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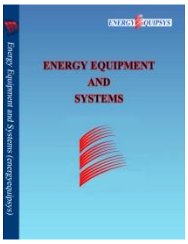

Effects of supportive spaces and people on heating energy demand in cold climate in Iran

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ABSTRACT

Decreasing heating needed energy of building located in mountainous areas without any urban infrastructure of energy supply and services is one of the most important things to get thermal comfort. Accordingly, using building conditions based on different types of applicability and passive design strategies should be considered. Therefore, the objective of this study was to achieve the proper heating needed energy for proposing functional model as a mountainous shelter located in Iran. Two influence factors namely, number of people per area and different supportive space were considered. The analysis has been performed by Honeybee and Ladybug add-ons in Rhino/Grasshopper software. Material characteristic, zone load, location and climate data as sub-parameter were calculated using ASHRAE Standard 90.1-2010. The results indicated that regarding to time-use period of the shelter that is mostly in warm months, the highest performance of the space, based on minimum heating needed energy was attributed to the maximum size of supportive space by 608 m2 when the number of people was 0.26 per area. The reduction of heating needed energy was 17% in cold month and 23% in warm month.

Keywords: Heating Needed Energy, Number of People Per Area, Supportive Space.

1. Introduction

Decreasing the heating energy demand (HED) by the passive method is one of the most important considerations in early-stage design. Previous studies have investigated building envelopes as the passive elements to lose and gain the heating energy. The use of local materials in regions that have no infrastructure to meet the energy demand of buildings is the solution that has been referred to as "simulation" in the initial stage. Accordingly, several parameters in material characteristics have an effect on the energy performance of buildings, such as experimental and simulation approaches. In addition, the estimation of HED without considering the occupancy schedule cannot always cause a decrease in the building energy consumption. Table 1 shows that previous works have mostly investigated masonry materials, thermal resistance (R-values), the performance of insulated walls, the insulation thickness of the building, the window-wall ratio (WWR), and the glazing in residential, commercial, and office buildings in different climate zones. For example, different variations of heating and cooling loads have been investigated in different

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changing climates based on different building characteristics [1–4]. Regarding these, it can be observed that heating and cooling loads were decreased and increased respectively [1]. On the other hand, by changing the simulation parameters, the results can be reversed in different climates [3].

Moreover, some researchers have emphasized the effects of WWR, window material, and orientation on energy consumption [5–7]. Yang et al. [5] indicated that an increase in the window size is directly related to an increase in energy consumption. Lee et al. [6] reported that the north face of envelopes in Manila and Taipei, with the lower WWR of 25% for an opaque envelope, produced advantageous results for the tested environments. A study by Goia et al. [7] focused on the building offices in four locations in Europe to find the optimal WWR. Based on this survey, most of the optimal WWR values are found in a partly narrow range. In Turkey, wall materials and insulation types were considered to gain the optimum insulation thicknesses [8–9]. In two simulations, the effect of degree-day value was desired. In both studies, energy consumption decreased considerably.

HED is one of the most important parameters in the evaluation of building energy consumption in different ranges based on a variety of occupancy schedules. Meester et al. [10] studied the impacts of occupant behavior on residential heating consumption. They found that the number of inhabitants and their lifestyle can reduce the heating loads of a detached house, and an increase in the insulation of a house generally provides better results than the mere adaptation of the occupation mode. Some previous papers have investigated the effects of the changes in the occupant behavior on energy saving. For example, in Wei et al.'s [11] study, some factors, such as active behavior and window opening in residential buildings, were considered as the occupants' potential influence on the heating behavior. Its simulation is developed on the lightweight example room that contains one window and one door in winter. A significant contribution is made to the reduction in energy demand when an active heating user changes to a medium heating user and, further, to a passive heating user.

Most recent studies have measured HED for residential and office buildings [1–11]. In this paper, the HED was investigated for a mountainous shelter building. Due to the limited literature information about the effects of supportive space in shelters, the main aim of this study was to evaluate the effects of three sizes of supportive spaces (SSs), as energy spaces, in the building. To obtain a better understanding of the SS, it should be mentioned that its function is not only to act as insulation but also as a place to be used when many visitors come to stay. From this aspect, three types of number of people per area (PPL), human behavior, and occupancy modes were considered in this simulation. Finally, the appropriate model of the lowest HED at peak-time use is suggested. However, the interpretation of SS in building simulation may be considered as a subject of further research in the future.

Table 1. Literature review of previous study on HED

Author	Method	Location	Major Conclusion
Wan et al. [1]	Prognostications from GCMs (general circulation models) to generate a new combinatory climate, multi-year building energy simulation, correlation between simulated loads, regression model evaluation, the estimation of the likely changes in heating and cooling loads in office buildings.	Harbin Beijing Shanghai Kunming Hong Kong	A decreasing and increasing trend of heating and cooling load due to climate change in future years were observed.
Yang et al. [2]	The typical principal component years were compared with the 30 individual years and the widely used typical meteorology in the respective year in public office buildings.	Harbin Beijing Shanghai Kunming Hong Kong	The TMY (typical meteorological year) and TPCY (typical principle component year) followed the 30-year long-term means quite closely. Predictions from the TPCY could be within 0.2%–1.5% of energy estimation.
Wang et al. [3]	The simulation of climate changes on cooling and heating energy consumption by residential and commercial buildings with different cooling modes by Energy-Plus. Future weather data was generated by the HadCM3 model for three CO2 scenarios and downscaled to hourly weather data by the use of the Morphing method.	United States	The energy simulation showed that the impact of climate change varied greatly among different types of buildings.

Table 1. Literature review of previous study on HED

Author	Method	Location	Major Conclusion
Zhao et al. [4]	The simulation model to achieve a good balance between investment costs, energy consumption, and indoor environment quality—various parameters as to the design of high-rise residential buildings.	China	The maximum total energy demand reductions: 75 kWh/(m^2a) in the severe cold zone, 40 kW h/(m^2a) in the hot summer and cold winter zones, 50 kW h/(m^2a) in the hot summer and warm winter zone, and 35 kW h/(m^2a) in mild zone.
Yang et al. [5]	The impact of WWR and window material kinds on the air-conditioning energy consumption is analyzed by a typical residential building using the Designer's Simulation Toolkit (DeST) software.	China	The results showed that the total energy consumption increased when the WWR was also increased. It became more obvious when the window orientation was east or west.
Lee et al. [6]	The evaluation of the relationship between the window properties and the office module energy performance by numerical simulation with a regression analysis.	Manila Taipei Shanghai Seoul Sapporo	The relative window size or WWR in the building envelope must be reduced. Except for the north face of envelopes in Manila and Taipei, a proposed lower WWR of 25% for an opaque envelope represents an advantage for the tested environments.
Goia et al. [7]	The methodology adopted to determine the optimal WWR value for each of the four orientations of a single climate needed a relatively high number of simulations in office buildings.	Oslo Frankfurt Rome Athens	Most of the optimal WWR values were found in a partly narrow range, $0.30 < WWR < 0.45$, even for buildings placed in very different climates. The south façade showed a larger variability, as the optimal transparent percentage can be as high as 0.60 in very cold climates and as low as 0.20 in very warm climates.
Ekici et al. [8]	The investigation of wall type and degree-day value's effects on optimum insulation (fiberglass, extruded polystyrene, expanded polystyrene, and polyurethane) thicknesses for different insulation materials in four different climatic zones according to TS 825.	Antalya Istanbul Elazıg Kayseri	The optimum insulation thickness varies between 0.2 cm and 18.6 cm; energy savings were different between 0.038 \$/m^2 and 250.415 \$/m^2, and payback periods vary between 0.714 and 9.104 years, depending on the city, the insulation material, the type of wall, and the cost of fuel.
Meral Ozel [9]	Investigation of the south-facing wall. Concrete, briquette, brick, Blok Bims, and autoclaved aerated concrete as the materials and extruded polystyrene and expanded polystyrene as insulation material are selected. Calculation of yearly cooling and heating transmission loads. Using an implicit finite difference method in steady periodic conditions. Economic model includes the consumption cost over a lifetime of 10 years.	Elazıg, Turkey	The variation of the optimum insulation thicknesses was between 2 and 8.2 cm, the energy savings vary between 2.78 and 102.16 \$/m^2, and the repayment periods vary between 1.32 and 10.33 years, depending on five structure materials and two kinds of insulation by considering the degree-days method.
Tatiana de Meester et al. [10]	A detached house under the meteorological climate data in the northern part of Europe was simulated by TAS[1], which is a software package for thermal analysis and dynamic energy simulations of buildings	Belgium	The number of inhabitants in their lifestyle reduced the heating loads of a detached house and the enhancement of the insulation of the house generally provided better results than the mere adaptation of the occupation mode.
Shen Wei et al. [11]	Active behavior and window opening are considered as the occupant's potential influence on the heating demand in the residential building. Its simulation occurred on the lightweight example room, which contains one window and one door in winter.	UK	A significant reduction occurred in heating behavior when a active heating user changed to a medium heating user and, further, to a passive heating user.

