The thermal performance of shelter modelling: improvement of temporary structures

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Abstract

There exist many disasters, whether natural or caused by human factors. In emergency situations, it is important to provide shelters to protect the population and the support against their environment and to give them some privacy. Unfortunately, contexts and exposure constraints in which these items are used can be very different which implies that their performance can be reduced with a direct impact on occupant comfort. Furthermore, given the very large scale of emergency camps, the intake of fuel in winter condition turns into a major logistical challenge.

It is crucial to improve the thermal performance of emergency shelters to 1) increase their indoor comfort and 2) reduce their fuel/wood consumption and related pressure on natural resources. The purpose of this paper is to discuss the difficulties in achieving a realistic thermal model of lightweight structures, taking into account the air permeability of fabrics, their light transmission and the imbrication of several elements (multi-layered shelter).

We created such a model of the IFRC/ICRC/UNHCR standard family tent, based on the building oriented Energy+ thermal simulation model. This model is calibrated and validated by comparing simulation results with in situ measurements realised in the Belgian Building Research Institute (BBRI) facility in Limelette, Belgium. To evaluate the quality of the thermal model, we consider de mean deviation between calculated and measured temperatures. The calculated deviation varies from 1.6°C to 1.9°C. This model provides objective

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assessment of the performance of that shelter for any given context and climate exposure. Furthermore, this model is a starting point for the thermal analysis of lightweight structures.

Keywords: simulation, modelling, sensitivity analysis, thermal performance, multi-layer, light transmission, calibration, shelter.

1 Introduction

There exist many disasters, whether natural or caused by human factors. In emergency situations, it is important to provide shelters to protect the population and the support against their environment and to give them some privacy. Unfortunately, tents commonly used in humanitarian context do not ensure comfortable conditions for the occupants. Furthermore, such intervention leads to very large scale emergency camps. Indeed, for example, 117,000 shelters have constructed between 2002 and end of 2004 and 21,500 additional shelters were planned for 2005 in support to refugees in Afghanistan [1]. In winter conditions, the intake of fuel turns into a major logistical challenge.

The objective of our contribution is to discuss the difficulties to establish a thermal model of such shelter and shows the accuracy we achieved while trying to create one starting from traditional building physic tools. This discussion will help further developments of dedicated models.

About building physics, field experiments are obviously the most accurate way to collect data and compare existing alternative design and actual conditions. Thermal models should be used to test new designs before the prototypal stage. The relevance of such models depends on their ability to reproduce the actual behaviour of a tent. Therefore it is useful to start by assessing the accuracy of the developed thermal model by confronting it to monitoring values.

2 Hypothesis

2.1 Shelter description

The tent we study is known as a family shelter for emergency situations. It is used by the UNHCR, the IFRC and ICRC [2]. This tent is composed of one outer skin and one inner skin. The inner skin envelops a central space that may be divided in two equal parts. The outer skin creates two transitional spaces in front of both entrances. Figure 1 shows the plan and view of that tent. A 10 cm gap exists laterally between the inner and the outer skins. Openings are set on both sides of the central space and on outer skin in transitional spaces. A moveable flap and a mosquito net close them. Ventilation openings exist above both doors. Table 1 summarizes the main characteristics of the materials, based on laboratory measurements except for thermal conductivities and compositions which are values respectively based on material properties available in DesignBuilder database [3] and on tent description [2].

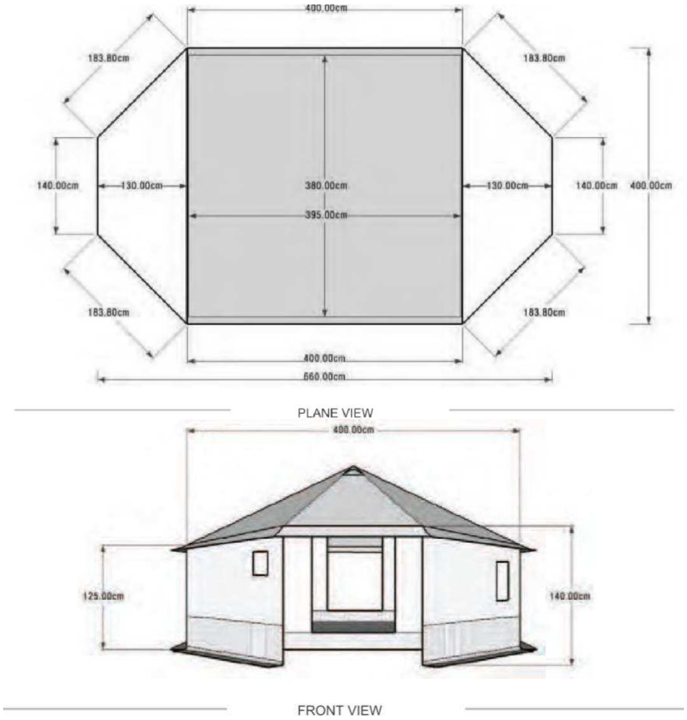

Figure 1: Plan and view of the tent [2].

