9	307.3	0.0	0.0	332.2	12.6
8	7.6	255.8	0.0	0.0	332.2	12.4
9	7.8	138.1	0.0	0.0	321.5	12.2
10	8.1	111.2	0.0	0.0	332.2	12.4
11	7.4	40.5	0.0	34.3	321.5	12.0
12	8.1	10.3	0.0	173.5	332.2	12.6
Total	91.1	1219.6	0.0	604.4	3911.5	147.2

A4- Case 2- Phase 1- ET- Energy

Delivered Energy: output object in C2-Phase 1-ET

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
	Lighting, facility	185	5.3	0.15
	Electric cooling	1013	28.8	0.95
	HVAC aux	0	0.0	0.0
	Total, Facility electric	1198	34.0	
	Fuel heating	292	8.3	2.78
	Domestic hot water	960	27.3	0.11
	Total, Facility fuel*	1252	35.5	
	Total	2450	69.5	
	Equipment, tenant	321	9.1	0.76
	Total, Tenant electric	321	9.1	
	Grand total	2771	78.7	

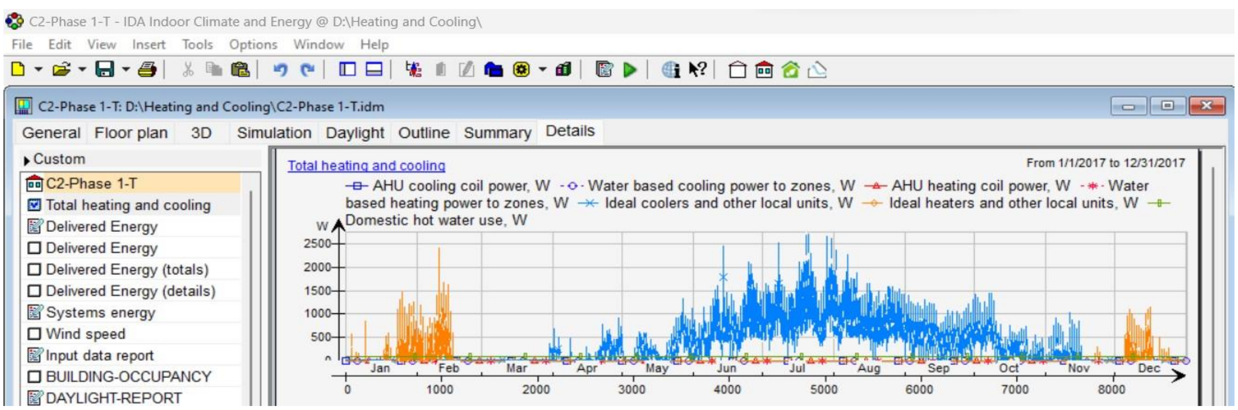


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	16.3	4.5	0.0	80.9	81.5	27.0
2	14.5	4.1	0.0	129.6	73.7	24.6
3	16.0	5.1	0.0	0.0	81.5	26.2
4	16.1	27.7	0.0	0.0	78.9	27.5
5	15.0	49.9	0.0	0.0	81.5	27.1
6	13.7	172.1	0.0	0.0	78.9	25.4
7	14.7	277.1	0.0	0.0	81.5	28.3
8	16.0	235.7	0.0	0.0	81.5	27.0
9	16.0	132.4	0.0	0.0	78.9	26.8
10	16.2	80.4	0.0	0.0	81.5	27.1
11	14.4	19.6	0.0	3.6	78.9	26.2
12	15.7	4.5	0.0	77.9	81.5	27.6
Total	184.8	1013.2	0.0	291.9	960.1	320.7

A5- Case 2- Phase 1- T- Energy

Delivered Energy: output object in C2-Phase 1-T

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
■	Lighting, facility	185	5.3	0.15
■	Electric cooling	986	28.0	0.92
■	HVAC aux	0	0.0	0.0
	Total, Facility electric	1171	33.2	
■	Fuel heating	177	5.0	2.65
■	Domestic hot water	960	27.3	0.11
	Total, Facility fuel*	1137	32.3	
	Total	2308	65.5	
□	Equipment, tenant	321	9.1	0.76
	Total, Tenant electric	321	9.1	
	Grand total	2629	74.6	

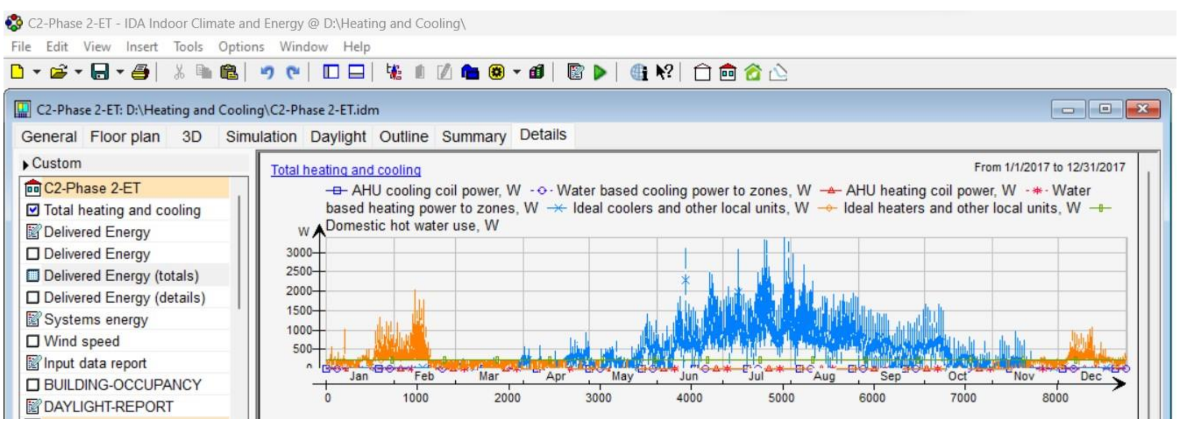


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	16.3	4.5	0.0	46.5	81.5	27.0
2	14.6	4.1	0.0	89.7	73.7	24.6
3	16.0	6.7	0.0	0.0	81.5	26.2
4	16.1	34.1	0.0	0.0	78.9	27.5
5	15.1	51.0	0.0	0.0	81.5	27.0
6	13.7	163.2	0.0	0.0	78.9	25.4
7	14.7	260.7	0.0	0.0	81.5	28.3
8	16.0	221.6	0.0	0.0	81.5	27.0
9	16.0	127.4	0.0	0.0	78.9	26.8
10	16.2	81.7	0.0	0.0	81.5	27.1
11	14.4	26.5	0.0	0.6	78.9	26.2
12	15.7	4.5	0.0	39.8	81.5	27.6
Total	184.8	986.2	0.0	176.6	960.1	320.7

