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Energy Use and Indoor Environment Performance in Sustainably Designed Refugee Shelters: Three Incremental Phases

Rojhat Ibrahim [1,2,3,*], Bálint Baranyai [3,4], Haval Abdulkareem [2,*] and Tamás János Katona [1]

1 Marcel Breuer Doctoral School, University of Pécs, Boszorkány u. 2, 7624 Pecs, Hungary
2 Department of Architectural Engineering, University of Duhok, Duhok 42001, Iraq
3 Energy Design Research Group, Institute of Architecture, Faculty of Engineering and Information Technology, University of Pécs, 7624 Pecs, Hungary
4 Department of Building Structures and Energy Design, Institute of Architecture, Faculty of Engineering and Information Technology, University of Pécs, 7624 Pecs, Hungary
* Correspondence: rojhat.barwary@uod.ac (R.I.); haval.abdulkareem@uod.ac (H.A.)

Abstract: Globally, natural and man-made disasters continue to force the displacement of masses of people. 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. 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 10,000 kWh per unit per year, equivalent to almost 2500 USD savings in energy bills. This is while achieving accepted level for almost 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%.

Keywords: upgrading strategies; post-disaster shelters; sustainable prototypes; low-impact constructions; energy efficiency; thermal comfort

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1. Introduction

The problem of the displacement of a large number of people is now considered one of the continuous global challenges that the individual, society, states, and even international and Non-Governmental Organizations (NGOs) suffer from [1–3]. The root causes of the continuous and increasing migration of masses of people are natural disasters and global warming, conflict and persecution, ethnic and religious discrimination, and economic and political instability, besides demographic factors [4–8]. The last report of the global trend for the United Nations High Commissioner for Refugees (UNHCR) stated that the number of forcibly displaced people reached 100 million, which means a significant milestone exceeded during just one decade (more than double), and one from every 78 people is displaced on earth [9].

Millions of people worldwide, such as Palestinian, Sahrawi, Rohingya, Kurdish, Afghan, and Somalian refugees, have been displaced for decades and live in camps [10–15]. Temporary and inefficient transitional shelters are the predominant typology for many of the displaced people. This has a great burden on refugees, host countries, international organizations, and the environment; besides, its short lifespan costs billions of dollars annually [9,16]. Existing studies show that there are many issues and bad consequences that both camps and shelters have suffered from, as follows:

- The short lifespan of the shelters compared to the displaced period: Waste of resources such as materials and energy, waste of money, and pollution from manufacturing, transportation, and landfill [16–18].
- Inadequate planning and designing systems: Lack of coordination, insufficient services and sheltered areas, lack of safety and security, and more crime because of narrow alleys in the planning system, shared services, and poor quality of doors, windows, and walls. There are also defective materials, land waste due to an isolated unit (detached) approaches, extreme horizontal expansion, and a lack of, or insufficient, upgrading strategies [17,19,20].
- Disregarding socio-cultural aspects: Ignoring social and religious needs, lack of community engagement, shared sanitation, messing privacy, gender-based violence, and conflicts [17,20–22].
- Energy sources and consumption: Fossil fuel energy sources are used widely in camps due to poor efficiency. Their emissions impact the environment and contribute to the global warming issue [23,24].
- Indoor environment issues: Insufficient thermal discomfort, improper ventilation, and relative humidity and high levels of CO_2 concentration, which lead to inadequate health, poor productivity, and discomfort. In addition, the increased use of kerosene-based heaters and the resultant indoor air pollution lead to health risks and 20,000 deaths annually, according to the World Health Organization (WHO) [17,25–28].
- Environmental issues because of the abovementioned problems: Land and resources waste and degradation, pollution from unrenewable energy sources, and nonrenewable waste of materials [16,17,20,29].

Therefore, implementing different strategies and methods is recommended to mitigate the impact of the mentioned issues and enhance the quality of life for displaced people to achieve more sufficient camps and shelters. For instance, energy demand and nonrenewable dependence sources can be avoided dramatically due to passively achieving thermal and indoor environment comfort [30,31]. Furthermore, for investigating indoor environment performance, several categories could be addressed, for instance, carbon dioxide (CO_2) concentration levels could be used to measure indoor air quality (IAQ) [28,32]. Additionally, the predicted mean vote (PMV) is the main indicator of the Fanger comfort model for assessing thermal comfort based on air temperature and mean radiant temperature air velocity, humidity, metabolic rate, and clothing [33].

Another strategy involves low impact construction (LIC) materials and techniques in the industry of displaced shelter construction via both the top-down (prefabricated) method and the bottom-up method [34]. The bottom-up method is considered more acceptable approach culturally, because there is a high level of satisfaction for shelters that are built with locally sourced materials, building on site, construction management by local authorities or NGOs, cost efficiency, durability, social involvement in the construction process, and low environmental impact [18,21,34]. The incremental methodology is another 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. It is usually incorporated into affordable dwelling solutions. The incremental strategy aims to provide the basic functional shelter phase to be upgraded and improved later through other phases, due to shortages in time, finances, and construction material resources [35–37].

