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Impact of Passive Techniques on Thermal Behavior of Emergency Shelters

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ABSTRACT

Due to emergency situations, many people are living under degraded conditions as displaced persons and refugees. Unfortunately, shelters commonly used in humanitarian context do not ensure comfortable conditions for their occupants. This study investigates the impact of utilizing passive climatization techniques on the indoor thermal comfort of the occupants in refugee settlements under Jordan's climate using the Design Builder software. Several passive techniques were simulated, including orientation, floor, wall and roof insulation, and natural ventilation. The simulation results indicated that the thermal comfort has improved when using the aforementioned techniques by 9.72% offering 23% comfort hours throughout the year.

Keywords: passive techniques, thermal behavior, emergency shelters

INTRODUCTION

Due to emergency situations, whether natural or caused by human factors, many people are living under degraded conditions as displaced persons and refugees. Even today, refugees are living in shelters that unfortunately do not ensure comfortable conditions for their occupants. Tents are the most common used housing typology in emergency situations because of their ease of transportation and assembly; however, the poor indoor living conditions which mainly depend on the climate are not taken into consideration. From such observations there is a need to improve the thermal behavior and comfort conditions inside the canvas shelters. One reasonable solution to achieve this goal is to benefit from natural resources using passive techniques that can enhance the indoor thermal environment.

Several studies were conducted on refugee shelters. Borge-Diez, et al. (2013) presented an integrated solution of passive systems including cool roof technology, external layout distribution, and enhanced natural ventilation to reduce the energy consumption and increase the thermal comfort in concrete shelters. He proposed a low cost building solutions using concrete as the only material for shelters to house displaced persons in hot climate. The proposed solution, which was simulated using the Energy Plus software, has shown a 16% improvement in the thermal conditions inside the building when cool roof and natural ventilation technologies are applied. The final integration of the passive systems allowed the peak power demand to be reduced by up to 50% and the yearly energy consumption to be reduced by approximately 40% (Borge-Diez, et al., 2013). Another study carried out by Barbosa, et al. (2015) has assessed the impact of double skin façade, shading devices and thermal mass on naturally ventilated building thermal performance using the IESVE building thermal simulation software in order to optimize the design options to maximize the thermal comfort levels within the building. The results indicated that acceptable thermal comfort levels can be achieved for almost 70% and the integration of double skin facade as part of a mixed-mode ventilation system has a major role in energy consumption reduction.

Sheweka (2011) investigated the use of mud bricks as a temporary building construction in Gaza (Palestine). This study has revealed that mud-bricks used as construction material meet the heat conductivity and compressive strength requirements as well as stabilize the indoor temperatures during summer and winter for its insulation properties, which lead to reduced energy consumed for heating and cooling. A study on thermal comfort in low-cost, adobe refugee shelters in arid climates has been carried out by Ajam (1998) on behalf of United Nation Relief and Works Agency (UNRWA) for Palestine and Near East. The study focused on adobe shelters using DEROB to simulate a small low-cost refugee shelter by varying some design parameters such as; roof insulation, building materials, infiltration and ventilation. The simulation showed that a well-sealed, insulated building with southern windows will help in keeping the heat inside the building and lessen the heat loss in winter while a night-ventilated building with good insulation can help keeping the indoor climate more tolerable in summer.

Obyn, et al. (2015) presented a model using the Energy plus simulation program to study the thermal behavior of the family shelter for emergency situations used by UNHCR, IFRC and ICRC. The model was calibrated and validated with in situ measurements which provides an objective assessment of the shelter performance for any given context and climate exposure. A study on the thermal behavior of emergency shelter by Cornaro, et al. (2015) was carried out under the climatic conditions in Italy using building dynamic simulation software (IDA ICE 4.5). The study concluded that the use of insulating materials together with the employment of heating and cooling systems has improved the internal thermal conditions and energy efficiency.

Attia (2014) carried out a study to develop the tools to assess the quality and comfort in Bedouin tents shelters using the Energy Plus simulation software to construct a model for a prototype tent. The tent was tested under hot conditions with an internal vapor load. Temperature, humidity and air speed measurements were calculated inside the shelter while the external temperature was kept at 40°C. The simulation results showed that thermal comfort is hardly achieved within the tent; in summer, the natural ventilation is not enough to dissipate the heat and during winter the tent air tightness and cloth resistance are not enough to prevent the temperatures from going below 18°C.