A6- Case 2- Phase 2- ET- Energy

Delivered Energy: output object in C2-Phase 2-ET

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	99	3.0	0.06
Electric cooling	1062	32.4	1.12
HVAC aux	0	0.0	0.0
Total, Facility electric	1161	35.4	
Fuel heating	763	23.3	2.25
Domestic hot water	2113	64.5	0.24
Total, Facility fuel*	2876	87.8	
Total	4037	123.2	
Equipment, tenant	883	26.9	0.83
Total, Tenant electric	883	26.9	
Grand total	4920	150.2	

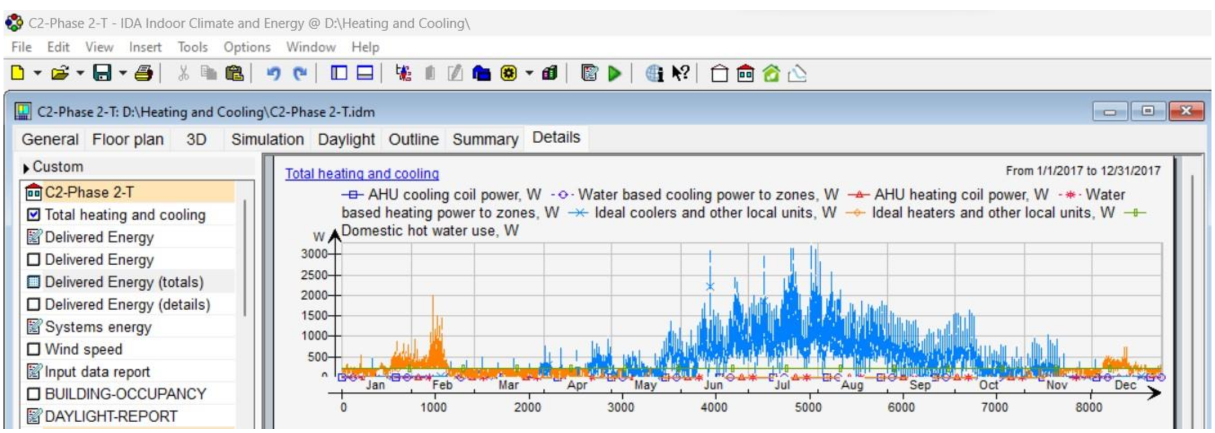


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	8.8	4.3	0.0	193.3	179.5	74.8
2	7.9	3.8	0.0	217.5	162.1	67.8
3	8.6	7.4	0.0	71.4	179.5	74.0
4	8.4	41.4	0.0	17.6	173.7	73.8
5	8.1	51.3	0.0	1.2	179.5	74.8
6	7.4	178.9	0.0	0.0	173.7	71.6
7	7.9	295.7	0.0	0.0	179.5	76.1
8	8.4	244.1	0.0	0.0	179.5	74.8
9	8.5	126.3	0.0	0.0	173.7	73.0
10	8.8	78.3	0.0	0.2	179.5	74.8
11	8.0	26.4	0.0	62.1	173.7	72.4
12	8.7	4.2	0.0	199.8	179.5	75.3
Total	99.4	1062.1	0.0	763.1	2113.4	883.1

A7- Case 2- Phase 2- T- Energy

Delivered Energy: output object in C2-Phase 2-T

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
	Lighting, facility	99	3.0	0.06
	Electric cooling	1028	31.4	1.09
	HVAC aux	0	0.0	0.0
	Total, Facility electric	1127	34.4	
	Fuel heating	690	21.1	2.23
	Domestic hot water	2113	64.5	0.24
	Total, Facility fuel*	2803	85.5	
	Total	3930	120.0	
	Equipment, tenant	883	26.9	0.83
	Total, Tenant electric	883	26.9	
	Grand total	4813	146.9	

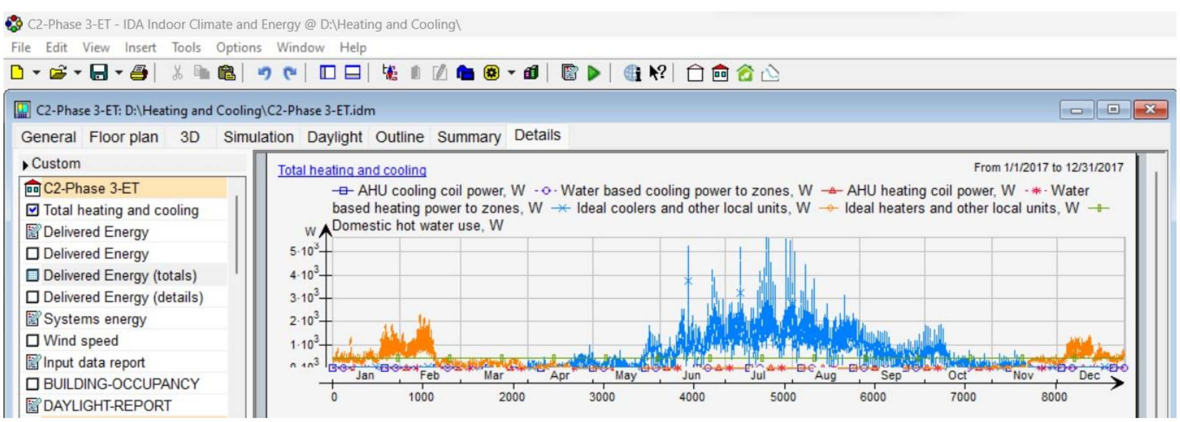


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	8.8	4.6	0.0	171.8	179.5	74.8
2	7.9	4.2	0.0	189.4	162.1	67.8
3	8.6	8.9	0.0	71.0	179.5	74.0
4	8.4	47.1	0.0	17.6	173.7	73.8
5	8.1	51.3	0.0	1.2	179.5	74.8
6	7.4	169.1	0.0	0.0	173.7	71.6
7	7.9	277.8	0.0	0.0	179.5	76.1
8	8.4	228.7	0.0	0.0	179.5	74.8
9	8.5	120.6	0.0	0.0	173.7	73.0
10	8.8	78.5	0.0	0.2	179.5	74.8
11	8.0	32.4	0.0	61.5	173.7	72.4
12	8.7	4.5	0.0	177.7	179.5	75.3
Total	99.5	1027.6	0.0	690.3	2113.4	883.1