Consequently, many pieces of literature globally investigated how to minimize the impact of displaced issues and enhance the quality of life for shelters and camps via different methods and strategies. For instance, Wagemann [38] analyzed and illustrated how people adapt their dwellings after disasters through different incremental phases via transforming temporary structures to permanent ones, with attention to socio-economic, materials, and lifespan. Another study [39] has established the superiority of the traditional earthen techniques over other humanitarian shelters by simulation assessment for energy and indoor environment performance. Through concentration on the novel design and existing solutions, another study [20] investigated and analyzed different displaced shelters via pros and cons for the three pillars of sustainability. A self-built upgrading technique embodied in the staggered-based planning design strategies system has been proposed by a study [40] for internally displaced people (IDP) in Syria. Askar et al. [37] 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.

To conclude, the investigation of the existing studies shows that several factors must be considered regarding achieving sustainable shelters for displaced people for instance:

- Incremental strategies and prolonging the lifespan.
- Affordability by host countries and displaced people.
- Achieving sufficient thermal and air quality comfort.
- Energetically sufficient.
- Socio-cultural aspects.
- Integrated with local planning and design system.
- It must have less impact on the environment.

Whereas there is a gap and limitation in the literature concerning integrating all those factors, especially regarding the context of this study. Therefore, the main contribution and real novelty of this study are to fill that gap by integrating the above factors in the six refugees' core shelters prototypes which have been designed based on the Middle Eastern cultural context using locally available sustainable construction materials and techniques established in [41,42] and to be embedded in the local planning system their three incremental phases. Subsequently, the main aim of this study is to empirically evaluate the energy and indoor environment performance of the six refugees' core shelters typologies through three incremental phases with two different positions, i.e., terraced (T) and end-of-terraced (ET).

2. Study Area

The context of the study focused on Duhok City in the north of Iraq (Figure 1) for study sampling (shelters for displaced people). The altitude of Duhok city is around 565 m above sea level while 36.52° N and 42.94° E are it is coordinating [43]. Concerning the climate and weather, it is characterized by semi-arid cool winters and Mediterranean hot dry summers, it is mean-daily temperature is 32–36 °C in summer while is 4–11 °C in winter [44].

Reducing energy consumption is a critical factor to preserve the environment globally however 40% of the consumption is for the building sector [45,46]. Additionally, concerning Duhok city and energy supplied in form of electricity, there is a huge shortage in daily providing by simply 13 h [44], however, 85% is from fossil fuel-based sources [47]. The huge number of displaced people in Duhok City has accelerated the issue of energy and its impacts on the environment.

The Directorate of Migration and Crises Response-DMCR in Duhok City [48] stated in the last updated report (February 2023) that there are 108,393 families and 540,702 individuals displaced people in the Duhok governorate. Moreover, it mentioned that simply in Domiz-one camp (visited case-study as the largest Syrian refugee camp in Iraq) there are 29,232 refugees distributed to 6132 families while there are just 5496 shelters (Figure 1).