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[1] TAS is a software package for thermal analysis and dynamic energy simulations of buildings

2. Methodology

In this study, the computer simulation of a building was used to evaluate the effect of the SS and the PPL on the HED of a shelter building. The analysis was conducted as follows:

- Modeling the case study with three supportive spaces and defining the three PPL.
- Simulating the energy of the case study based on the climate data.
- Comparing the influences of supportive spaces and the PPL on the HED in two periods in a year: warm and cold months.
- Proposing the functional model based on the occupancy schedule and supportive space in peak-time use with an emphasis on HED.

2.1. Modeling the case

2.1.1. Supportive space (SS)

The method was applied to test four spaces in a five-story building to investigate the effect of SS parameters with three different areas on the variations of HED in cold climate. To minimize the heat loss of energy due to the shape of the building, the cubic form was selected in accordance with the best form in cold climate. The shape factor has a significant impact on the HED regarding the thermal envelope properties. The rectangular form of buildings performs better in saving energy in a cold climate [12–13]. In the analysis, the HED was achieved by increasing the SS area surrounding the core spaces at three levels, 168 m^2, 320 m^2, and 608m^2. Each area was determined according to the maximum number of persons who can stay together in a place in two positions: standing and lying down. Fig. 1 depicts the embedded persons in a defined building model regarding two positions in the place. Accordingly, the ratios of the surface area to the volume (A/V) of the building are 36%, 32%, and 28% respectively. Based on the results of previous studies, these ratios are expected to cause reduced heat loss compared with the core space with 49% A/V.

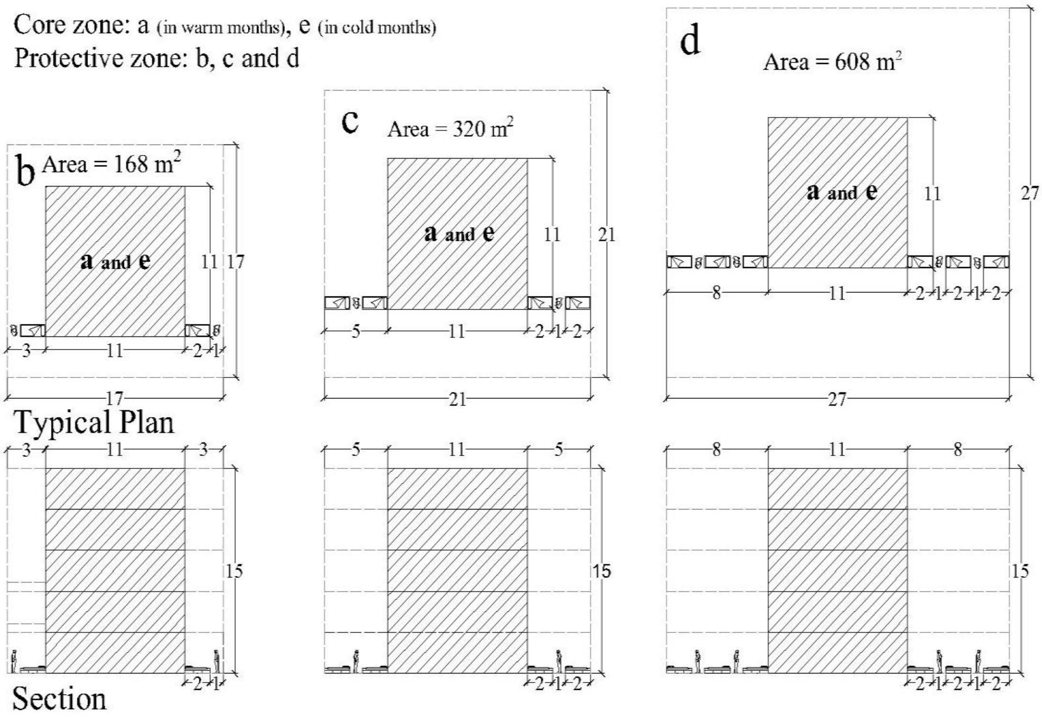


Fig. 1. Schematic of three supportive spaces

2.1.2. Number of people per area (PPL)

In this analysis, we considered three different numbers of people, which are high (0.5), medium (0.26) and low (0.02), based on the place capacity. Therefore, in the present paper, there are three alternatives to SS, and three modes of PPL are selected to represent a range in the severity of the HED in warm and cold seasons. Since these kinds of places are used in summer more than in winter, two cases of the number of people (0.26 and 0.5) are considered more.

2.2. Case study location

In this paper, the case is located in a very cold climate, in the latitude of 35.926391 and the longitude of 52.109230 at an elevation of 4184 meter, which is very close to the highest summit in Iran and even in the Middle East, Mt. Damavand. Table 2 shows the climatic characteristics of the location.

2.3. Climate data

Climate data is one of the most important variables for computing building energy consumption. In the simulation process, the input parameters are selected from ASHRAE Standard 90.1-2010 [14]. Using the parameters described above, the performance of the case building was simulated by weather data file from the Meteonorm 7 application, which has an EPW file as the climate inputs [15]. Figure 2 shows climate data regarding the study location, which is shown in Fig. 3.