A8- Case 2- Phase 3- ET- Energy

Delivered Energy: output object in C2-Phase 3-ET

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	179	2.7	0.09
Electric cooling	1399	20.9	1.87
HVAC aux	0	0.0	0.0
Total, Facility electric	1578	23.6	
Fuel heating	1510	22.6	2.52
Domestic hot water	4240	63.4	0.48
Total, Facility fuel*	5750	86.0	
Total	7328	109.7	
Equipment, tenant	906	13.6	0.83
Total, Tenant electric	906	13.6	
Grand total	8234	123.2	

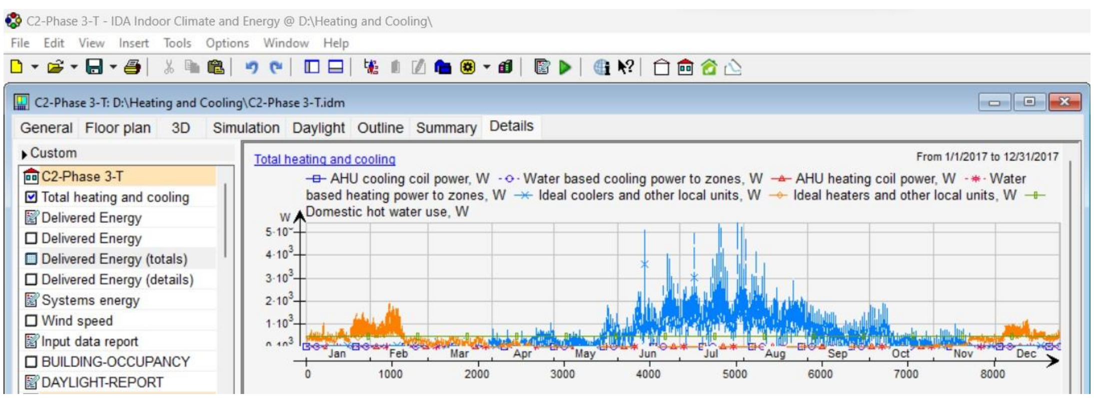


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	16.5	8.6	0.0	402.2	360.1	76.8
2	14.8	7.8	0.0	416.2	325.3	69.5
3	16.0	8.7	0.0	132.0	360.1	75.8
4	15.2	29.9	0.0	27.9	348.5	75.7
5	13.6	59.3	0.0	0.1	360.1	76.6
6	11.7	250.7	0.0	0.0	348.5	73.4
7	12.7	430.6	0.0	0.0	360.1	78.1
8	14.8	343.1	0.0	0.0	360.1	76.6
9	15.7	150.0	0.0	0.0	348.5	74.8
10	16.4	84.7	0.0	0.8	360.1	76.8
11	15.2	16.5	0.0	123.4	348.5	74.2
12	16.3	8.6	0.0	407.1	360.1	77.3
Total	178.8	1398.6	0.0	1509.7	4240.0	905.6

A9- Case 2- Phase 3- T- Energy

Delivered Energy: output object in C2-Phase 3-T

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	179	2.7	0.09
Electric cooling	1327	19.9	1.8
HVAC aux	0	0.0	0.0
Total, Facility electric	1506	22.5	
Fuel heating	1380	20.7	2.1
Domestic hot water	4240	63.4	0.48
Total, Facility fuel*	5620	84.1	
Total	7126	106.6	
Equipment, tenant	906	13.6	0.83
Total, Tenant electric	906	13.6	
Grand total	8032	120.2	

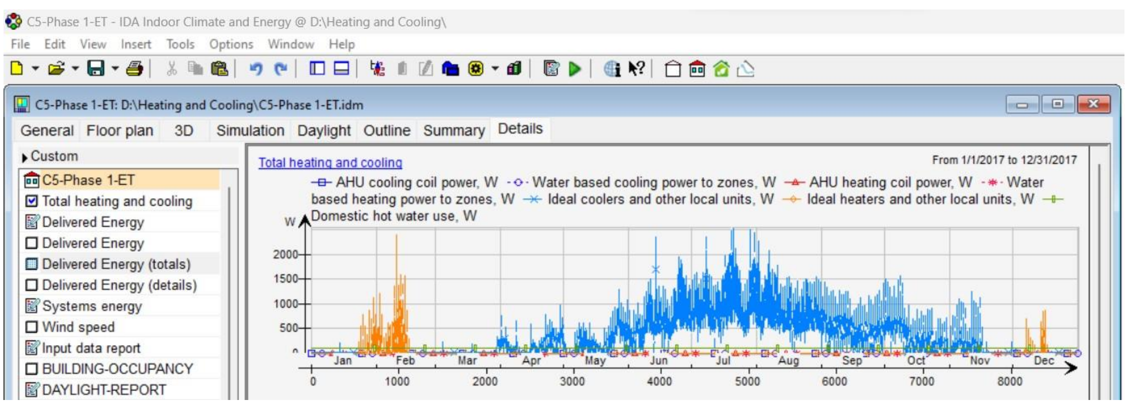


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	16.5	8.6	0.0	365.6	360.1	76.8
2	14.8	7.8	0.0	361.7	325.3	69.5
3	16.0	9.9	0.0	130.3	360.1	75.8
4	15.2	42.9	0.0	27.4	348.5	75.7
5	13.6	60.0	0.0	0.1	360.1	76.6
6	11.7	231.5	0.0	0.0	348.5	73.4
7	12.7	396.0	0.0	0.0	360.1	78.1
8	14.8	313.0	0.0	0.0	360.1	76.6
9	15.7	138.3	0.0	0.0	348.5	74.8
10	16.4	84.4	0.0	0.8	360.1	76.8
11	15.3	26.1	0.0	122.4	348.5	74.2
12	16.3	8.6	0.0	371.3	360.1	77.3
Total	178.8	1327.0	0.0	1379.6	4240.0	905.6

A10- Case 5- Phase 1- ET- Energy

Delivered Energy: output object in C5-Phase 1-ET

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	185	4.4	0.15
Electric cooling	981	23.2	0.85
HVAC aux	0	0.0	0.0
Total, Facility electric	1166	27.6	
Fuel heating	61	1.4	2.64
Domestic hot water	1034	24.4	0.12
Total, Facility fuel*	1095	25.9	
Total	2261	53.5	
Equipment, tenant	321	7.6	0.76
Total, Tenant electric	321	7.6	
Grand total	2582	61.0	