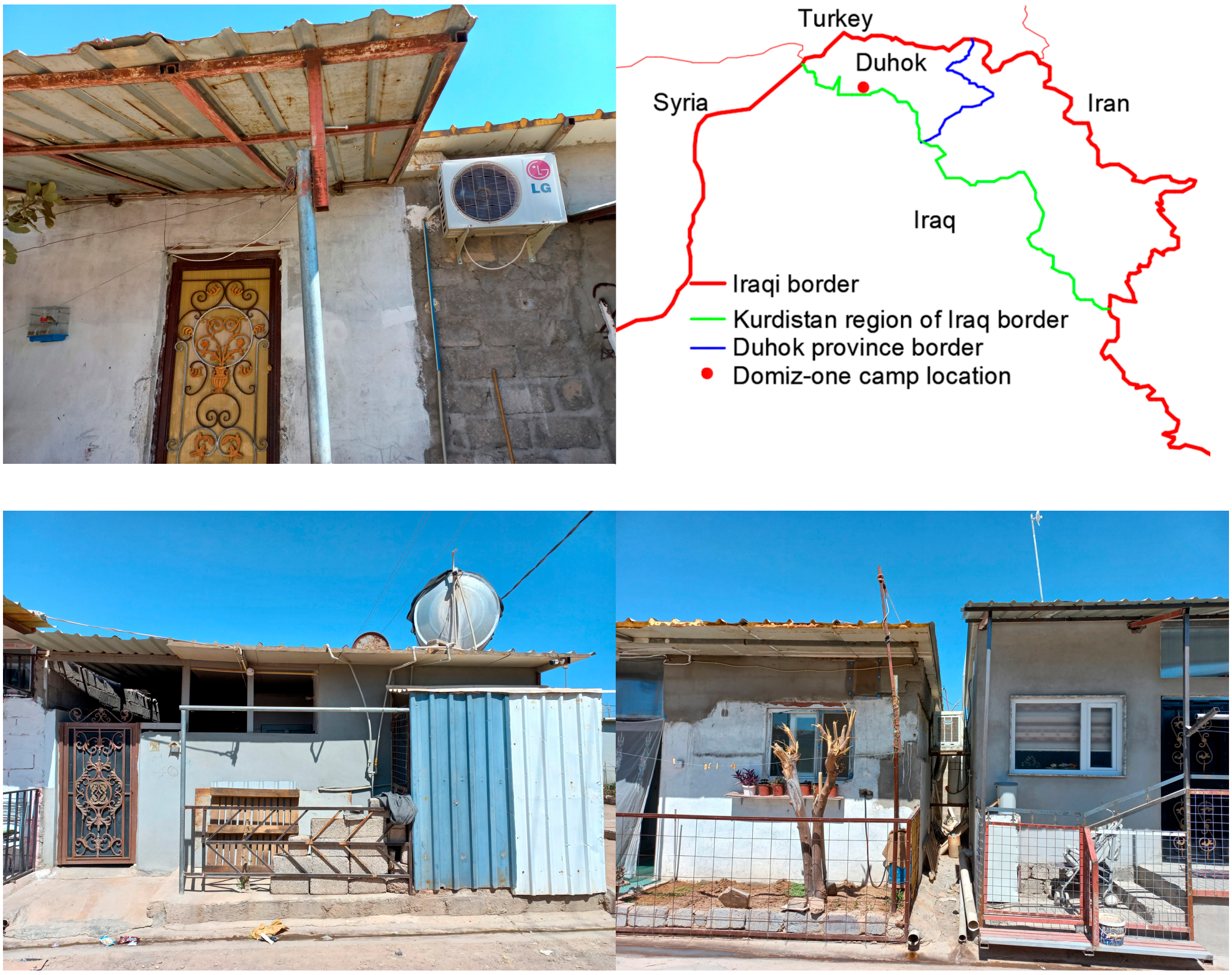

Figure 1. Domiz-one refugee camp location and core shelters photos. (Source 1st Author).

3. Materials and Methods

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. As presented below, the following methods have been adopted to find the answer for this question.

3.1. Theoretical Models

The assessed models represent those six Cases designed and developed based on the previous studies' data presented in [41,42] (Table 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 the yard (Cases 2 and 3) and compact (Cases 4–7) layout design scheme.
- The separated spaced (Cases 2,4, and 6) or studio (Cases 3,5 and 7) layout design.
- Horizontal (Cases 2–5) and vertical (Cases 6 and 7) plot sited layout design system.

Regarding this study's scenarios, 48 scenarios from the previous six Cases based on eight cardinal and ordinal directions for each case have been assessed to identify the best orientation and to be established for the incremental phases' scenarios. Later, 36 scenarios resulted from the six Cases 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 1. Conceptual framework.

Reference [41]	**Data:** Literature review, conducting stakeholders in Duhok, north of Iraq, and observation. **Aim:** To investigate the effect of low-impact construction (LIC) through the bottom-up method on developing shelter performance. **Models' numbers:** Nine different scenarios (S) for one case model (Case 1).
Reference [42]	**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. **Models' numbers:** Six designed prototypes (Cases) + the base case model one (C1S9).
Current study	**Data:** References [41,42], Literature review, and observation. **1st Aim:** To assess the impact of orientation on the energy performance of six different core shelter housing prototypes (Phase 2) with end-of-terraced (ET) positions to identify the best orientation and be adopted for the next step of the study (assessment of the incremental phases). **Main Aim:** Evaluate the prototypes' energy and indoor comfort performance in three incremental phases with two positions, i.e., terraced (T) and end-of-terrace (ET). **Models' numbers:** Regarding orientation: 48 scenarios from six cases and 36 scenarios were assessed concerning incremental phases.

3.2. Data Analysis and Evaluation Process

The analysis started by assessing the six designed cases (Cases 2, 3, 4, 5, 6 and 7) established in a previous study [42] through eight different cardinal (S, W, N, E) and ordinal (SW, NW, NE, SE) directions to identify the best orientation and be adopted for the further step of the study (incremental phases). Afterward, regarding construction techniques, materials, and prototype parameters, scenario nine (C1S9) techniques from [41,42] have been selected for this study for affordability and adaptability reasons. Other identified parameters are shown in Table 2.

Table 2. The 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 [42], the attached planning block systems have been modified and designed to consist of the plot layout for the prototypes in their various systems (horizontal and vertical) and phases (Phases 1–3). Additionally, pedestrians, gardens, and vegetation areas between the units were designed while there is a limitation in assessing its effectiveness through the utilized simulation software in this study. To Include horizontal-sited layout plot prototypes (Cases 2–5), the planning block system in Figure 2 was designed however to avoid extreme sprawl planning the vertical-sited layout in Figure 3 was designed for cases 6 and 7 typologies.

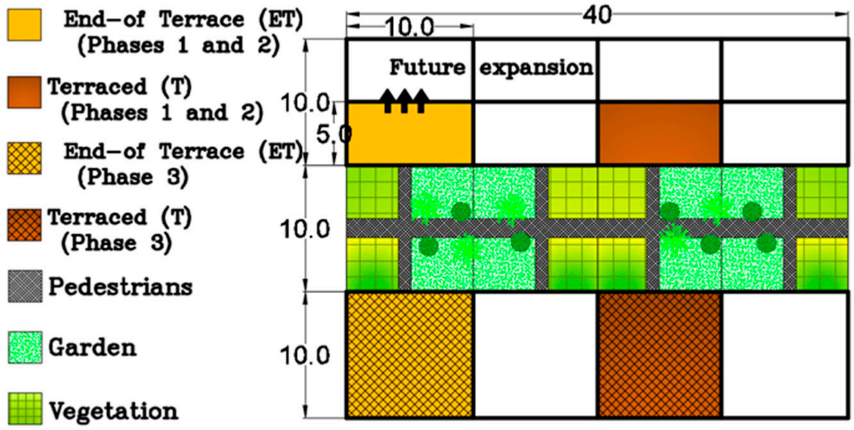

Figure 2. Planning system for horizontal sited layout plot Cases (Cases 2–5).

