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Thermal performance of shelter modelling: Improvement of temporary structures

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ABSTRACT

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, 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).

Such a model of the IFRC/ICRC/UNHCR standard family tent is created, 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 BBRI facility in Belgium, in Burkina Faso and in Luxembourg. This model provides objective assessment of the performance of that shelter for any given context and climate exposure except for night overcooling phenomenon.

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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 [1,2]. Unfortunately, tents commonly used in humanitarian context do not ensure comfortable conditions for the occupants, as showed by measurement realised in Burundi from 20 to 25 July 2013 (Fig. 1). Furthermore, such intervention leads to very large-scale emergency camps. Indeed, for example, 117,000 shelters have been constructed between 2002 and end of 2004 and 21,500 additional shelters were planned for 2005 in support to refugees in Afghanistan [3]. In winter conditions, the intake of fuel turns into a major logistical challenge.

Scientific researches about emergency sheltering focused on design proposals such as deployable structures [5–9] or adaptable, versatile and compatible construction systems and shelter kits [10–14]. Dedicated design approaches have been proposed for these specific structures, such as 4-dimensional design [11,15]. Very few publications focused on the energy efficiency of these shelters [9,13,16–19]. Crawford et al. [16] proposed a thermal model adapted to a specific shelter. They calibrate the crack area in order to obtain an inside calculated temperature almost equal to the air temperature measured during testing. However, they identified divergences between simulation results obtained with their thermal model and the experimental data, mainly in terms of air change rates. Also, they studied a rigid insulated shelter which behaves more like a standard construction than lightweight structures, as considered in the present research. Consequently, the feasibility of using building oriented simulation model to study shelters has yet to be proved.

This lack of interest on the thermal behaviour of emergency shelters is surprising since inappropriate hygro-thermal conditions outdoors and indoors have proven to be related to various health hazard and stress, both in cold and warm conditions [20–22].

Our contribution aims three objectives. Firstly, this contribution proposes a framework for further studies about such shelters. Secondly, based on field measurements, it documents the thermal behaviour of the most popular family shelter among emergency

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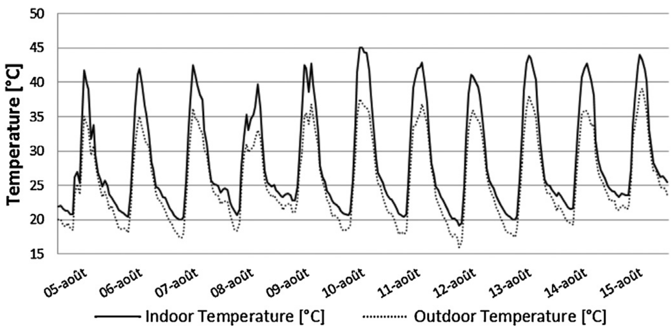

Fig. 1. Measurements in Burundi [4].

agencies under various climates. This documentation intends awareness rising of the poor thermal behaviour and comfort conditions of such shelters. Thirdly, it discusses 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.

A building physic analysis of family shelters or other emergency housing should aim two main objectives: (1) improving indoor conditions through passive design, both for cold and hot climates, in order not to threaten the health of disasters victims; (2) reducing fuel demands for heating in order to make fuel supply easier and less expensive.

To do so, alternative designs for shelters may be proposed. But these alternatives have to consider their impact on the other specificities of the shelter in a holistic way. Key parameters to consider are [23]:

1. the geometry: warehouse, transport and handling aspects limit the weight and size of the shelter;
2. the social aspect: size, intimacy and adaptability of the shelter must be considered;
3. other constructive aspects such as mechanical resistance.

Anyhow, it is obvious no single discipline could develop an ideal shelter by itself. A multidisciplinary approach must be preferred.

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. It might also be useful to compare the accuracy of the model with the one achieved by previous models. Such information is important to ensure a proper interpretation of the results. Finally, it might be useful to compare the performance of alternative designs proposed by various authors. This will be possible only if all studies consider similar conditions.

For all these reasons, we propose in the next section standard hypotheses, and weather data to be used for thermal model comparison of shelters.

2. Hypothesis

2.1. Shelter description

The studied tent is known as a family shelter for emergency situations. It is used by the UNHCR, the IFRC and the ICRC agencies [24]. 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. Figs. 2–4 show plans and views 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 summarises the main characteristics of the materials, based on laboratory measurements. Composition, weight, solar and visual transmittance and reflexions and air and water permeability's are measurement results made on samples from an actual tent. Thermal conductivities are indicative values based on literacy [25].

2.2. Field measurements

Monitoring's were conducted on three different climates: Brussels in Belgium, Sag Nioniogo in Burkina Faso and Bertrange in Luxembourg. Fig. 15 shows temperatures and radiation values observed during field experiments for the first period of measurement in Brussels.

Investigations in the Brussels area took place at the BBRI research facility of Limelette during the months of October and November 2013 (Figs. 5 and 6). It was a true experimental investigation, out of emergency situation. The shelter was monitored thanks to 13 thermocouples (Fig. 6) for a period of 39 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 26 November 2013 with inner and outer vents opened. Extensive meteorological data are available from an on-site weather station.

Fig. 6 describes the position of data acquisition material used to collect these data in Brussels. 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/m^2 of internal gain.

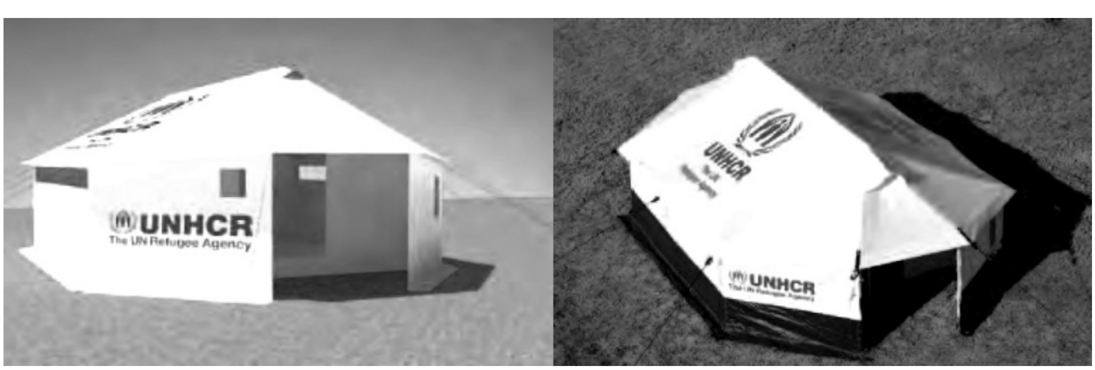

Fig. 2. View and photo of the studied tent [24].

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