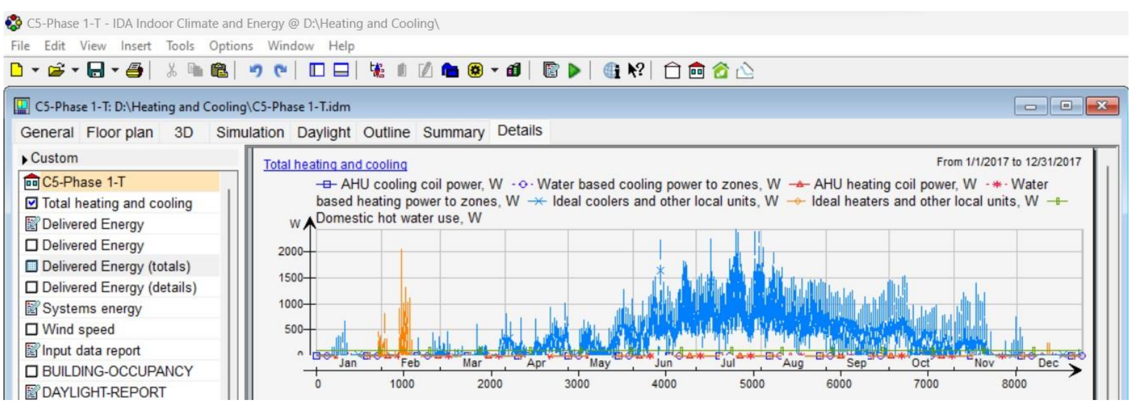


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	15.8	5.6	0.0	12.4	87.8	27.0
2	13.9	4.9	0.0	41.6	79.3	24.6
3	15.9	8.1	0.0	0.0	87.8	26.2
4	16.4	44.1	0.0	0.0	85.0	27.5
5	15.5	51.9	0.0	0.0	87.8	27.1
6	14.3	155.5	0.0	0.0	85.0	25.4
7	15.2	245.6	0.0	0.0	87.8	28.3
8	16.4	208.4	0.0	0.0	87.8	27.0
9	16.1	122.3	0.0	0.0	85.0	26.8
10	15.7	89.6	0.0	0.0	87.8	27.1
11	14.1	39.5	0.0	0.0	85.0	26.2
12	15.4	5.5	0.0	7.1	87.8	27.6
Total	184.6	981.0	0.0	61.1	1034.3	320.9

A11- Case 5- Phase 1- T- Energy

Delivered Energy: output object in C5-Phase 1-T

	Purchased energy		Peak demand
	kWh	kWh/m²	kW
Lighting, facility	185	4.4	0.15
Electric cooling	970	22.9	0.81
HVAC aux	0	0.0	0.0
Total, Facility electric	1155	27.3	
Fuel heating	18	0.4	2.25
Domestic hot water	1034	24.4	0.12
Total, Facility fuel*	1052	24.9	
Total	2207	52.2	
Equipment, tenant	321	7.6	0.76
Total, Tenant electric	321	7.6	
Grand total	2528	59.8	

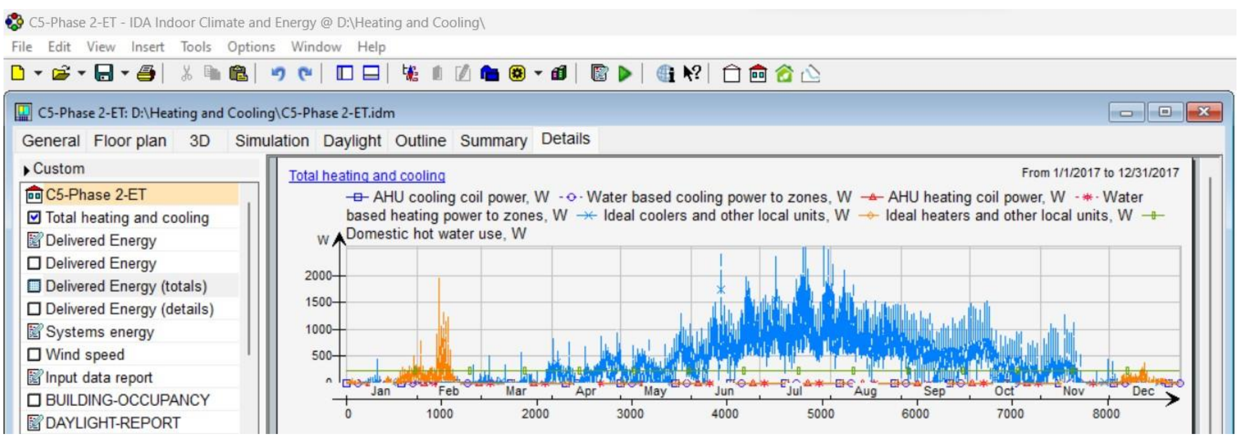


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	15.8	8.1	0.0	1.3	87.8	27.0
2	13.9	6.7	0.0	16.3	79.3	24.6
3	15.9	15.9	0.0	0.0	87.8	26.2
4	16.4	54.6	0.0	0.0	85.0	27.6
5	15.5	52.9	0.0	0.0	87.8	27.1
6	14.3	145.8	0.0	0.0	85.0	25.4
7	15.2	228.4	0.0	0.0	87.8	28.3
8	16.4	193.8	0.0	0.0	87.8	27.0
9	16.1	116.7	0.0	0.0	85.0	26.8
10	15.7	91.1	0.0	0.0	87.8	27.1
11	14.1	49.0	0.0	0.0	85.0	26.2
12	15.4	6.4	0.0	0.3	87.8	27.6
Total	184.6	969.5	0.0	17.9	1034.3	321.0

A12- Case 5- Phase 2- ET- Energy

Delivered Energy: output object in C5-Phase 2-ET

	Purchased energy		Peak demand
	kWh	kWh/m^2	kW
Lighting, facility	122	3.0	0.07
Electric cooling	1053	26.1	0.84
HVAC aux	0	0.0	0.0
Total, Facility electric	1175	29.1	
Fuel heating	96	2.4	2.14
Domestic hot water	2193	54.3	0.25
Total, Facility fuel*	2289	56.7	
Total	3464	85.8	
Equipment, tenant	883	21.9	0.83
Total, Tenant electric	883	21.9	
Grand total	4347	107.7	