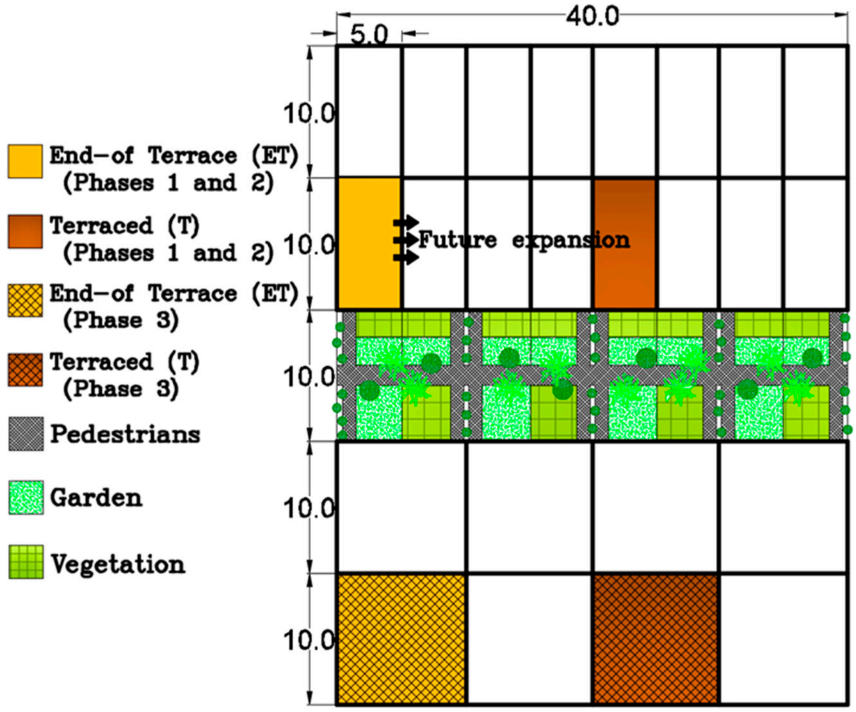

Figure 3. Planning system for Vertical sited layout plot Cases (Cases 6 and 7).

Concerning the design of the prototypes, the six Cases with an area of 50 m^2 for each of them designed in the previous study [42] were considered phase two for the Cases developed in this paper (Figures 4–6). 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, it is an upgrade of phase two with an area of 100 m^2 (Figures 4–6), and to host 6 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 both the planning and designing prototype systems.

Figure 4. Open to the yard Cases (Cases 2 and 3) with their three phases.

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

Figure 6. 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 in parallel to the CO_2 concentration weak result, consequently, the opening schedules have been tested and relatively modified to assess better results. Furthermore, the input data regarding domestic hot water (DHW) has also been reviewed and modified. For instance, 15 L/Person daily has been specified that is based on the essential water supply ratio as guidance for displaced people [17] which counted 15 L. However, based on the cultural context of the middle eastern region, five other litres have been added for the ablution process so it would be 20 L/P. While according to [42,49], using the 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 20 L/P in eight months while just 5 L/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 straw-bales with earth-bags technique in Case 3 and straw-bales with 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 two reasons: to identify the best orientation through assessing energy in eight different cardinal and ordinal directions (Figure 7) and then to assess all the prototype scenarios in different incremental phases based on the best orientation. IDA-ICE simulation and Excel sheets software have been used to evaluate and calculate the performance of models. Concerning orientation, the second phase for the six Cases with the End-of-Terraced (ET) location has been selected for assessing energy performance annually through heating, cooling, and lighting categories while DHW and equipment were not considered due to the similarity in the results in all scenarios. As shown in Figure 7, the results revealed the superiority of the south (S) orientation while the worst direction was generally northwest (NW). Thereby, the next step of the study (assessment of the incremental phases) prototypes were established based on these results.

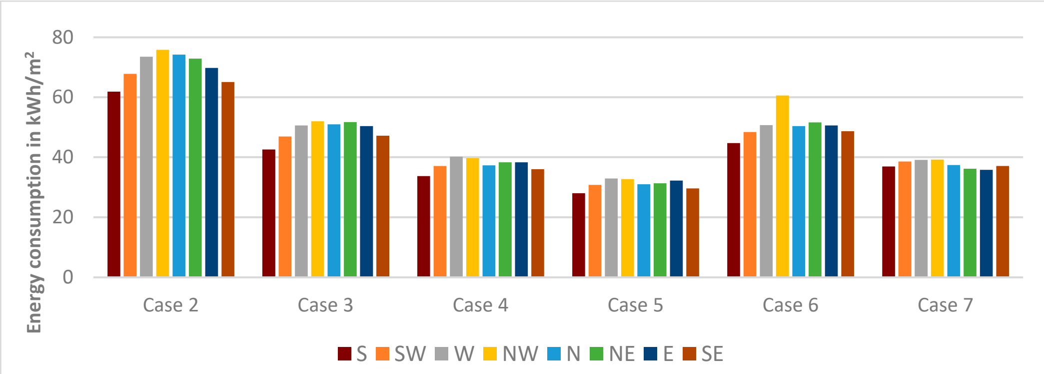

Figure 7. Assessment of orientation impact.