Table 2. Annual characteristics of climate region

Average dry bulb temperature	1 C
Average dew point temperature	-13.1 C
Average relative humidity	40 %
Average wind speed	3.24 m/s
Average wind direction	233 degree
Average radiation	514.5 Wh/m^2
Average barometric pressure	233 Pa

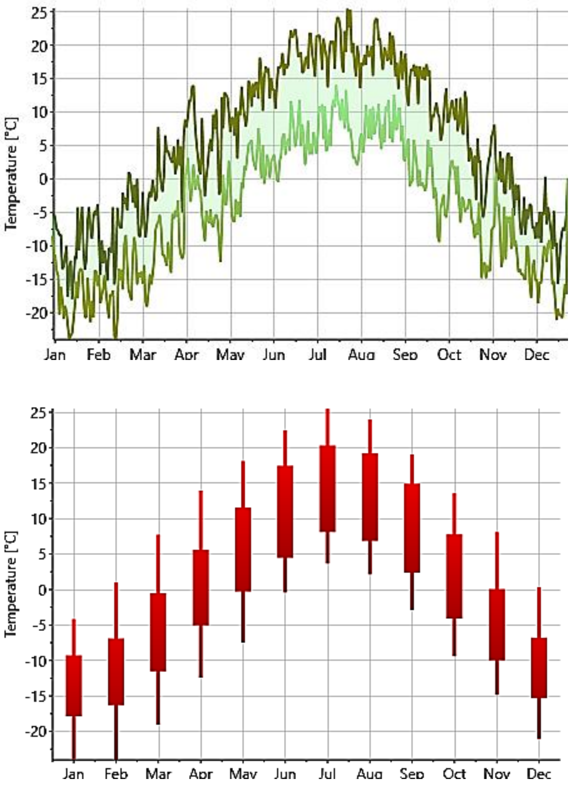


Fig. 2. Daily and monthly temperatures

Fig. 3. Location of the case study (photo by Google Map)

2.4. Case study materials

The accuracy of the HED evaluation model using the building-energy simulation tools depends on different input parameters like software engine, material characteristics, and climate data. Material characteristic is one of the most important variables in computing building energy consumption. In this study, to simulate building energy, the ASHRAE Standard 90.1-2010 was used. This standard has a variety of material recommendations for different climates, as shown in Table 3. Common materials are selected from the table with respect to the region. They are highlighted, as shown in Table 3. Figure 4 shows the materials used mostly in the region.

2.5. Simulation tools and details

The great complexity encountered in building-energy simulation by powerful new optimization methods has motivated researchers significantly to use new software like Grasshopper. It has many add-ons in a variety of fields for analysis and optimization. Firstly, the geometric algorithm in Grasshopper—parametric modeling for Rhino—is used to define the building model [16]. Heating energy simulation is one of the most common simulations in architectural designing process. Secondly, after the completion of the parametric design model, the algorithm for energy simulation is constructed using the two plug-ins, Ladybug (LB) and Honeybee (HB).

Fig. 4. Local material (photo by author)

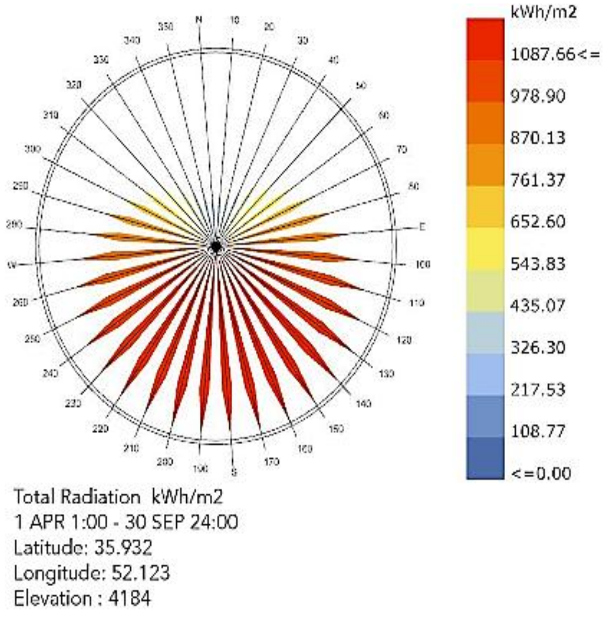
Table 3. Characteristics of materials

Type	Recommendations by ASHRAE standard	Details of selected materials	Thickness(m)	U(W/m^2.K)
Wall	EXTWALL MASS CLIMATEZONE 7-8 EXTWALL MASS CLIMATEZONE ALT-RES 6-7 EXTWALL METAL CLIMATEZONE 7-8 EXTWALL STEELFRAME CLIMATEZONE 4-8 EXTWALL STEELFRAME CLIMATEZONE ALT-RES 7 EXTWALL WOODFRAME CLIMATEZONE 6-7	1IN Stucco 8IN CONCRETE HW Ref Bldg Mass Wall Insulation R-16.84 IP 1/2IN Gypsum	0.253 0.2032 0.145 0.127	27.343 6.451 0.337 12.598
Roof	EXTROOF IEAD CLIMATEZONE 2-8 EXTROOF METAL CLIMATEZONE 6-7	1/2IN Gypsum Attic Floor Insulation R-35.07 IP 1/2IN Gypsum	0.0127 0.302 0.127	12.598 0.161 12.598
Floor	ATTICFLOOR CLIMATEZONE 2-7	M11 100mm lightweight concrete F05 Ceiling air-space resistance F16 Acoustic tile	0.101 - 0.19	5.216 5.555 3.141
Ceiling	INTERIOR CEILING	Metal Roofing Metal Roof Insulation R-19.63 IP Metal Decking	0.0015 0.169 0.0015	30004 0.289 30004
Window	EXTWINDOW METAL CLIMATEZONE 7-8 EXTWINDOW NONMETAL CLIMATEZONE 7-8	Metal	-	2.555

These software help to explore and evaluate environmental performance. Ladybug imports climate data into Grasshopper and provides a variety of graphics to support the decision-making process during the initial stages of design. Because of the visual nature of simulations, designers in thermal and energy modeling progress more commonly use these software. Honeybee connects the visual programming environment of Grasshopper for validating building energy consumption by a simulation engine (EnergyPlus) [17]. In the previous studies on HED, this visual software, simulation engine, and different validations have also been used [18–29].

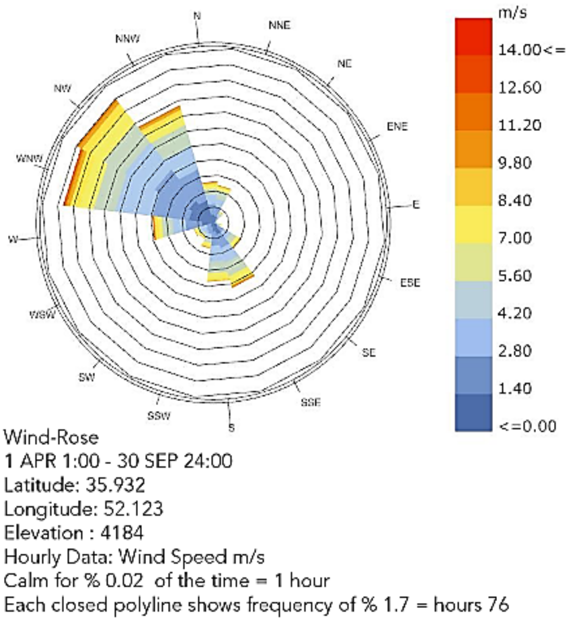
Two keys for choosing façades, namely glazing windows and WWR, are shown from Ladybug visual graphs regarding the related location in this paper. The WWR of southern walls is 20% and eastern walls, 5%. Based on Fig. 5, most of the total radiation belongs to the south orientation. Regarding that, WWR in this orientation is more than that in the east. Besides, there is no glazing in the north, because there is no considerable radiation. It has to be mentioned that based on the highest wind speed on the western side (Fig. 6), the installment of glazing on that side is avoided.