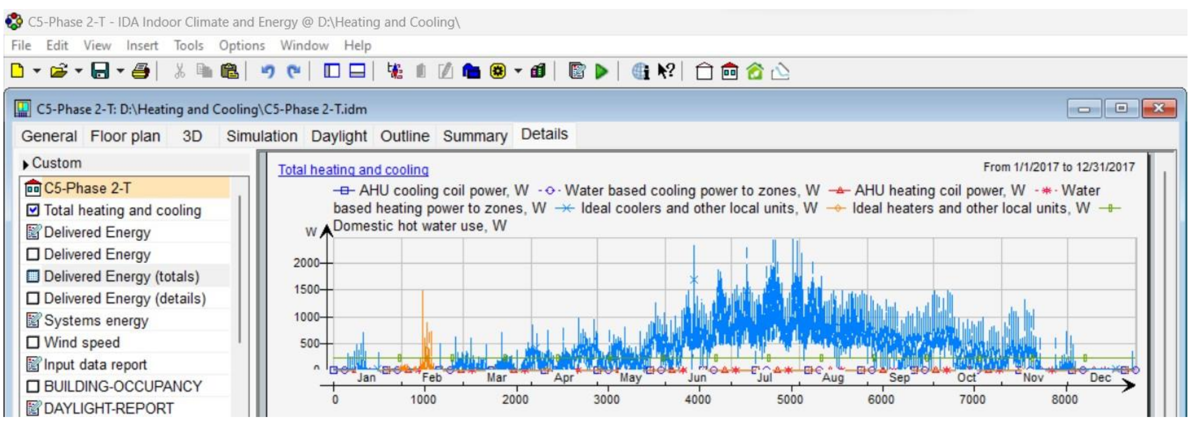


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	10.3	6.3	0.0	20.0	186.3	74.8
2	9.2	5.1	0.0	51.4	168.2	67.7
3	10.4	13.5	0.0	0.0	186.3	74.0
4	10.5	58.7	0.0	0.0	180.3	73.8
5	10.4	60.4	0.0	0.0	186.3	74.8
6	9.8	161.8	0.0	0.0	180.3	71.6
7	10.4	250.9	0.0	0.0	186.3	76.1
8	10.7	214.9	0.0	0.0	186.3	74.8
9	10.4	129.6	0.0	0.0	180.3	73.0
10	10.4	97.0	0.0	0.0	186.3	74.8
11	9.1	48.7	0.0	0.0	180.3	72.4
12	9.9	5.7	0.0	24.2	186.3	75.3
Total	121.7	1052.5	0.0	95.6	2193.5	883.0

A13- Case 5- Phase 2- T- Energy

Delivered Energy: output object in C5-Phase 2-T

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
■	Lighting, facility	122	3.0	0.07
■	Electric cooling	1058	26.2	0.82
■	HVAC aux	0	0.0	0.0
	Total, Facility electric	1180	29.2	
■	Fuel heating	11	0.3	1.63
■	Domestic hot water	2193	54.3	0.25
	Total, Facility fuel*	2204	54.6	
	Total	3384	83.9	
□	Equipment, tenant	883	21.9	0.83
	Total, Tenant electric	883	21.9	
	Grand total	4267	105.7	

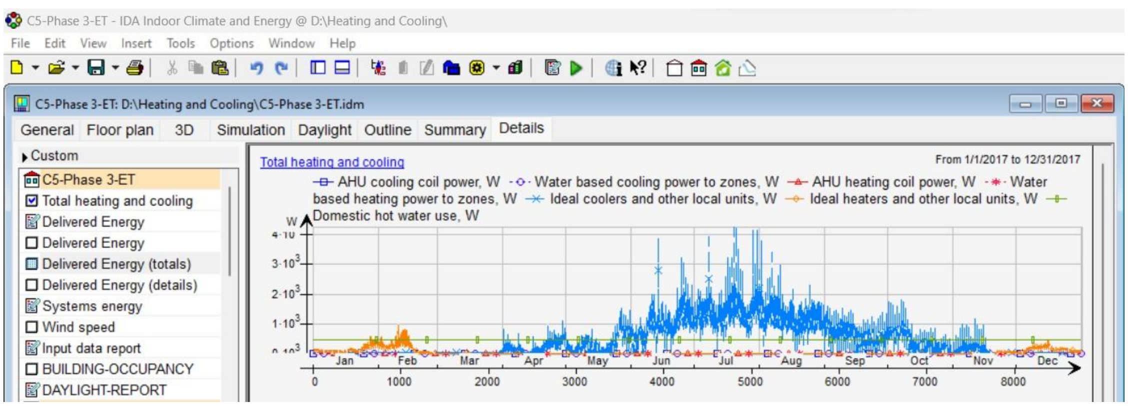


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	10.3	10.3	0.0	0.4	186.3	74.8
2	9.2	8.8	0.0	10.3	168.2	67.7
3	10.4	27.0	0.0	0.0	186.3	74.0
4	10.5	68.0	0.0	0.0	180.3	73.8
5	10.4	61.9	0.0	0.0	186.3	74.8
6	9.8	154.0	0.0	0.0	180.3	71.6
7	10.4	236.7	0.0	0.0	186.3	76.1
8	10.7	202.8	0.0	0.0	186.3	74.8
9	10.4	124.9	0.0	0.0	180.3	73.0
10	10.4	98.7	0.0	0.0	186.3	74.8
11	9.1	57.8	0.0	0.0	180.3	72.4
12	9.9	7.5	0.0	0.0	186.3	75.3
Total	121.7	1058.5	0.0	10.6	2193.5	883.0

A14- Case 5- Phase 3- ET- Energy

Delivered Energy: output object in C5-Phase 3-ET

		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
■	Lighting, facility	207	2.5	0.11
■	Electric cooling	1358	16.3	1.42
■	HVAC aux	0	0.0	0.0
	Total, Facility electric	1565	18.8	
■	Fuel heating	378	4.5	1.06
■	Domestic hot water	4413	53.0	0.5
	Total, Facility fuel*	4791	57.5	
	Total	6356	76.3	
□	Equipment, tenant	904	10.9	0.82
	Total, Tenant electric	904	10.9	
	Grand total	7260	87.1	