Quaglia, et al. (2014) presented a multi-objective shape optimization methodology which balances the energy efficiency in rapidly deployable shelters especially designed for the military and disaster relief. A final optimized solution that reduces thermal energy loads was found and compared with the existing military solutions using a parametric finite element program and the Energy Plus software to calculate the thermal energy. For the optimized solution, the annual energy demand was 70% less than the standard military tents.

Manfield (2000) carried out a series of experiments on temporary shelters for emergencies in cold climates. Wind tunnel, environmental chambers and field tests have been used to examine how the thermal performance of these shelters could be enhanced through several alterations to the initial design, whilst quantifying the associated implications for cost, weight and volume. The test results indicated the need for greater thermal insulation efficiency, particularly relating to the type and distribution of insulating material employed within the shelter. Most of the previous studies on refugee shelters are based on the study and evaluation of an existing model and proposed different functions to study and improve the environmental conditions.

This study aimed to improve the occupants' thermal comfort in refugee shelters under Jordanian climate via characterizing the current refugee shelters, determining what types of passive techniques can be applied to refugee shelters, investigating the performance of these passive techniques under Jordanian climate conditions, optimizing the selected passive techniques, and proposing new tent specifications that will improve the thermal behavior of refugee shelters in a manner that focuses on rebuilding endeavors based on minimizing energy consumptions, cost and time of construction, simple passive strategies, as thermal mass, orientation, and natural ventilation, to be considered in this design approach.

THE MODEL

A full detailed description of the proposed model is represented in this section. As shown in Figure 1, the model is a UNHCR family tent in a refugee camp (UNHCR, 2015) which is located in the Al-Mafraq region in Jordan (32.2° North latitude, 36.10° East longitude and altitude of 705 m above sea level). The tent is composed of outer and inner layers with 10 cm gap in between, it is provided with a ground sheet and has a total area of 23 m^2 distributed as 16 m^2 main floor area and two 3.5 m^2 transitional spaces in front of both entrances. On the basis of the recommended minimum living area in hot and temperate climates (3.5 m^2 per person); it is suitable for a family of five people (UNHCR, 2014). The structure of the tent consists of two long windows with movable rain flap and mosquito netting on both sides of exterior tent along with two openings (Doors) in transitional spaces and two triangle vents above with netting and rain flap.

Thermal modeling

In this study, Design Builder software combined with Energy Plus engine were used to generate a three-dimensional model to investigate the thermal behavior of the shelter. The shelter properties are not comprehensible for the use of thermal model software as the manufacturing fabric is not opaque and has small thermal mass causing low insulation level, besides the major impact of outdoor temperatures and the interaction between the inner and outer tents. Consequently, the shelter (block) is divided to two zones; inside and outside connected by resistive and airflow model as indicated in Figure 2. The inside thermal zone includes the inner tent while the outside zone includes the wall gaps between the outer and inner tent, the roof gap between the inner and outer tents and the transitional spaces in front of both entrances. The gap between the inner and outer tents is considered as a double skin façade; "A curtain wall construction comprising an outer skin of glass and an inner wall constructed as a curtain wall that together with the outer skin provide the full function of a wall" (Design Builder, 2015). The ground sheet is considered as an opaque material in the model.

The adaptive comfort equation presented hereunder, proposed by Nicol and Humphreys (2002), is used to calculate variable comfort temperature for shelter over the year:

$$T_c = 13.5 + 0.54\,T_o;\;\; 10\,^{o}\text{C} \le T_o \le 33\,^{o}\text{C} \qquad (1)$$

where: T_c – the optimum comfort temperature.
T_o – monthly mean of outdoor air temperature.