In the final stage, regarding incremental phases and for all prototypes, the assessment involves energy and indoor comfort performance. For the energy performance assessment, the total energy demand has been quantified in their 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 identified and compared with the two base case scenarios models (S1 and S2) in [41].

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 previous study [42] Equation (1) was applied.

$$\mathbf{N_{ah}} = \frac{\sum_{z=1}^{z=n} \mathbf{N_z} \times \mathbf{A_z} \times \mathbf{O_z}}{\sum_{z=1}^{z=n} \mathbf{A_z} \times \mathbf{O_z}} \tag{1}$$

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, **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 accepted hours ratios have been quantified. Then category C as an accepted comfort standard concerning predicted mean vote (PMV) assessment has been determined [33]. Finally, the maximum acceptable level of the CO_2 concentration represented in 1500 parts per million (ppm) has been simulated [50].

3.3. Modeling Tool and Input Parameters

Simulation program Indoor Climate and Energy IDA ICE 4.8 SP2 has been applied in this study to assess the orientation performance of 48 scenarios (6 × 8) for the six cases through simulating energy, then energy and indoor environment performance of 36 scenarios (6 × 3 × 2) for the three incremental phases of the six cases and in two different positions (T and ET). 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 [51,52]. Simulating all the modules was under an annual situation from the 1st of January till the 31st of December. While before running simulations, the comfort level setpoint for cooling and heating controller level [18] besides parameters in Table 3 were specified. Concerning DHW for the modules of phase three, based on the middle eastern context [53] 25 L/P has been identified, it resulted from 5 litres for the summer months and 35 litres for others (8 months × 35 L + 4 months × 5 L).

Table 3. Set points and input parameters.

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 TVs
Orientation	South	South for the assessment of the incremental phases	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

4. Results and Discussion

To identify the performance of incremental phases prototypes, the assessment covered 36 scenarios (6 × 3 × 2) including six Cases at three phases and two different positions, i.e., terraced (T) and end-of-terrace (ET).

4.1. Energy Assessment

4.1.1. 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 8. 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/m^2, 105.7 kWh/m^2, and 83 kWh/m^2 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/m^2, 150.2 kWh/m^2, and 123.2 kWh/m^2 equivalent to 2771 kWh, 4920 kWh, and 8234 kWh annually.

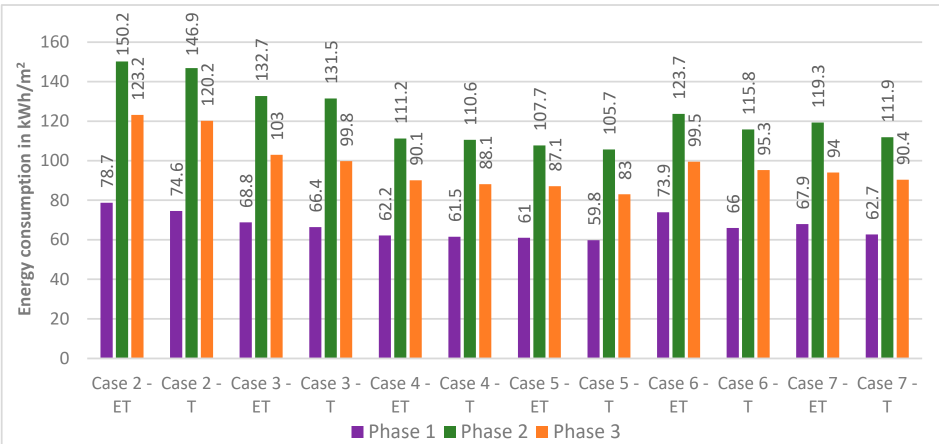

Figure 8. Total Energy assessment for Cases scenarios.

4.1.2. 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. 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-the-yard cases (Cases 2 and 3) Figure 9. 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 result for Phases 1 and 2 were for Case 4 and 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 and phase 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.