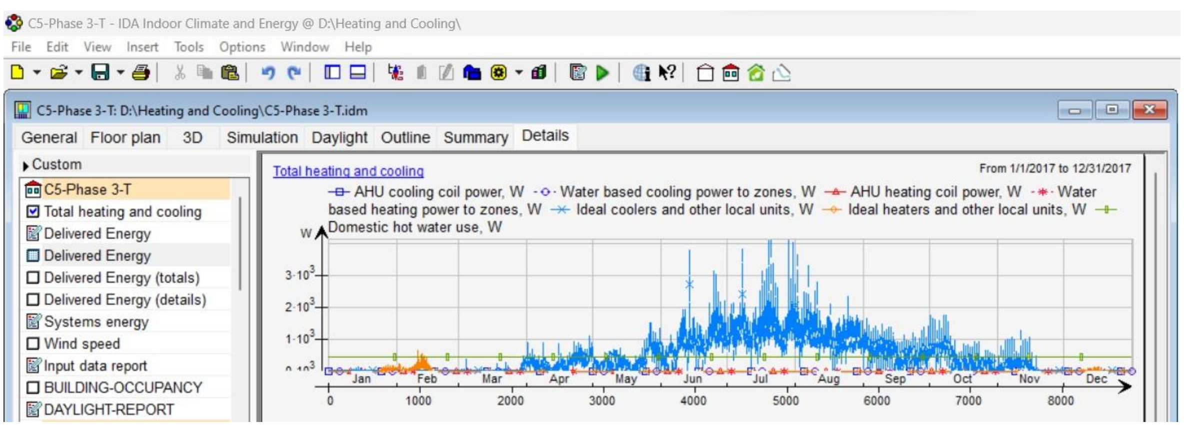


Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	18.5	10.8	0.0	106.9	374.8	76.6
2	16.6	9.7	0.0	141.2	338.6	69.3
3	18.1	11.1	0.0	2.8	374.8	75.6
4	18.0	55.1	0.0	0.0	362.7	75.6
5	16.4	70.3	0.0	0.0	374.8	76.6
6	13.9	227.9	0.0	0.0	362.7	73.4
7	15.5	366.2	0.0	0.0	374.8	78.0
8	17.9	302.3	0.0	0.0	374.8	76.5
9	18.1	154.4	0.0	0.0	362.7	74.8
10	18.6	102.1	0.0	0.0	374.8	76.8
11	16.8	37.5	0.0	15.2	362.7	74.1
12	18.2	10.7	0.0	111.8	374.8	77.1
Total	206.6	1358.2	0.0	377.8	4413.0	904.3

A15- Case 5- Phase 3- T- Energy

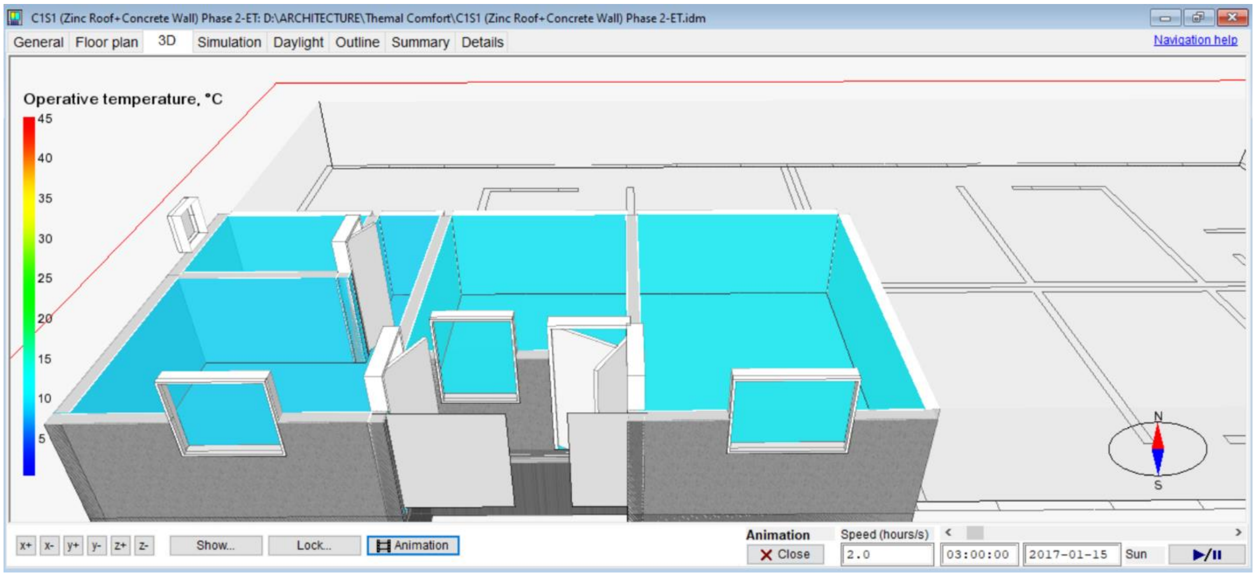
Delivered Energy: output object in C5-Phase 3-T

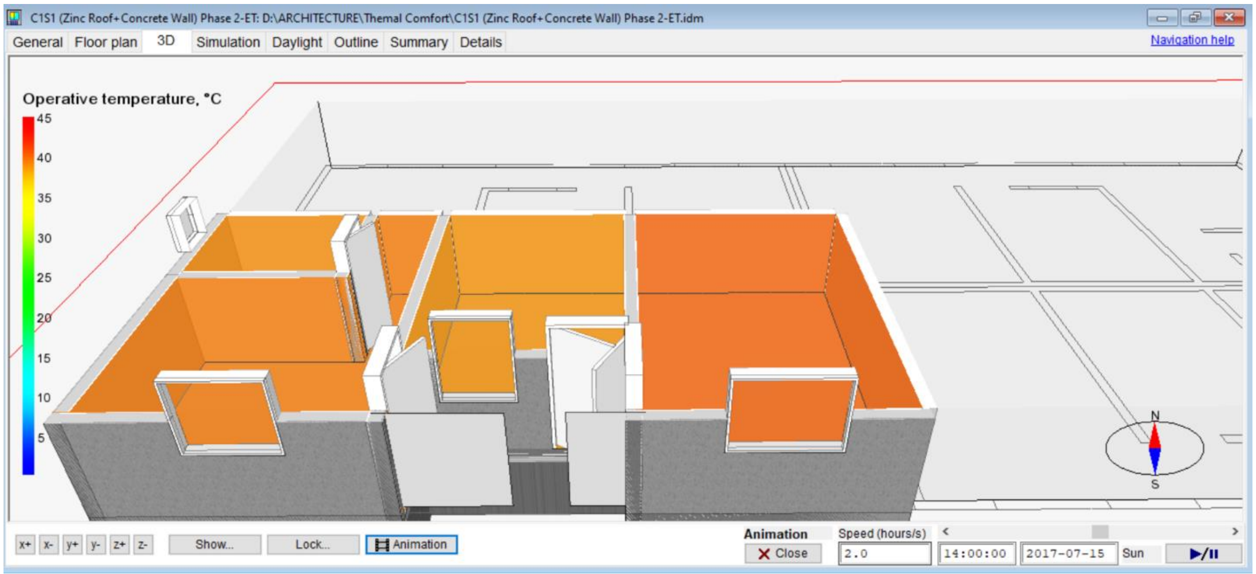
		Purchased energy		Peak demand
		kWh	kWh/m^2	kW
(yellow)	Lighting, facility	207	2.5	0.11
(cyan)	Electric cooling	1325	15.9	1.38
(cyan)	HVAC aux	0	0.0	0.0
	Total, Facility electric	1532	18.4	
(red)	Fuel heating	62	0.7	0.67
(magenta)	Domestic hot water	4413	53.0	0.5
	Total, Facility fuel*	4475	53.7	
	Total	6007	72.1	
(green outline)	Equipment, tenant	904	10.9	0.82
	Total, Tenant electric	904	10.9	
	Grand total	6911	83.0	