The shelter is simulated without occupants to study its thermal behavior. In order to improve the thermal behavior of the shelter, several passive

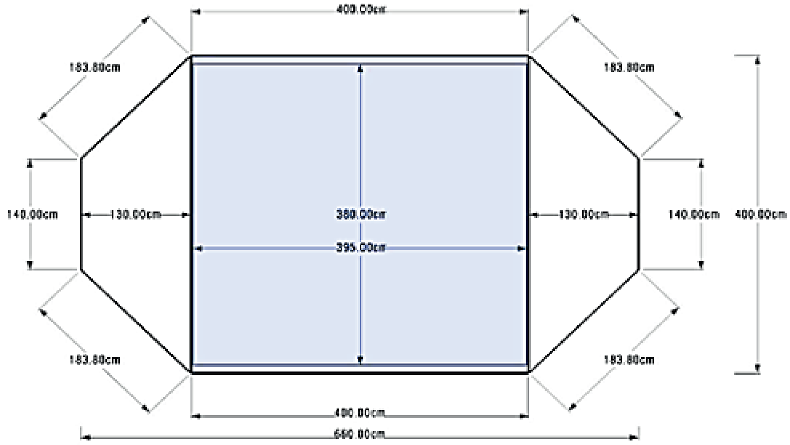

Figure 1. Plan view of the family tent (UNHCR, 2014)

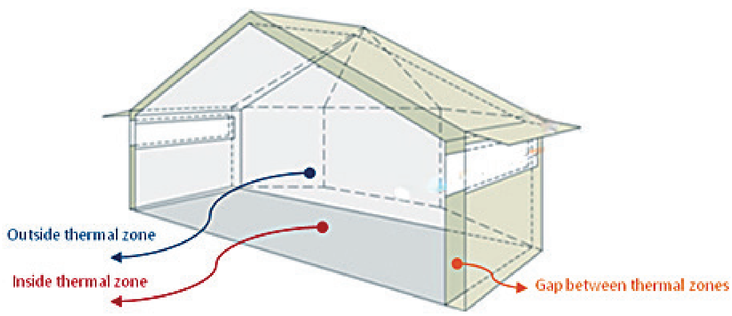

Figure 2. Thermal zones used in simuation model

techniques are proposed to be studied including orientation, insulation, and natural ventilation.

Orientation

There is no fixed orientation in refugee camps planning as refugees structure their shelters randomly. Appropriate orientation is the primary aspect of passive solar design through which greater comfort levels can be achieved and lower energy needed to reach thermal comfort are required (Morrissey, et al., 2011). In this study, four orientations of the shelter are simulated due to the symmetrical form of the shelter, as illustrated in Figure 3.

Insulation

The shelter under investigation uses insulation materials for walls, roof and floor. Figure 4 indicates the insulation layers in the floor in which four layers of insulation materials are used, while figure 5 shows the insulation materials used to insulate the shelter walls and roof.

The impact of natural ventilation on thermal comfort conditions inside the tent will be studied. The tent is ventilated using minimum fresh air requirements per person (7.5 L/s) based on the ASHREA ventilation standards.

RESULT AND DISCUSSION

Base case

The results indicate that the shelter is following a similar trend to the outside thermal conditions with higher values as a result of its fabric characteristics, low insulation level and small thermal mass as shown in Figure 6. As indicated in Table 1, in a base case scenario only 13.3% of hours are complying with thermal comfort conditions during the year. On the basis of the aforementioned analysis of the impact of passive techniques; a final simulation is conducted to assess the impact of combined passive techniques on the thermal comfort conditions.

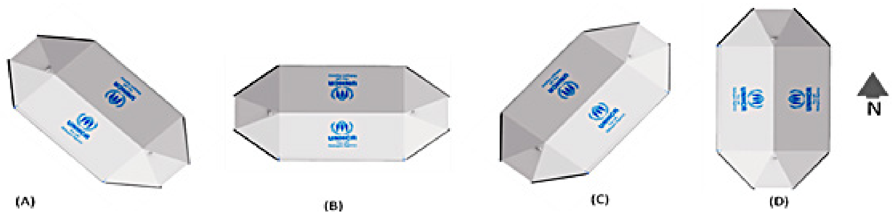

Figure 3. (A) Shelter is oriented NW-SE, (B) Shelter is oriented E-W, (C) Shelter is oriented NE-SW, (D) Shelter is oriented N-S