In the simulation process, several factors can affect building energy demand, such as outdoor temperature (C0), wind speed (m/s), building form factor, and material properties. In this simulation, the characteristics of spaces, such as the infiltration rate per area, ventilation per area, ventilation per person, lighting density per area, and equipment load per area, are assumed to be at a low level for calculating the maximum heating needed based on the ASHRAE standard, as shown in Table 4. The flowchart of the methodology process is depicted in Fig. 7.



Total Radiation kWh/m2
1 APR 1:00 - 30 SEP 24:00
Latitude: 35.932
Longitude: 52.123
Elevation : 4184

Fig. 5. Radiation rose



Wind-Rose
1 APR 1:00 - 30 SEP 24:00
Latitude: 35.932
Longitude: 52.123
Elevation : 4184
Hourly Data: Wind Speed m/s
Calm for % 0.02 of the time = 1 hour
Each closed polyline shows frequency of % 1.7 = hours 76

Fig. 6. Wind rose

Table 4. Characteristics of zone load

	Min	Middle	Max	Application
Equipment load per area (W/m^2)	2	-	-	For just a laptop or two in each space
Infiltration rate per area (m^3/s per m^2/façade)	0.0002	-	-	-
Lighting density per area (W/m^2)	3	-	-	For efficient LED bulbs
Ventilation per area (m^3/s per m^2/floor)	0.0025	-	-	-
Ventilation per person (m^3/s per person)	0.001	-	-	-
Number of people per area (people/m^2)	0.02	0.26	0.5	-

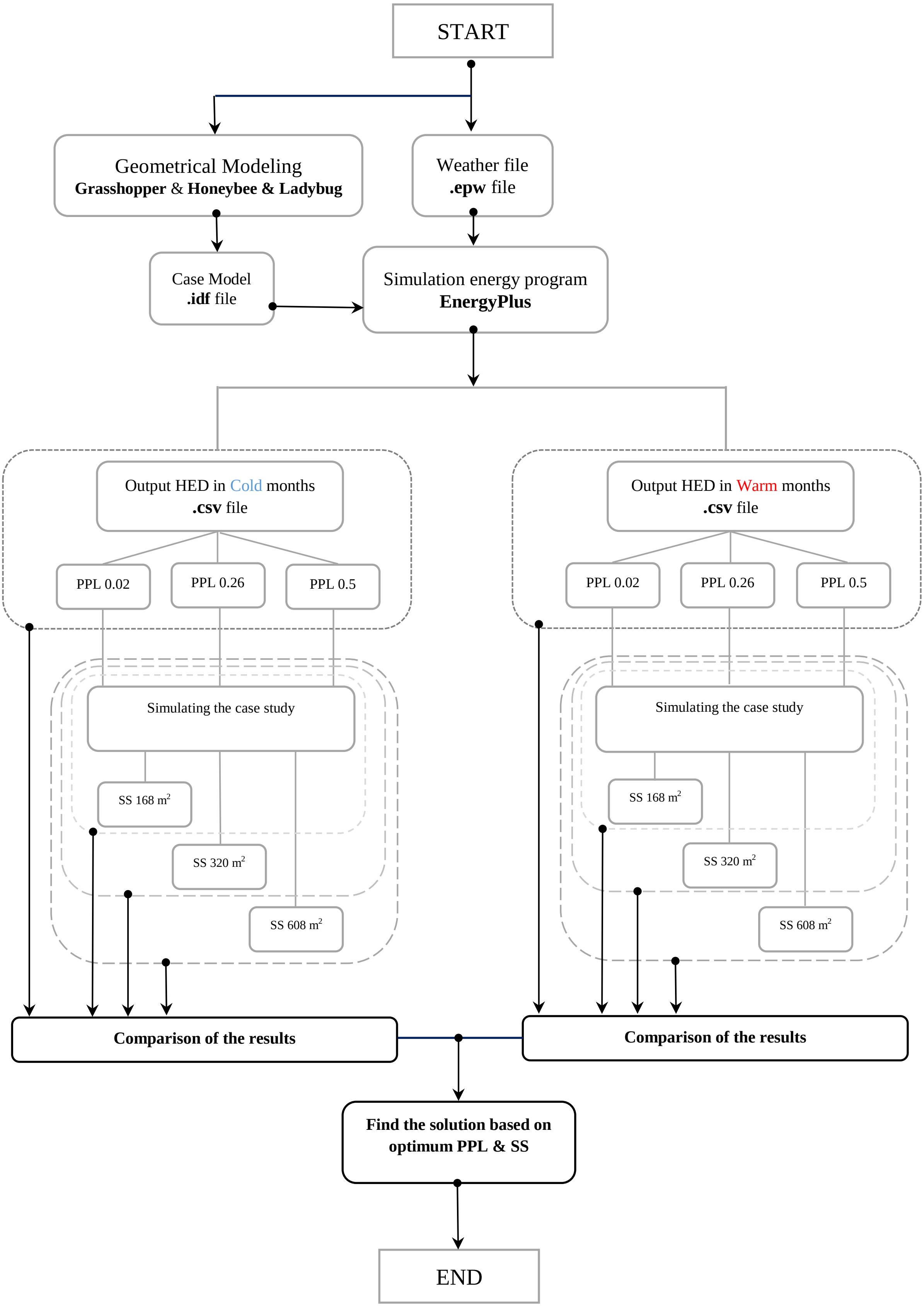


Fig. 7. Flowchart of the methodology process

3. Results and discussions

As mentioned in the introduction, most recent studies have found that energy consumption and building energy demand have been affected by different thicknesses of insulation and protective shells. On the other hand, the consideration of effective parameters like occupancy schedule has given different results in a variety of circumstances. Fig. 8 shows the average of HED of four kinds of spaces in the shelter building: One core space without SS and three kinds of SS with different areas. The graph covers the two periods between April and September as warm months and between October and March as cold months. According to the simulation results, it is observed that the average of HED is very different for the warm months compared to the cold ones. Figs. 8 to 10 provide details about the effect of three types of PPL on the average HED of the spaces monthly.

In the cold period, from October to December, there is a significant rise in the average HNE of spaces. It can be seen that the indicated slope on the graph indicates a modest rise, regarding space "a" in cold climate (a1c, a2c, and a3c), which means that SSs have influences on decreasing average HED. The slope of rising HED in the building without SS is more than that of the others. Additionally, it shows that the effect of SS is significant when the weather is colder. This is followed by a modest increase, about 500 kWh, between December and January. Over the next two months, a decrease is observed.

Two kinds of trends show that all effects of SS have the same trend, just in the cold period. This means a similar pattern is repeated in different conditions of PPL identically. By comparing these three graphs, the only difference is about the influence of an enhancement of PPL on a decrease in the average HED. The simulation result indicates that the highest average HED is related to space "a": 6641(kWh), 6144(kWh), and 5651(kWh) for PPL 0.02, 0.26, and 0.5 respectively. The average HED in each step has decreased by around 7%. This shows that the total decrease in HED is almost 14% regarding the maximum size of the SS. In addition to an increase in the SS areas ("b," "c," and "d"), as Figs. 8 to 10 show, there is no significantly different effect between "b" and "c" on a decrease in the average HED in space "a". In addition, the most decreasing average HED in cold weather is achieved in space "a" based on space "d".