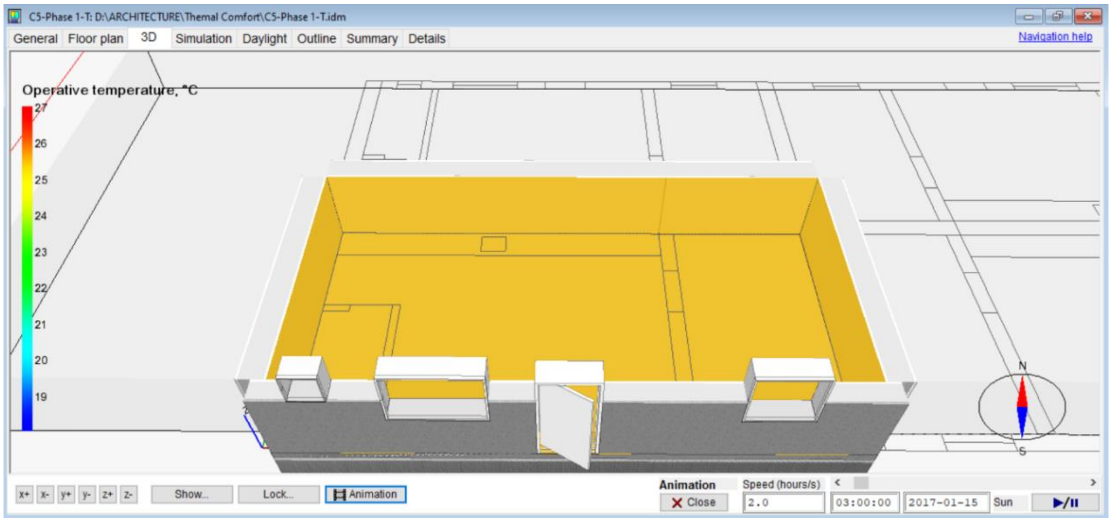
Month	Facility electric			Facility fuel (heating value)		Tenant electric
	Lighting, facility	Electric cooling	HVAC aux	Fuel heating	Domestic hot water	Equipment, tenant
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
1	18.5	10.9	0.0	11.1	374.8	76.6
2	16.6	9.7	0.0	41.9	338.6	69.3
3	18.1	14.3	0.0	0.0	374.8	75.7
4	18.0	71.1	0.0	0.0	362.7	75.5
5	16.4	72.5	0.0	0.0	374.8	76.6
6	13.9	214.5	0.0	0.0	362.7	73.4
7	15.5	342.5	0.0	0.0	374.8	78.0
8	17.9	281.6	0.0	0.0	374.8	76.5
9	18.1	145.6	0.0	0.0	362.7	74.8
10	18.6	103.4	0.0	0.0	374.8	76.8
11	16.8	48.2	0.0	0.0	362.7	74.1
12	18.2	10.8	0.0	9.2	374.8	77.2
Total	206.7	1325.1	0.0	62.2	4413.0	904.4

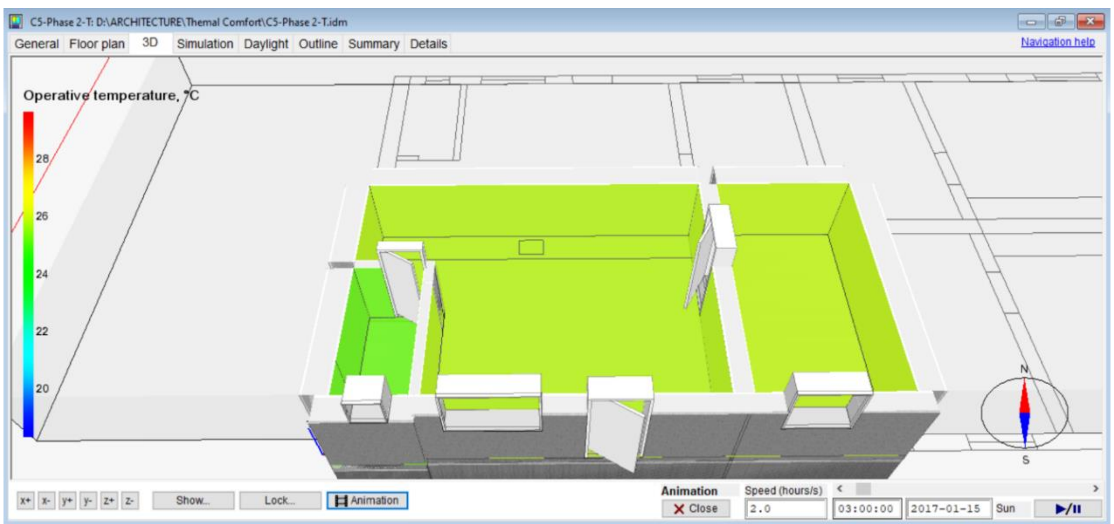
A16- C1S1- Phase 2- ET- Operative temperature- Winter and Summer