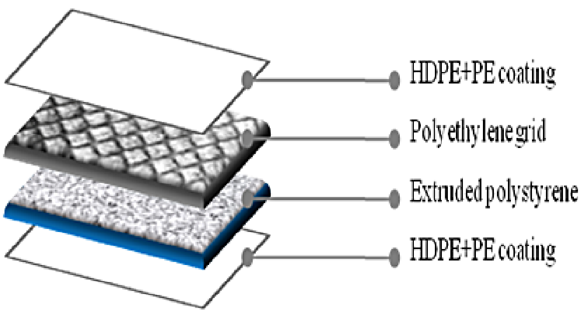

Figure 4. Insulation package for the floor

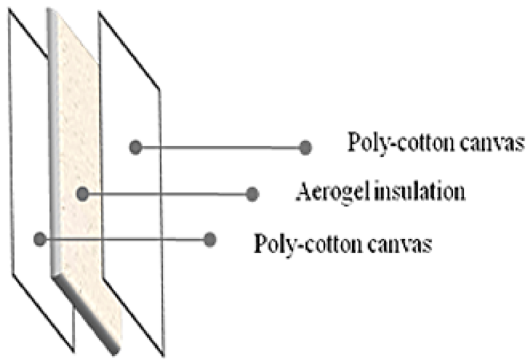

Figure 5. Thermal insulation package for walls and roofs

Table 1. Number of comfortable hours

Thermally comfort days based on Eq. 1														
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	[%]
No. of comfort hours	98	73	71	91	114	82	87	87	94	137	138	91	1163	13.3

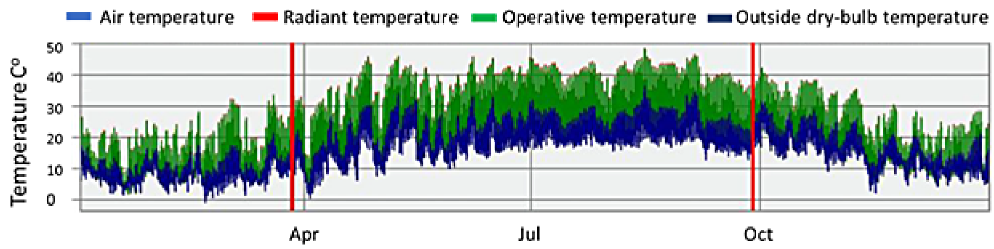

Figure 6. Inner tent thermal behavior without occupants

Orientation

The simulation results showed that all orientations resulted in more annual comfort hours when the long sides of the tent are facing north and south in East-West orientation as shown in Table 2. The east-west orientation provides more comfort hours in the summer months and the north-south orientation provides more in winter.

The simulation results for floor insulation are indicated in Figure 7. The results showed that only 0.6% improvements in comfort hours is achieved through the floor insulation. However, the floor insulation is recommended for hygienic purposes and for protection from wet ground in winter. The outer tent insulation has increased the thermal comfort hours by 17.42%. Air, radiant and operative average monthly temperatures are indicated in Figure 8. The inner tent insulation has increased thermal comfort hours by 16.38%. Air, radiant and operative average monthly temperatures are indicated in Figure 8.

The simulation results, as illustrated in Figure 10, revealed that the inside thermal comfort conditions have improved by 0.52% when a ventilation rate of 7.5 (L/s-person) is applied to the outer tent. The simulation results, as illustrated in Figure 11, revealed that the inside thermal comfort conditions have improved by 0.43% when a ventilation rate of 7.5 (L/s-person) is applied to the inner tent.

Table 2. Shelter thermal comfort hours in different orientations

Thermally comfort hours based on Eq. (1)	[%]
North-South orientation (base case)	13.28
East-West orientation	14.10
Northwest-Southeast orientation	13.94
Northeast-Southwest orientation	13.30

Shelter optimization

For the final optimization, and based on the aforementioned analysis of the impact of passive techniques; a final simulation is conducted to assess the impact of combined passive techniques on thermal comfort conditions including orientation, floor, walls and roof insulation of the inner