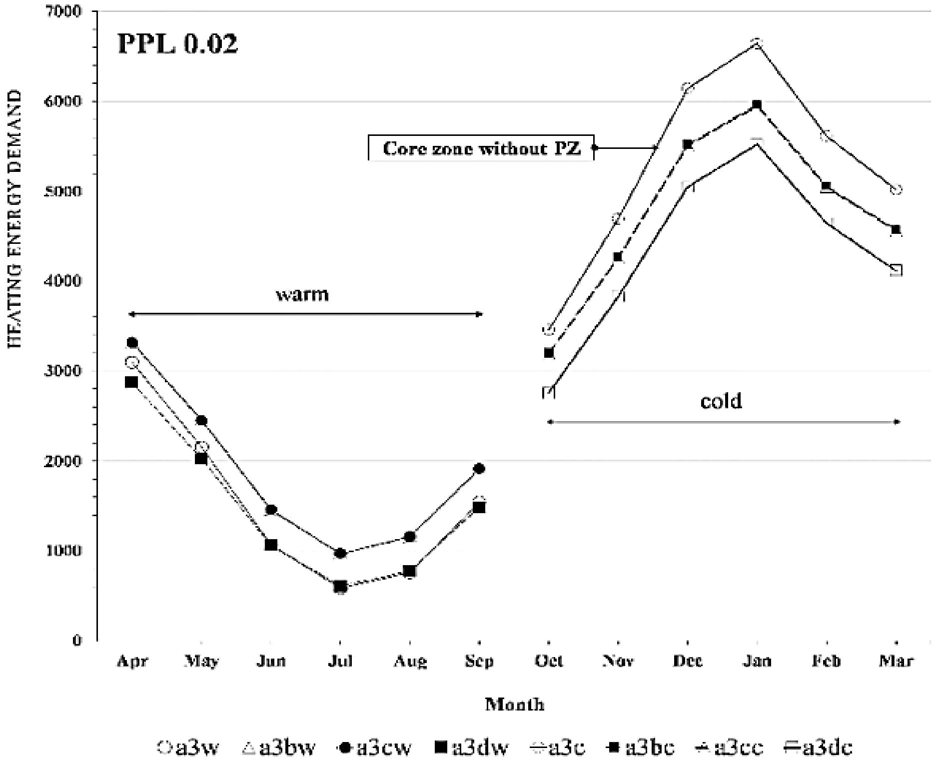


Fig. 8. HED in four spaces (PPL = 0.02)

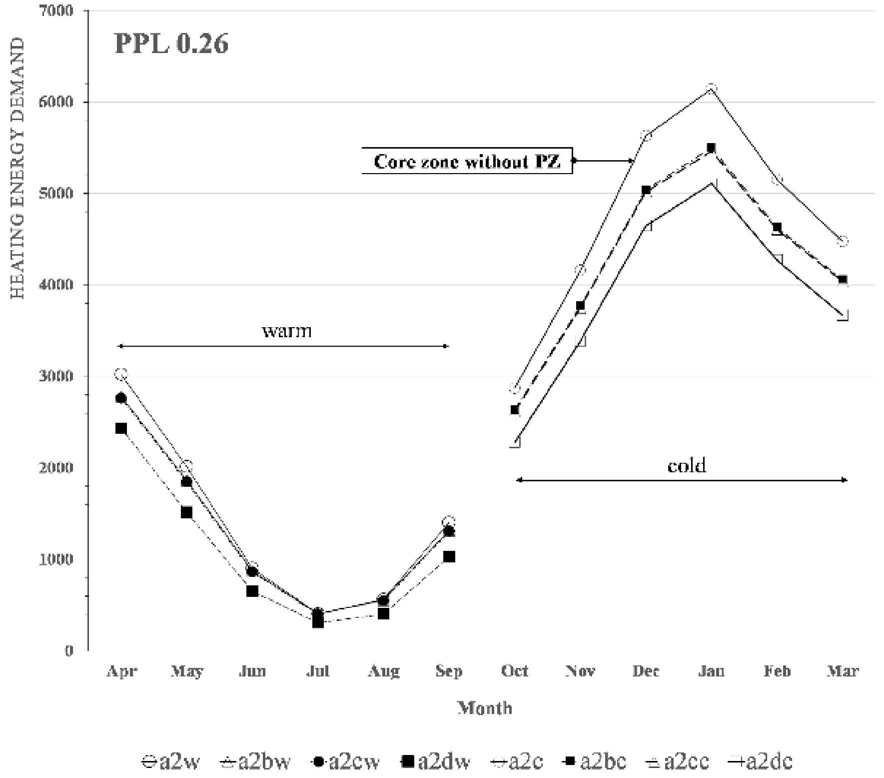


Fig. 9. HED in four spaces (PPL = 0.26)

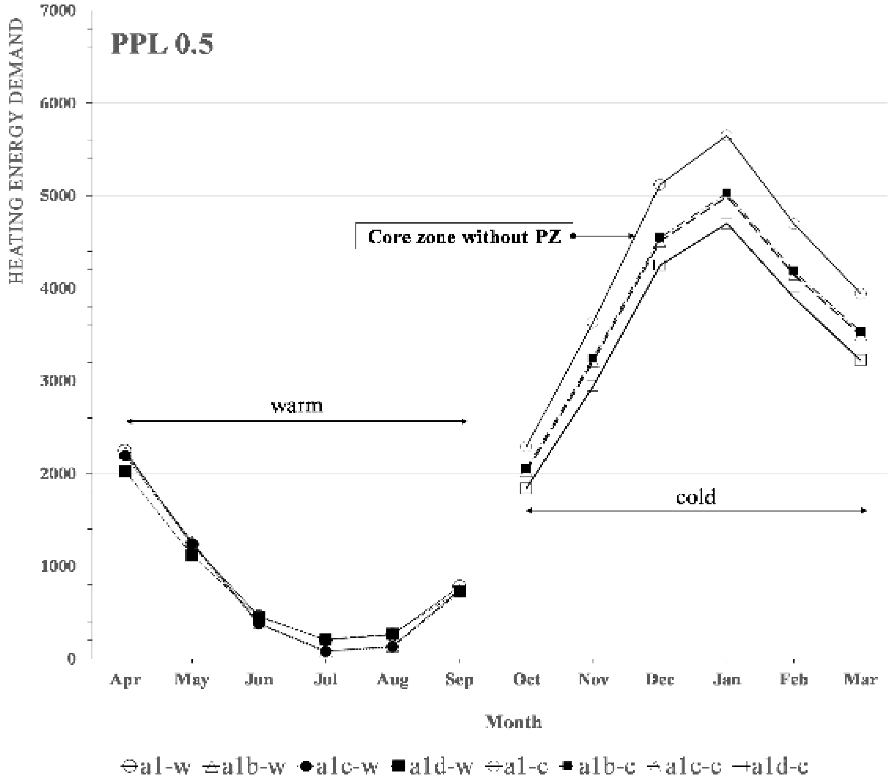


Fig. 10. HED in four spaces (PPL = 0.5)

3.1. Warm months

Figure 11 shows that by enhancing PPL from 0.02 to 0.5 in the warm months, the average HNE decreases the same as in the cold months. The difference between the trends of warm and cold months is due to the effects of SS (“b,” “c,” “d”) on space “a” to the diminution of average HED. As Fig. 11 shows, the most interesting finding is that even an increase in the SS from “a” to “c” with the minimum number of people (0.02) does not bring about a decrease in the average HED, indicating that spaces “b” and “c” have negative effects on space “a”. Consequently, a possible explanation for this is that the loss of energy will increase when their roof surfaces are vaster. By increasing the area in the next SS (d), this loss of energy is recovered. Thus, the supportive spaces compensate for the energy loss by the vaster area as a protection. Therefore, we can conclude that Fig. 11 indicates that space “d”, even with an area five times larger than space “a”, does not have a significant effect on decreasing HED with PPL=0.02 and 0.5 during the warm months. However, the observed differences between the variations of HED between space “b” and “c” in warm months in this study are not significant. Space “d” with PPL=0.26 has the best performance compared to the others in warm seasons. It should be noted that in this case, as a shelter in which people use it mostly in warm months, the decrease in the HED of buildings based on the PPL and SSs can be a suitable solution to achieve a decision in the initial stage of design. Therefore, the best alternative SS as a design is space “d” when the PPL is 0.26. The average HED of space “a”, based on the influences of space “d” with 0.26 PPL, is 1052 kWh in warm months. Besides, the reduction of HED is 17% compared to the core space without any SS.