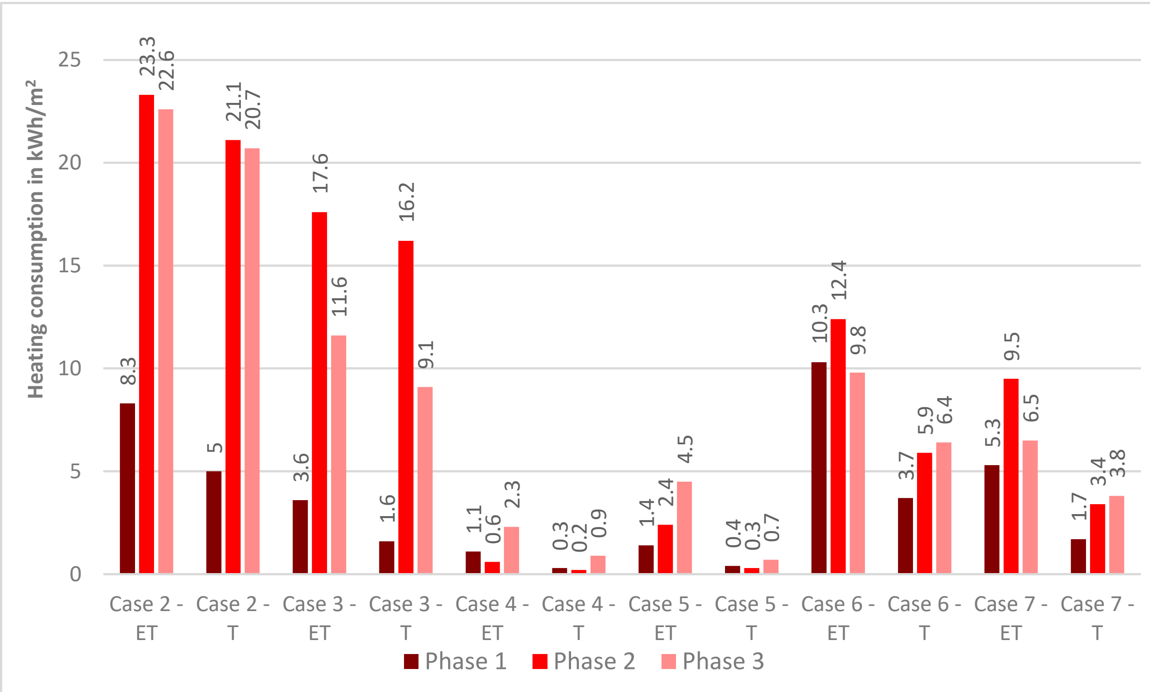

Figure 9. Heating energy assessment for Cases scenarios.

Concerning cooling energy demand even 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 10). 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 phase 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.

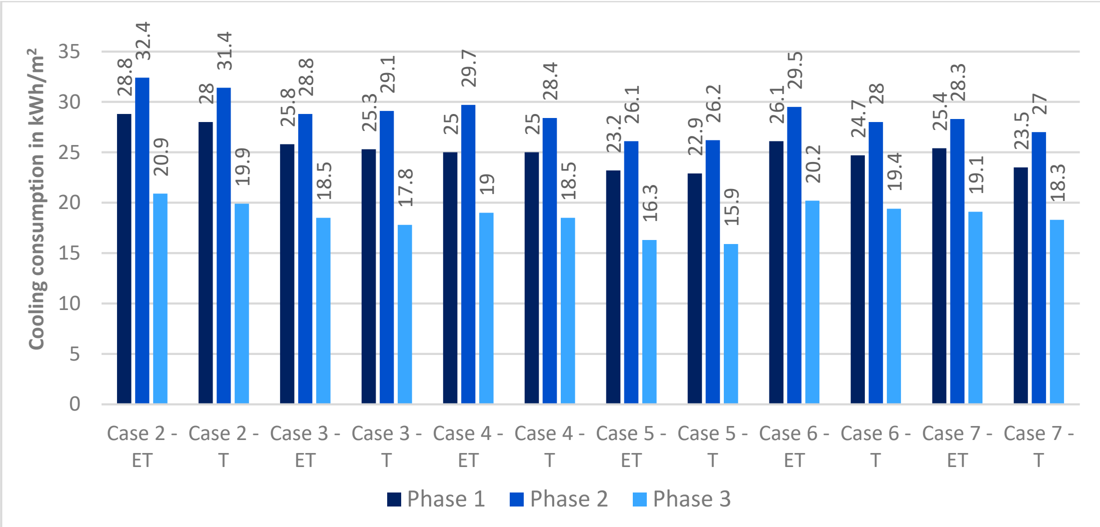

Figure 10. Cooling energy assessment for Cases scenarios.

4.1.3. Cost Implications

To realize more effect of applying low-impact construction (LIC) materials and techniques through the bottom-up method besides the effect of the designed prototypes on saving energy, the cost of heating-cooling energy has been countified (Figure 11). The assessment focused on phase 2 and End-of Terraced (ET) position for all the six designed Cases and base Case one (S9) with it is targeted bottom-up method to be compared with both base case scenarios (S1 with zinc sheets roof and concrete blocks wall and S2 with sandwich panels roof and concrete blocks wall) in [41]. 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 [54]. In conclusion, the assessment revealed that the best and worst results for designed cases (Cases 5 and 2) compared to (S1) can save 10,809 and 10,133 kWh equivalent to 2703 and 2534 US Dollars annually, additionally comparing to (S2) both cases can save 4469 and 3793 kWh equivalent to 1118 and 949 USD annually.