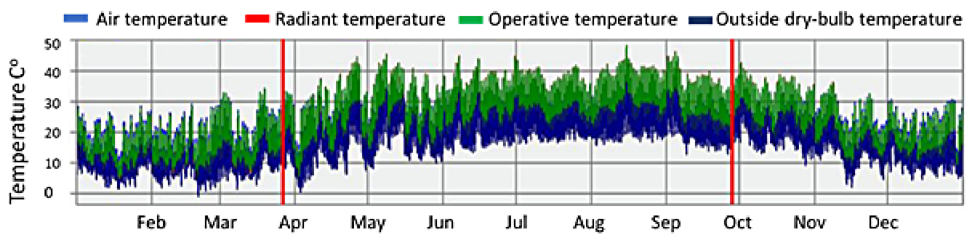

Figure 7. Hourly simulation results of the inner tent with floor insulation

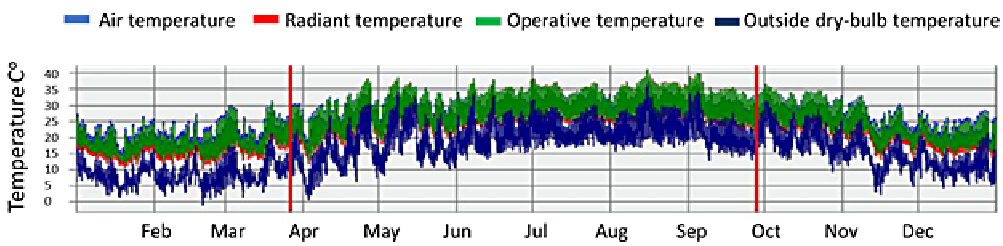

Figure 8. Hourly simulation results with insulated outer tent

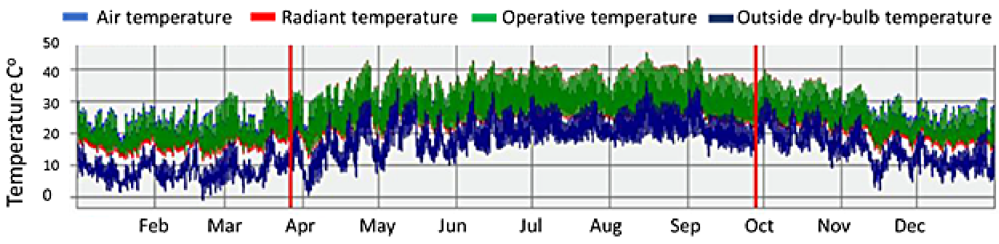

Figure 9. Hourly simulation results with insulated inner tent

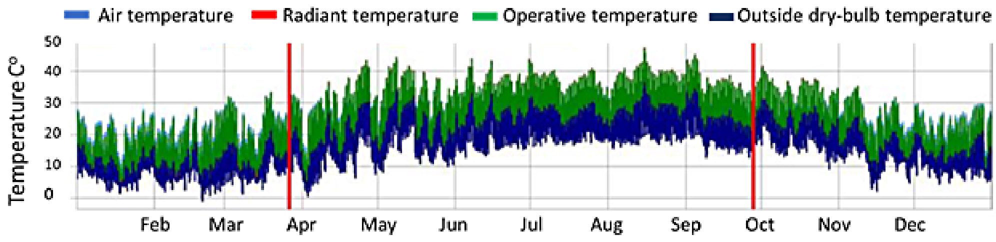

Figure 10. Outer tent hourly simulation results with 7.5 L/s per person ventilation

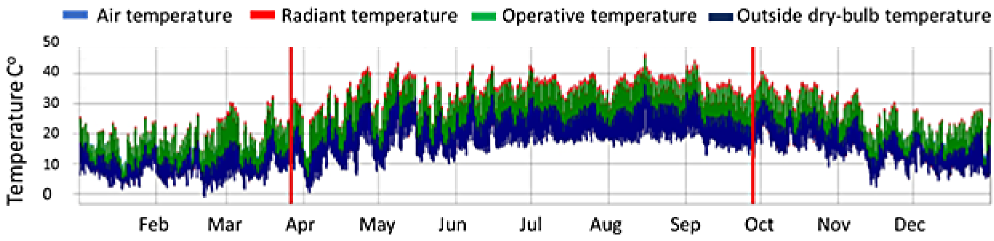

Figure 11. Inner tent hourly simulation results with (7.5 L/s-person) ventilation

tent and natural ventilation. Although the outer tent insulation showed more comfort hours, it is recommended to insulate the inner tent instead, as the outer tent doors are usually kept open during the day and that will reduce the effectiveness of the insulation. Table 3 indicates that when ventilation is applied all day the comfort hours increased only by 3.61%.