3.2. Cold months Fig. 12 shows that an increase in the number of people has a significant effect on a decrease in the heating energy demand. By comparing the effects of different spaces on “a”, the figure illustrates that “b” and “c” have about the same effect on “a”. By enhancing the areas of the SS (d), it can be seen that in this condition, the decrease in the HED of “a” is significant. The greatest effect is related to space “d” (608 m2) with an 8-m distance from space “a” when the PPL is 0.5 in the cold months. Since the number of people who visit the shelter in the cold months is not significant, this result will not be a functional decision in this paper. So, based on the results in the warm months with PPL=0.26 for design suggestion, the best recommended SS in cold months is space “d” when PPL is 0.26 too. Moreover, the average HED of space “a”, based on the effects of space “d” with 0.26 PPL, is 3893 kWh in the cold months. Finally, the reduction of HED is 23% compared to the core space without any SS.

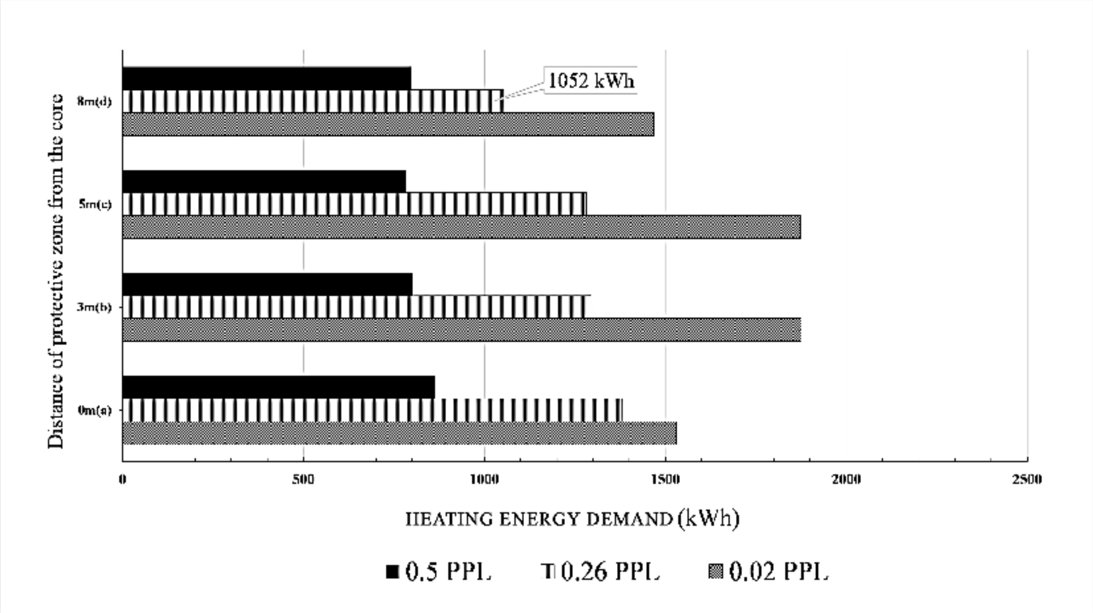


Fig. 11. Average heating energy demand in warm months

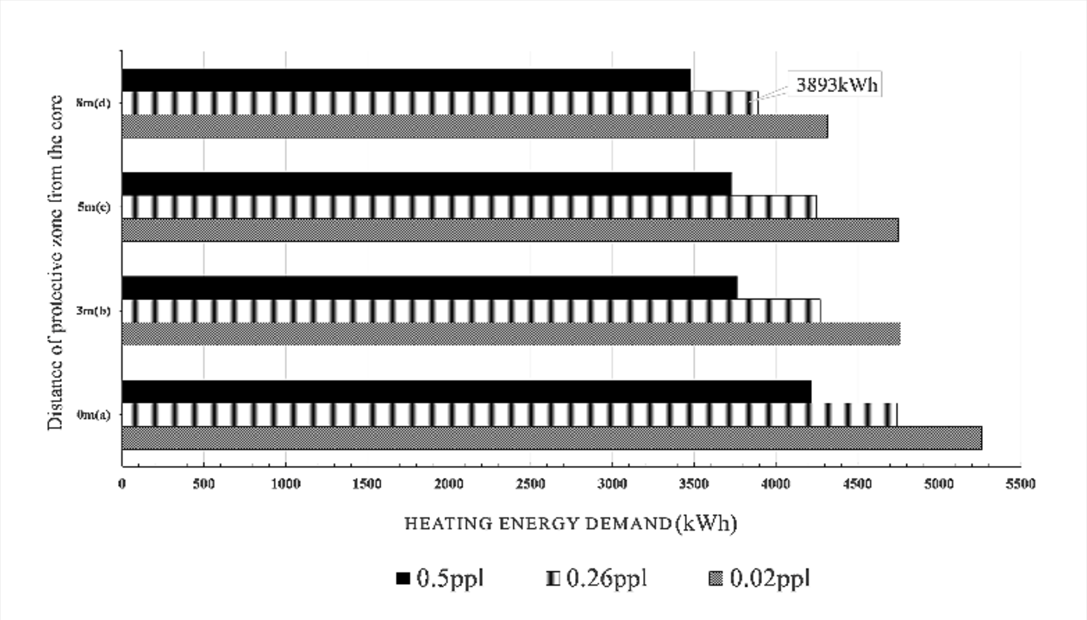


Fig. 12. Average HED in cold months

Based on Fig. 13, by increasing PPL in the same circumstances of different SS areas, the HED decreases significantly in the warm months. However, as it is evident from Fig. 14, an increase in the SS areas has fluctuating effects on a decrease in the HED in each of PPL conditions. Contrary to expectations, HED cannot be decreased by an increase in the SS areas. Thus, with an enhancement of SS areas from 168 m^2 (b) to 320 m^2 (c), in each circumstances of PPL, there is no substantial difference between them. Continuous expansion of the SS area to 608 m^2 (d) in accordance with PPL=0.5, there is no decline in HED compared to PPL=0.02 and 0.26, which means the enhancement of SS area in each condition of PPL has different effects. Consequently, to increase SS, it is recommended that the shelter in the medium size of PPL be used (0.26).