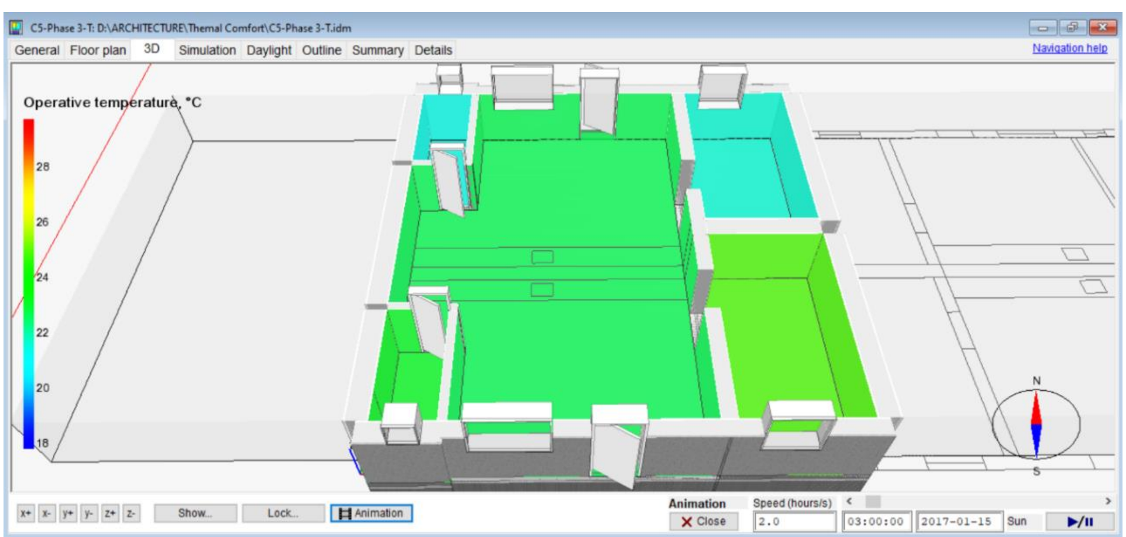




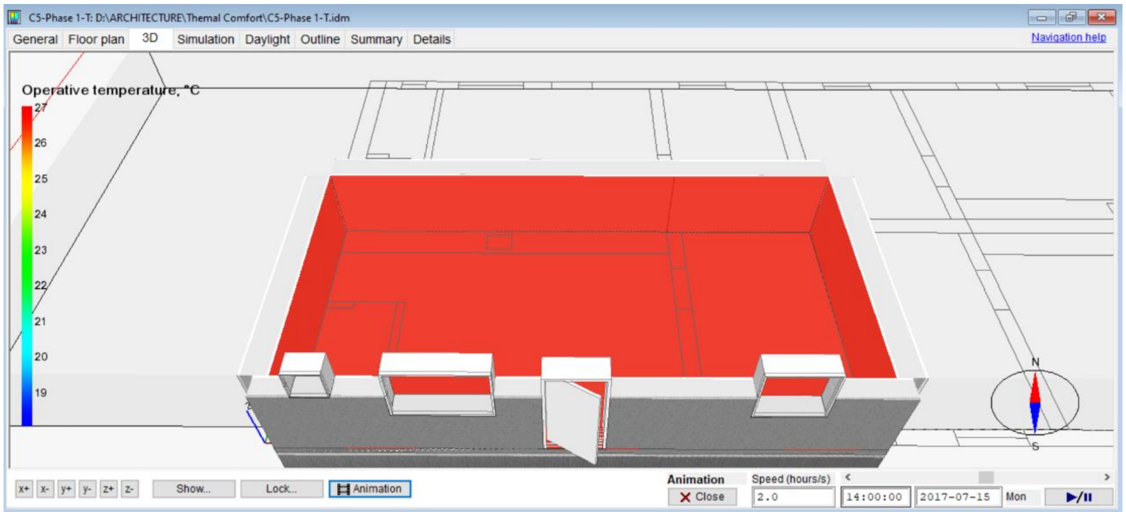
A17- C5- Phases 1, 2 and 3 - T- Operative temperature- Winter

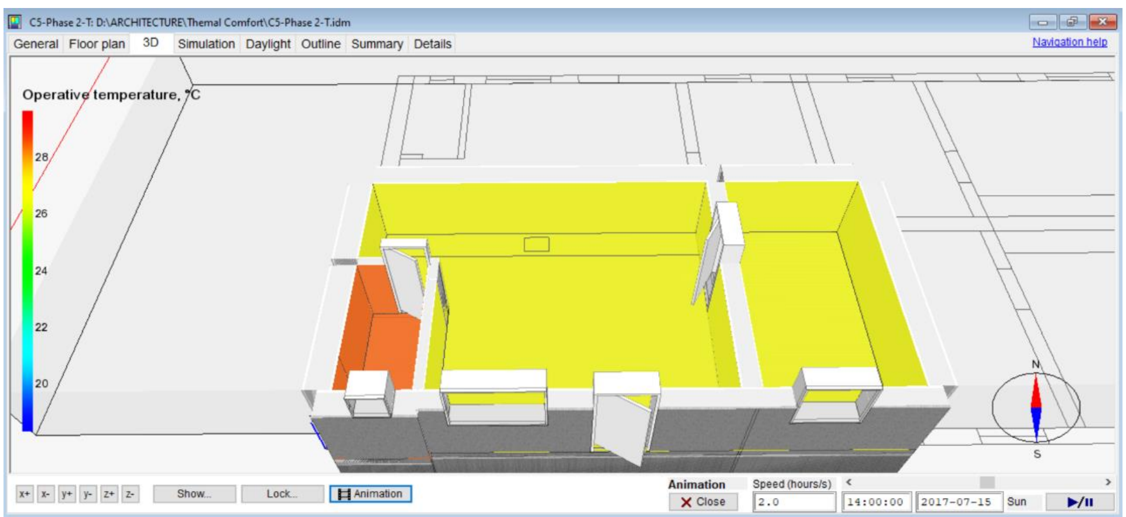


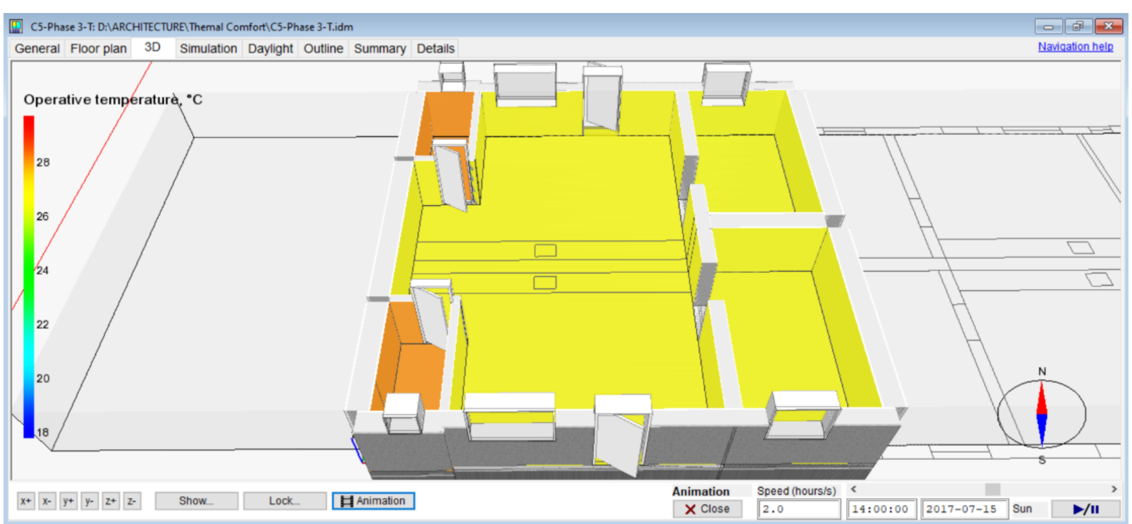




A18- C5- Phases 1, 2 and 3 - T- Operative temperature- Summer







A19- Syrian refugee camp shelters (Domiz-One) in Duhok-Iraq