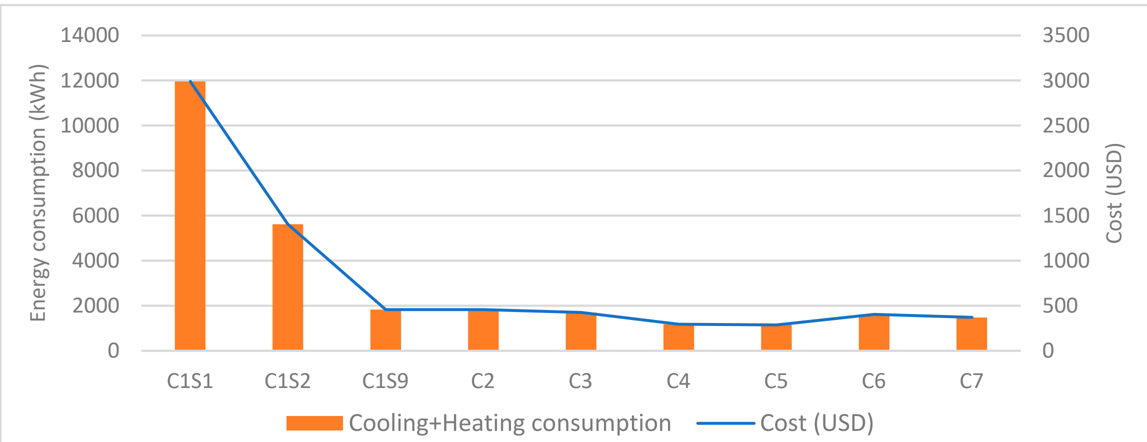

Figure 11. Cost assessment for energy.

To conclude, the results revealed that more than 1000 kW between the cases typologies (Cases 2 and 5) with the same phase and location can be saved similarly more than 300 kW can be saved (Case 6) between the same phase and typology by simply changing the position from (ET to 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 sited plot layout cases (Cases 6 and 7) gives superiority to the compact horizontal sited 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. Compared with other research which has assessed the superiority of the earth technique for detached shelter zones over other humanitarian shelters [39], the three phases of this study have a significant energy saving regarding kWh/m^2 duo the attached zones pattern for a single dwelling, planning block scheme, and adopted technique (variation wall materials). Similarly, regarding energy and cost and compared with the base case scenarios in [41] with conventional materials, the bottom-up method in this study prototypes have superiority to save energy by more than 10,000 kWh in simply one case equivalent to more than 2500 USA dollars annually consequently in a camp-scale those would be vital ratios.

4.2. Indoor Environment Comfort Assessment

4.2.1. Thermal Comfort Accepted Hours Ratio

The representative accepted category hours' percentage ratios in Figure 12 have been quantified based on Equation one, after assessing different zones with it is different occupancy hours annually. Depending on the range of specified setpoint temperatures in the modeling software (IDA ICE), the "accepted" hours were performed. 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 h while in Terrace (T) position were (Cases 7 and 4) with unaccepted ratios 0.10% and 5.60% equivalent to 9 and 491 h 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 h while in the (T) position were (Cases 6 and 3) with unaccepted ratios 0.09% and 7.87% equivalent to 7 and 610 h 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 h, while in the (T) position were (Cases 4 and 7) with unaccepted ratios 0.38% and 2.12% equivalent to 25 and 167 h ratio annually. The best and worst Cases performance results when changing position from (ET to T) revealed that Case 6 (+771 h) 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).

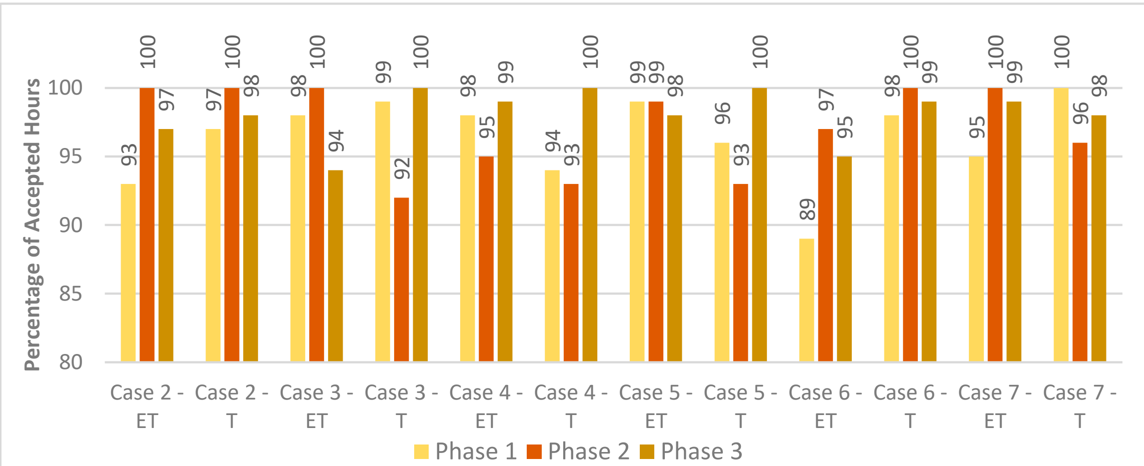

Figure 12. Thermal comfort—"accepted" category hours ratio.

4.2.2. Evaluation of Predicted Mean Vote (PMV)

The predicted mean vote (PMV) is an essential index of the Fanger comfort model, which has been measured in this study in it is "accepted" (C) ±0.7 categories according to ISO 7730 (2005) [33]. MPV measurement estimates air temperature, mean radiant temperature, air velocity, humidity, metabolic rate, and clothing variables in occupied zones. The results in Figure 13 are "accepted " (C) category hours, which have been quantified based on Equation one, after assessing different zones with 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%) accepted hours 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%.