Table 1: Materials properties.

Parameter	**Inner tent**	**Outer wall**	**Outer roof**	**Mud flaps and ground sheet**
Composition (%) [2]	40-Cotton 60-Polyester	40-Cotton 60-Polyester	40-Cotton 60-Polyester	Coated polyethylene
Weight (g/m²) ISO 3801-5	130	239	373	165
Thermal conductivity (W/(m.K)) [3]	1.2	0.2	0.2	0.2
Heat transmittance EN 410	27.5	13.38	8.52	0.46
Heat reflection EN 410	47.2	62.15	64.48	34.64
Light transmittance EN 410	20.2	12.74	7.66	0.09
Light reflection EN 410	39.2	73.79	76.48	43.54
Air permeability @100Pa (l/(m².s)) ISO 9237	?	30.1	3.88	< 0.1

2.2 Field measurements

Investigations in the Brussels area took place at the Belgian Building Research Institute (BBRI) research facility of Limelette during the months of October and November 2013 (figure 2). It was a true experimental investigation, out of emergency situation. The shelter was monitored thanks to twelve thermocouples (figure 3) for a period of 30 days in total distributed in three periods: from 4 to 10 October 2013 with all openings closed, from 10 to 24 October and from 7 to 27 November 2013 with inner and outer vents opened. Extensive meteorological data are available from an on-site weather station.

The thermocouples are placed in order to identify the thermal stratification inside the tent and the thermal behaviour of the gap between the inner and outer tent when exposed to the sun. For the acquisition, a computer is placed in the inner tent and provides 12.18 W/m² of internal gain.

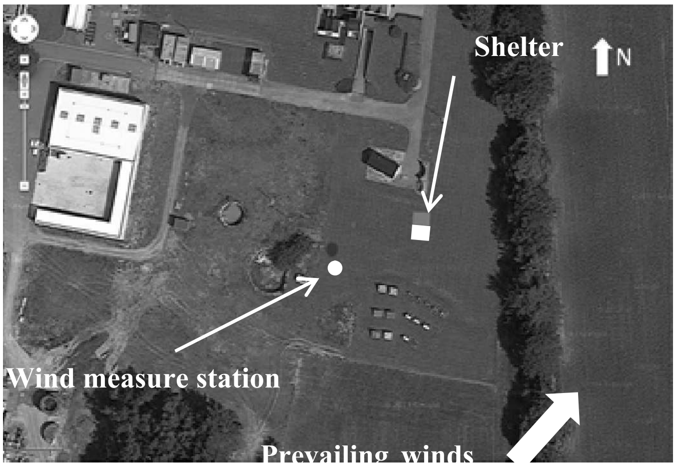

Figure 2: Site of measurements in Belgium (source: Google Maps).

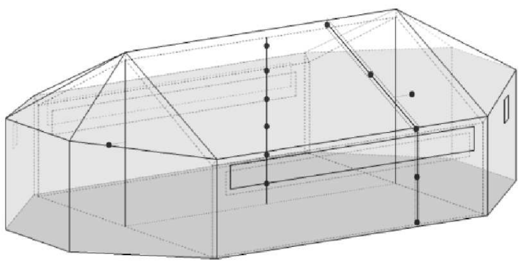

Figure 3: Position of thermocouples.

2.3 Thermal model

In this study, we used Energy+ along with the Sketchup Energy+ plugin in order to create a 3 dimensional model with an accurate evaluation of view factor for radiative heat exchange between surfaces.

A shelter shows specific properties for which the use of building thermal model software is not obvious. Those properties are related to the skin fabric that is neither airtight nor opaque. Other specificities are the very low insulation level, the very small thermal mass and the major influence of the ground temperature. Also, the interaction between the inner and outer skin has to be considered.

The model we develop deals with these specificities by dividing the shelter in seven thermal zones. Both a resistive model and an airflow model connect these zones. This way, the gap between the inner and outer tents is modelled in a similar way as a double skin façade, and the model may be compared to the data collected during the field measurement. All adjacent surfaces between zones, or between zones and the outside are considered as fully glazed. The glazing photometric properties are defined based on Table 1. This way, solar transmission through the fabric is considered. Only the ground sheet is modelled as an opaque material. Thermal conductivities of the glazing are also adapted to match values specific to the various fabrics used.