4. Conclusion

The study followed a parametric approach to create an innovation for building energy simulation. The significance of the occupancy schedule on HED was investigated using a computer simulation. The study focused on the impact of three different supportive spaces on

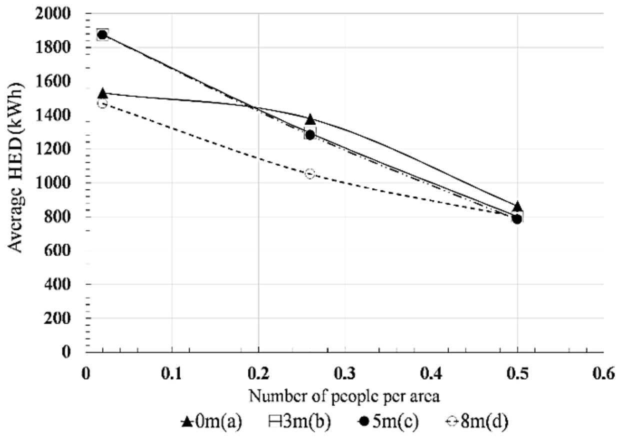


Fig. 13. Average HED in warm months

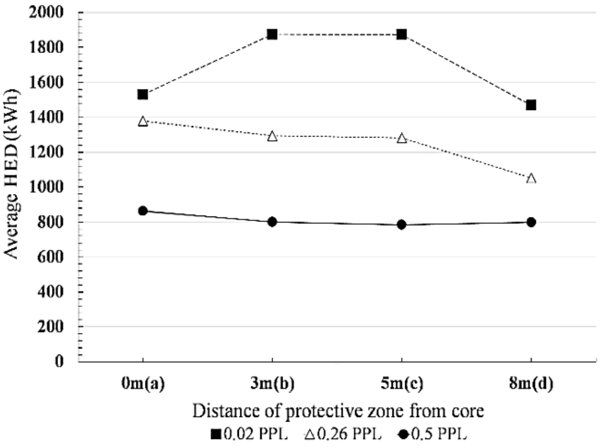


Fig. 14. Average HED in warm months

the HED of a mountainous shelter building in cold climate conditions located in Iran.

The following conclusions could be drawn from the study:

- The number of people per area has significant effects on the performance of core space regarding the supportive space. By increasing the number of people in the shelter, the HED decreased.
- According to the time-use of the mountainous shelter building in warm months, we can mostly count on the number of people in the space as an effective parameter to decrease the heating energy demand. Therefore, in this study, warm months will be close to real performance in early-stage design.
- When the number of people per area is of a medium size, we can conclude that the considerable size of the supportive space has the best performance. This shows that the integrated simulation modeling by considering the time-use of building in reality provides precise outputs for functional design.
- This research emphasizes that the number of people and the supportive space in the peak-time use of the mountainous shelter building can be applied as effective functional parameters to decrease HED in early-stage design.

In this study, the use of some passive design strategies was investigated. Since these mountainous shelter buildings were made in places with no infrastructure to supply their energy demands, a further study with more focus on the combination of PPL and SS by considering the application of renewable energy like solar energy is suggested.