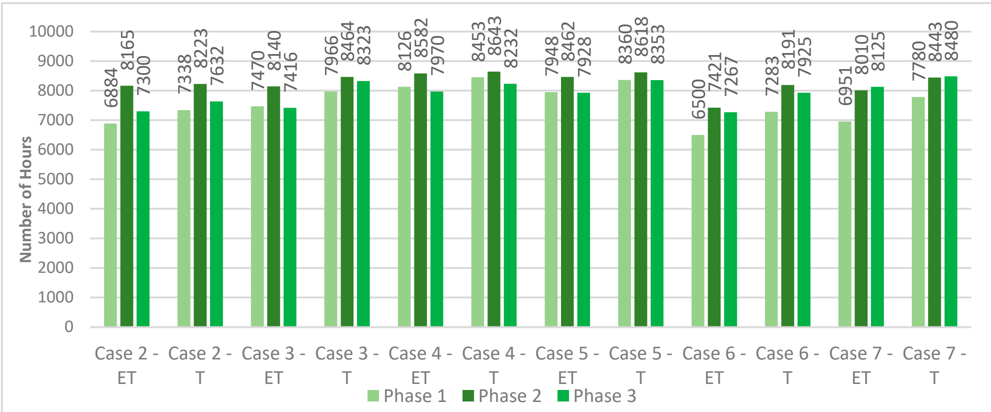

Figure 13. Accepted annual hours (category C) for PMV.

4.2.3. Carbon Dioxide Level (CO_2)

To assess indoor air quality performance, the CO_2 concentration level in it is accepted as the maximum recommended level (<1500 ppm) by European standard EN 13777 was simulated [50]. The revealed results concerning the accepted level (CO_2 concentration < 1500 ppm) in Figure 14 show that in both phases one and two and both end-of-terrace (ET) and terraced (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). Conversely, in phase three and both (ET and T) positions, separated zone layout design cases (Cases 2, 4 and 6) have better results.

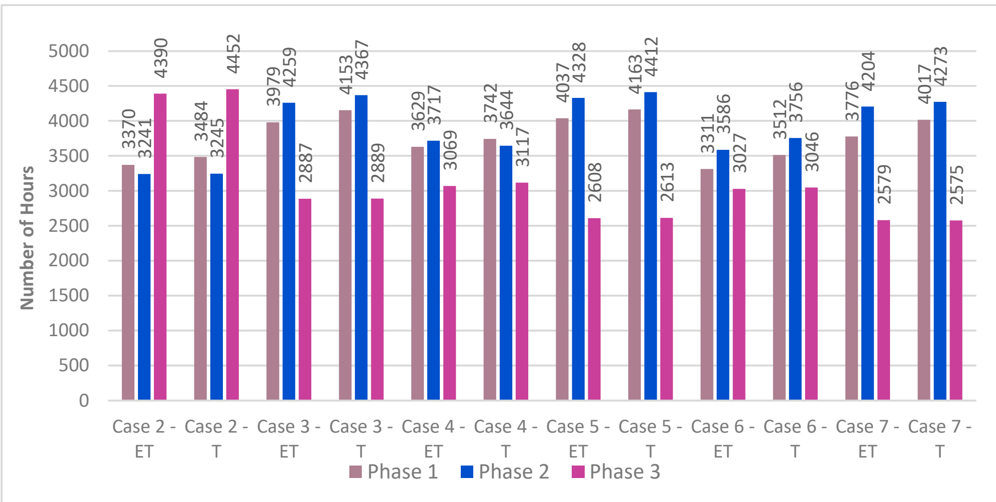

Figure 14. Average annual hours of CO_2 concentration <1500 ppm.

To conclude, even the performance of cases after reviewing the opening schedules have slightly improved compared with [42] as phase 2 of Cases. However, at the same time, there is still some overheating in some cases in both phases 1 and 2, especially in (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.

This study's data and recommendations contribute to a clear understanding of the performance of the indoor environment by assessing more than one 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 measurement variables of PMV. Moreover, concerning CO_2 concentration, the air volume 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 phases 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 for separated zones, cases were most sufficient.

Compared with another study that has assessed the superiority of the earth technique over others [39], this study still significantly has better results in both thermal comfort (the worst result of the percentage ratio for accepted hours are 89%, 92%, and 94% in three phases respectively) and PMV (the worst result of the percentage ratio for accepted hours are 74%, 85% and 83% in three phases respectively). However, concerning CO_2 concentration, the open to yard cases (Cases 2 and 3) have better results and other cases have performed almost the same, while generally, the 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 besides enhancing CO_2 concentration level.

5. Conclusions

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 study is to fill that gap by integrating the above factors in the six refugees' core shelters prototypes which have been 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 can 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). 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 10,000 kWh in simply one case equivalent to more than 2500 USA dollars annually. Furthermore, compared with other research which has assessed the superiority of the earth technique for detached shelter zones over other humanitarian shelters, the three phases of this study have significantly more energy saving regarding kWh/m^2 duo the attached zones pattern for a single dwelling, planning block scheme, and adopted technique (variation wall materials). Moreover, the findings for indoor environment comfort compared with other studies 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 CO_2 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%.

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/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 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 [41] 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.

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