The airtightness of the tent is the main difficulty. Indeed the fabrics are not airtight. Further, windows and doors are closed by Velcro bands only. The connection to the ground also shows air leakages. Airflows through the outer tent are related to both the temperature difference and the wind pressure. The effect of the temperature difference is easily modelled by the Archimedes equation. The wind pressure is modelled by using pressure coefficients which are determined thanks to TNO Cp Generator [4]. These coefficients are specific to the geographic position and environment and closed wind obstacles. There are then specific for the BRRI implantation and are not transposable. All openings are described by an area, a flow exponent and a flow coefficient. We determined an indicative area for all openings based on the actual geometry of the tent. To consider the air infiltration throw cracks and fabric, we consider that all glazed surface as fully opened and we calculate the discharge coefficient to correspond to the air permeability of the corresponding fabric.

3 Model calibration

The parameters to calibrate are the discharge coefficients used to model the air infiltration throw cracks and fabric of the tent and the soil thickness. To determine these coefficients, we proceed this way: firstly we simplify the model by considering that only five different values of discharge coefficient are to be identified, i.e. two for the outer tent openings (windows and vents), one for the mud flaps (mainly to represent crack infiltration), one for the inner tent fabric and one for the inner vents – considering only air permeability for other surfaces (outer roof and walls), based on laboratory measurements. We evaluated also soil thickness under the ground sheet which may be consider as part of the composition of the floor of the tent, distinguishing lateral, transitional and inner zones. Secondly, we make different simulations for various values of flow coefficients and soil thickness and we calculate the mean variation between the simulation results and monitored temperatures for the zone describing the inner tent. This exercise is done for the first monitoring period in Brussels (with all openings closed). Some results are shown in figure 4. Based on these results, we extrapolate the best value of each coefficient and select values presented in table 2 for the flow coefficients of soil thickness.

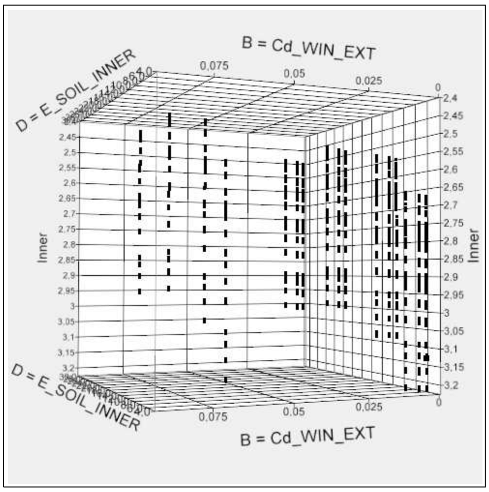

Figure 4: Results of simulations [5].

Table 2: Calibration results.

Parameter		Calibrated value
Discharge coefficient:	- Inner tent	0.0242
	- Mud flaps	0.0052
	- External windows, closed	0.0840
	- External vents, closed	0.1595
	- Internal vents, closed	0.1595
	- External vents, open	0.1595
	- Internal vents, open	0.2300
Soil thickness participating to floor composition of : - transitional and inner zones - lateral zones		 15 cm 5 cm

4 Results and discussion

Figure 5 presents the results of calibrated tent model for the first periods of measurements, with all opening closed. The correspondent values of discharge coefficient and soil thickness are presented in table 2. These lead to a mean deviation between measured and calculated temperature of 1.94°C. We observe that the value of discharge coefficient of outer vents have a small impact on goodness of the model. Considering only daily period, the best ground temperature to consider is 2°C higher than for the whole period. In the model, we can only choose a constant ground temperature or a ground temperature equal to outside temperature. We conclude that the ground temperature is difficult the modelled but have a large impact on result, i.e. in order of +0.12°C in mean deviation per degree in ground temperature. We may also note that it's difficult to reproduce the night overcooling in case of clear sky.

During, periods of 10 to 24 October and 7 to 11 November the inner and outer vents are open and their discharge coefficients are presented in table 2. The mean deviations between measured and calculated internal temperatures are respectively 1.59°C and 1.77°C. Results are presented in figures 6 and 7.