The previous analysis showed that when ventilation is used all day, the shelter showed a small improvement due to heat loss by external ventilation; hence, a simulation for the optimized shelter with controlled ventilation is conducted. Ventilation is activated when inside temperature is higher than the outside temperature and exceeds 24.5°C in summer and 22.5°C in winter. Table 4

Table 3. Final simulation results

Thermally comfort days based on Eq. 1														
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	[%]
No. of comfort hours / base case	98	73	71	91	114	82	87	87	94	137	138	91	1163	13.28
No. of comfort hours /final	109	91	90	123	140	104	115	108	117	162	187	123	1480	16.89
Difference	11	18	19	32	26	22	28	21	23	25	49	32	317	3.61

Table 4. Final simulation results

Thermally comfort days based on Eq. 4.1														
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	[%]
No. of comfort hours/base case	98	73	71	91	114	82	87	87	94	137	138	91	1163	13.28
No. of comfort hours/optimized	165	110	165	181	194	115	117	110	139	275	257	176	2015	23.00
Difference	67	37	94	90	80	33	30	23	45	138	119	85	852	9.72

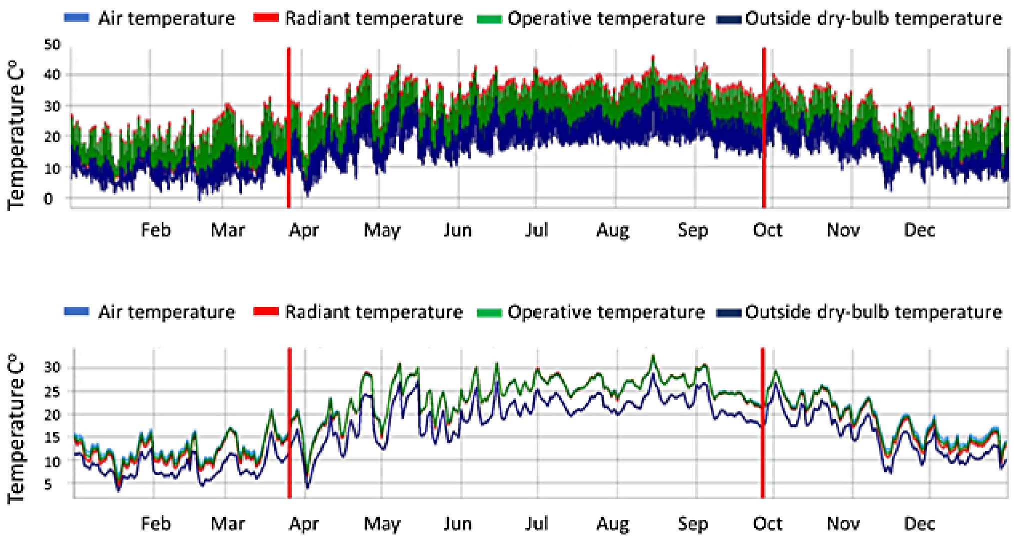

Figure 12. Inner tent final simulation results: (A) Hourly simulation data. (B) Daily simulation data

indicates that when controlled ventilation is applied, the comfort hours increased only by 9.72%. comfort inside the shelter based on the outside climatic conditions.

CONCLUSIONS

A study on the thermal behavior of UNHCR emergency shelter used in refugee camps was conducted under the al-Mafraq (Jordan) climate in which the largest refugee camp in Jordan is located. The Design Builder building simulation software was used to investigate the impact of passive techniques on the thermal behavior of the shelter and the inside thermal comfort conditions. Several passive techniques were simulated, including orientation, floor insulation, wall and roof insulation, and ventilation. The simulation results indicated that when passive techniques are applied; thermal comfort hours have increased by 9.72% which offers 23% comfort hours throughout the year.

The main contributors in this improvement are natural ventilation and wall and roof insulation. Although floor insulation showed small improvement in thermal comfort (0.6%); it is recommended to insulate the floor for hygienic purposes and to protect from wet grounds in winter besides reducing the loss of body heat through the floor. The proper use of windows for natural ventilation can highly contribute to achieving more comfort hours especially during the warm months of the year; however, in order for the ventilation to be applied efficiently, instruction must be given to refugees to raise awareness about natural ventilation role in increasing or decreasing thermal

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