6. Acknowledgement

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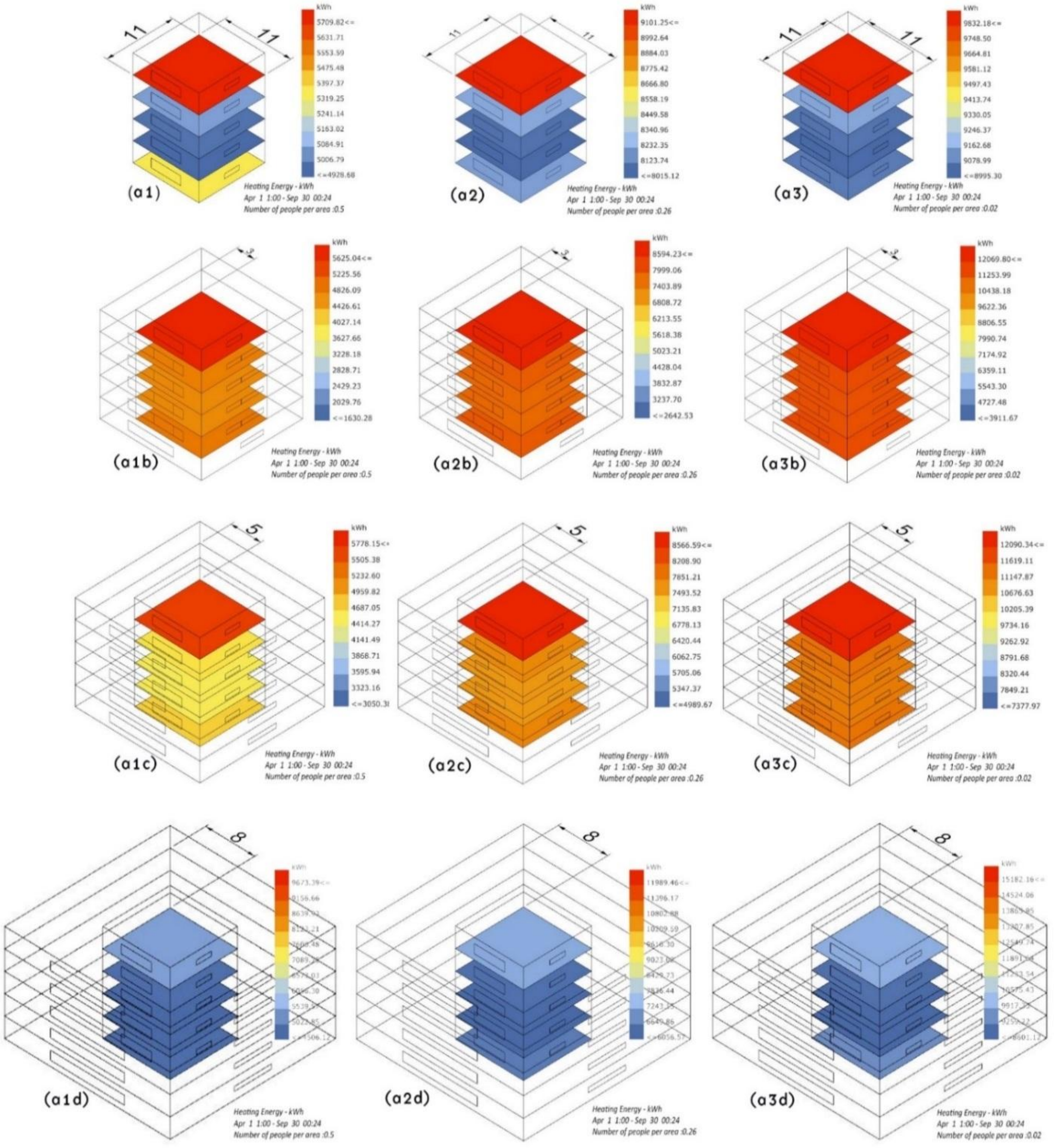
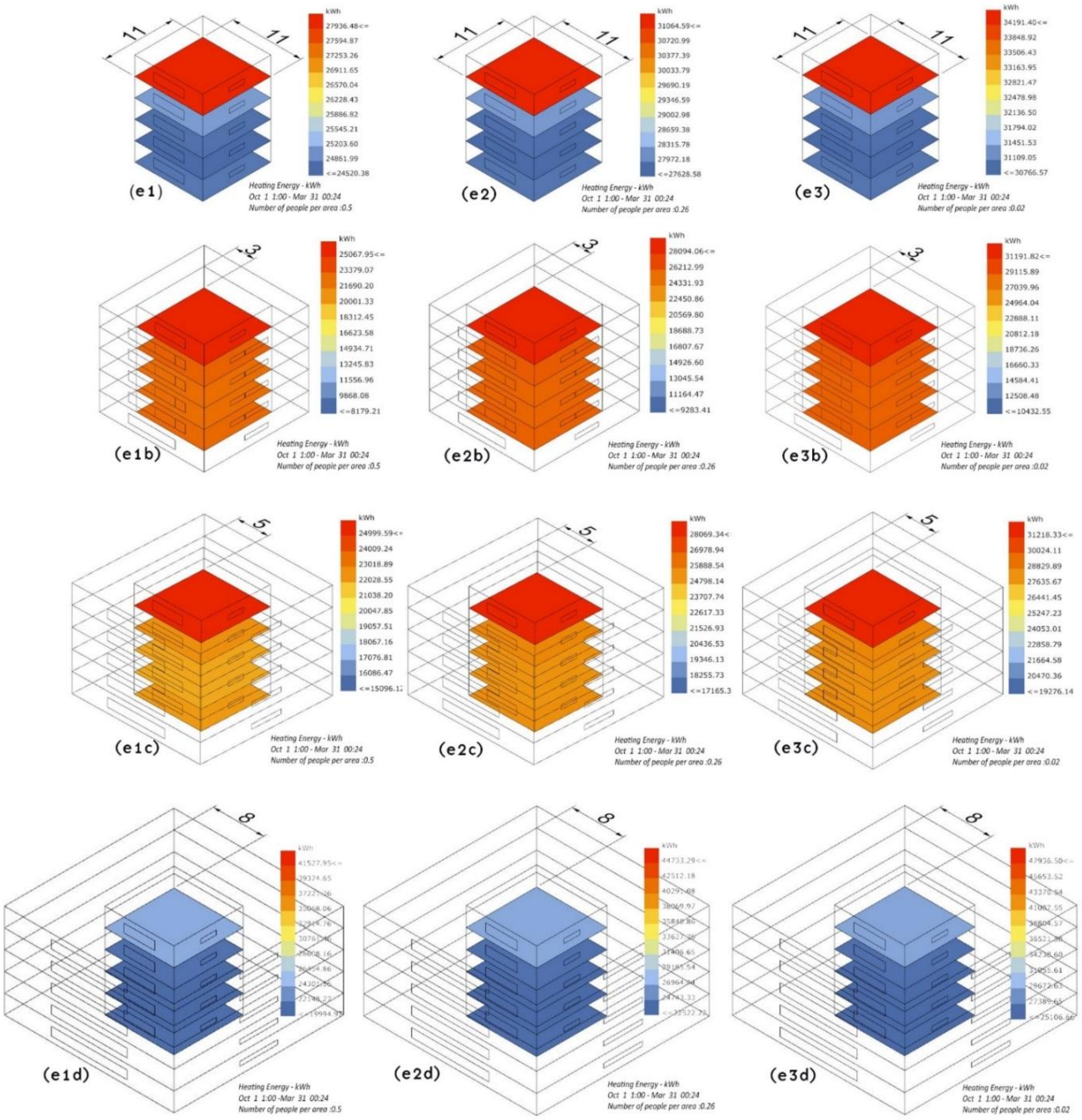
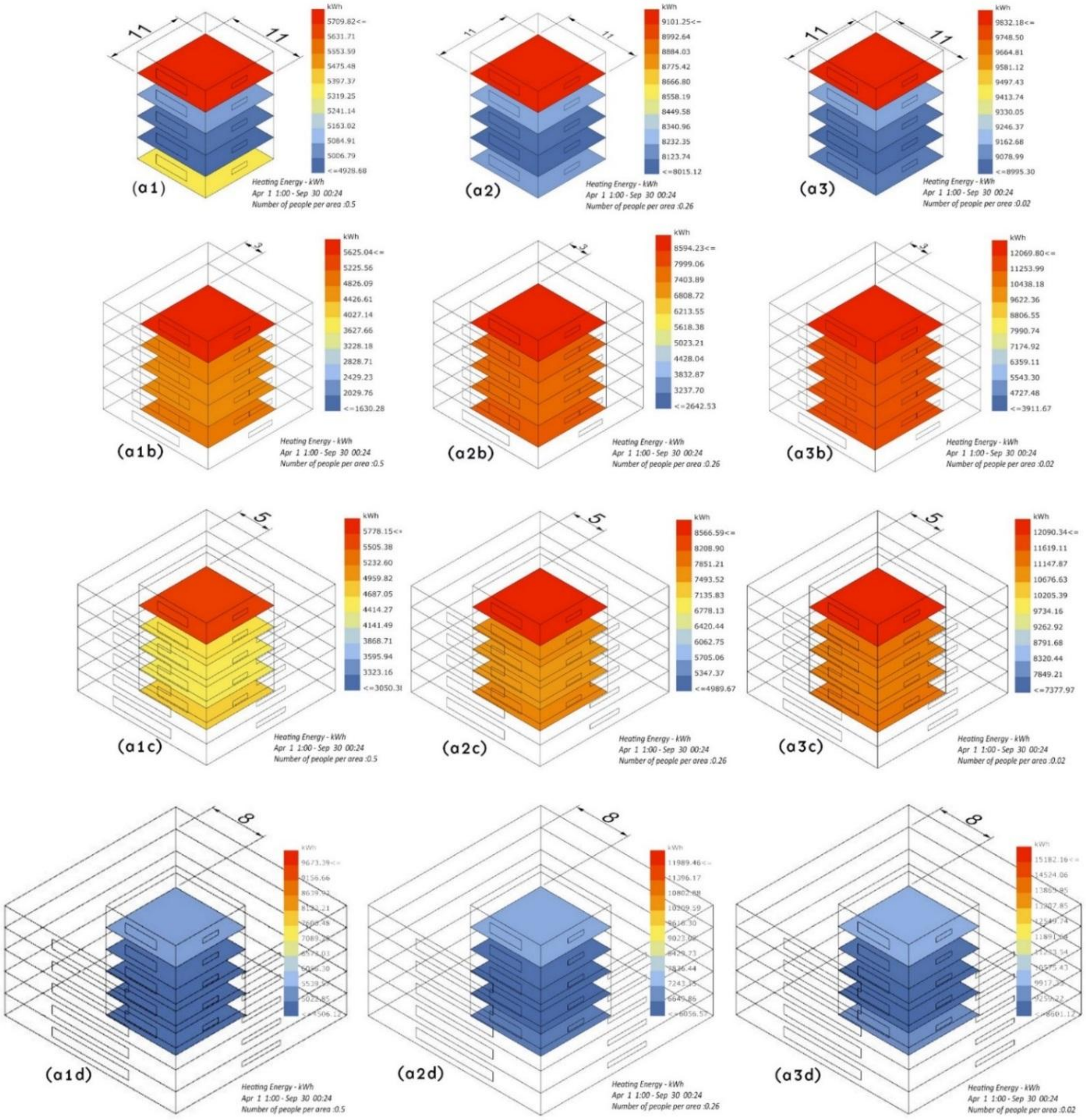
Appendix A. Heating energy demand in warm months



Appendix B. Heating energy demand in cold months



Appendix A. HED in warm months



Appendix B. HED in cold months