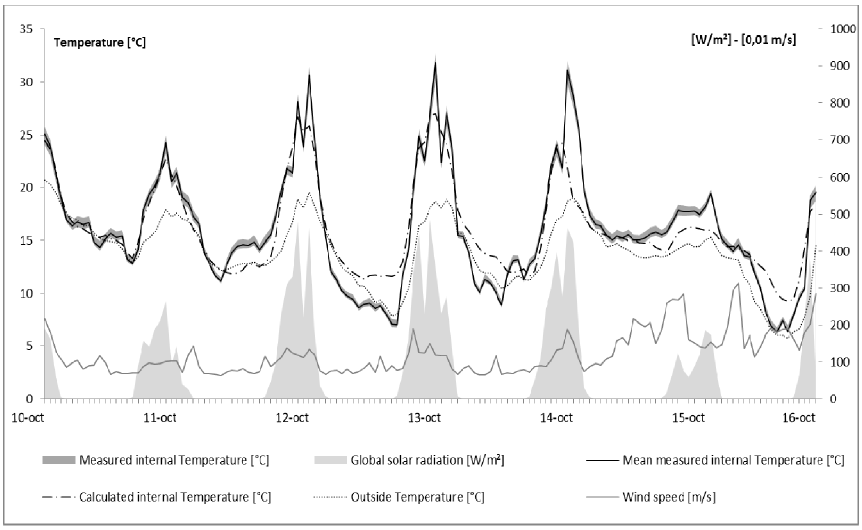

Figure 5: 4–10 October calibration.

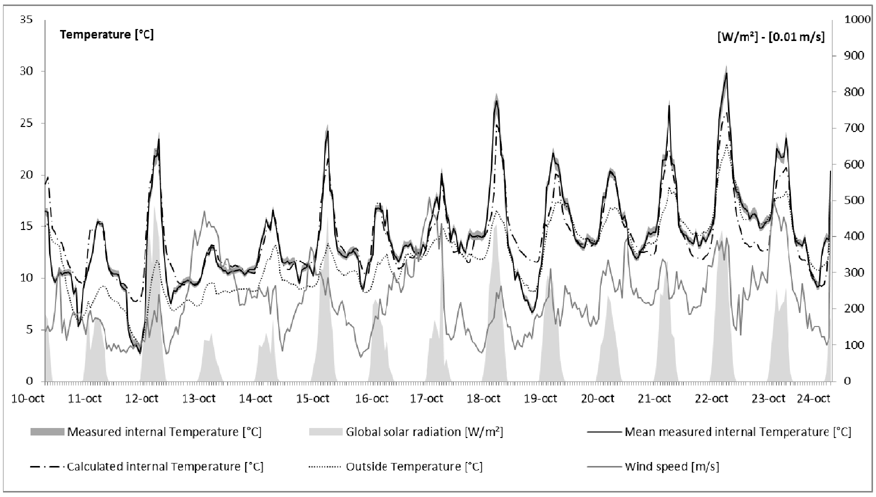

Figure 6: 10–24 October calibration.

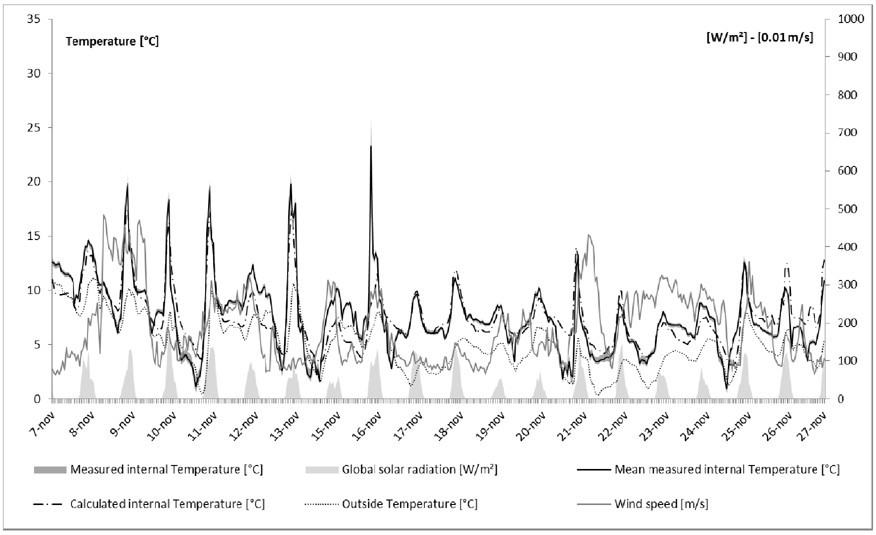

Figure 7: 7–27 November calibration.

5 Conclusion

The aim of this paper is to discuss the creation of a model representing the thermal behaviour of the family shelter for emergency situations used by the UNHCR, the IFRC and ICRC [2]. After calibration, the model is relevant and may reproduce the actual behaviour of a tent. The deviation calculated between the measured and calculated internal temperature, for different conditions (i.e. vents opened or closed), ranges between 1.6 and 1.9°C for the three periods of measurement considered.

Some phenomenon are difficult to reproduce, as overcooling during night in clear sky conditions. Also, the ground temperature has a wide impact on results but is difficult to model.

To conclude, using windows to model fabric of tent permits, by adapting discharge coefficient, to reproduce the properties of air permeability and luminous transmittance of fabrics and obtain a good representation of light structure thermal behaviour. Other similar models may be constructed in view to compare form, material, and design to assess the quality of such installation.

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