Design of Cold Climate

Temporary Shelter for Refugees

By

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Fourth Year Undergraduate

in Group A, 2000/2001

hons (no merit back then)

I herby declare that, except where specifically indicated, the work submitted herein is my own original work. I also declare that the work I shall submit in the conference style paper is also my own.

Signed: R Batt Date: 23/5/01.

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Contents

Summary

A liner was made for the existing UNHCR cold climate refugee tent. The shelter was tested to assess its performance according to physical, social and logistic criteria. A Matlab program was written, based on the experimental data, to model the power required to heat the tent for one year under Afghan weather conditions. It was found the shelter required 76% less fuel with the liner than the standard tent, resulting in large potential savings in terms of cost, weight and volume. Further improvements need to be made to the fire safety of the liner material.

4 Introduction

1.1 Background information

The United Nations High Commissioner for Refugees (UNHCR) defines refugees as "those who have fled their countries because of a well-founded fear of persecution for reasons of their race, religion, nationality, political opinion or membership in a particular social group, and who cannot or do not want to return."[(1)]

Hundreds of thousands of people are forced to live as refugees all over the world. Usually around 95% [(2)] of refugees find lodging with friends or relatives in a host population, in rented accommodation, or in converted community buildings such as town halls. However in some cases the facility for housing people in these ways is insufficient, and tented camps must be set up until alternative accommodation can be found or the displaced population can return home.

The use of tented camps is particularly unsatisfactory in cold conditions, but this is sometimes the only option. Refugees have spent the last winter in tents in Afghanistan and in the Balkans. Newspaper reports stated that two to three hundred of people had died of exposure in Afghan camps this winter, but the true figure is much higher, and occurs every year[(3)]. Here there is a problem that clearly needs to be addressed.

1.2 Design Brief

In an interview with Peter Manfield in April 2000, Wolfgang Neumann, Head Physical Planner at the UNHCR, indicated that he was open to the suggestion of 'add-on' products for the standard UNHCR tent, in the form of a 'winterised kit'(4). These could be used when appropriate in various situations and climates. The project design brief was drawn from this interview:

Create add-on components for the existing UNHCR tent, in order to form part of a winterised kit suitable for deployment in extreme weather conditions.

1.3 Project Approach

The standard UNHCR tents are canvas bell tents with a double skin roof and a thin cotton internal liner. They have a flue manifold hole, facilitating the use of an internal space heater in cold conditions.

Figure 1 (a): UNHCR Tent in use in rural Kosovo

Figure 1(b): Heater in use inside Tent

The thermal resistance of the canvas walls is extremely low, and the tent is inherently draughty, leading to large heat losses through both conduction and convection. The obvious solution to both of these problems is to create an **insulating liner** that can be hung inside the tent during winter months, and rolled up at the walls or removed entirely during warmer weather. The design and testing of a liner forms the main part of this project. Other components have been considered and are described at the end of the report.

2.0 Liner Design

2.1 Design Criteria

In order to be successful, and accepted as an option by the aid community, a shelter system must perform well in relation to various physical, social and logistic criteria.

2.1.1 Physical

Thermal Environment

The thermal environment can be defined by three factors:

- Air temperature
- Radiant temperature
- Air movement

The air temperature within a space is dependent on the rate of heat input, and the rate of heat loss due to conduction, convection and radiation. Conduction losses are dependent on the U-values of the boundaries to the space, where the U-value is the reciprocal of the sum of the thermal resistances of the boundary layers. Convection losses are dependent on the permeability of the boundary layers and of the structure as a whole. Radiant losses are dependent on the emissivity of the boundaries.

The radiant temperature is defined as the area-weighted average surface temperature. If the mean radiant temperature is more than around 3° C below the air temperature, then the room will be perceived as stuffy(5) and thermal comfort will be reduced.

Air movement affects thermal comfort because the perceived temperature decreases with increased air speed due to the increased rate of evaporation from the skin.

The thermal comfort is also dependent on the distribution of heat within a room. In poorly insulated or poorly ventilated spaces thermal stratification occurs, resulting in low ground level temperatures and high ceiling level temperatures.

Ventilation

Ventilation is required for the supply of fresh air for breathing and for the removal of moisture and smells from the atmosphere. At very low temperatures, humidity becomes a problem because the cold air is quickly saturated. Excessively damp conditions can cause condensation on the tent walls, leading to decreased thermal resistance of the material and rotting. Damp air also contributes to respiratory health problems. However excessive ventilation requires increased heating to maintain the same internal temperatures, so a balance must be drawn, preferably allowing the occupants of the tent control over the ventilation levels.

Structural Stability

Some cases of collapse of the existing tent under snow loading have occurred. The liner itself be stable and must not inhibit the proper erection of the tent.

Fire Safety

The liner must not increase the danger to health from fire within the tent, either through excessive flammability of the liner material, or through toxic combustion products.

Durability

The liner must be able to withstand U.V. degradation, rotting and normal wear and tear.

2.1.2 Social

It is important not to regard the shelter as merely a scientific model, but as a functional home. If the social as well as physical factors are not addressed, the shelter is likely to be rejected by the refugee population.

Buildability

The shelter is for use in extreme climates, so is likely to be erected in inhospitable conditions. The physical fitness and building ability of the refugee population cannot be predicted, and will vary from group to group. Thus the shelter must be easy to erect quickly.

Flexibility

The shelter must be adequate for use in varying weather conditions and for varying purposes (e.g. as a private home for different sizes of family groups, or as a communal use building).

Usability

The shelters are often lived in for periods of time up to several years, so it is important that they are as user-friendly as possible. This includes factors such as the door, window and flue outlet design, and the space and light levels within the shelter.

Thermal Comfort

Thermal comfort depends on the thermal environment and also on the needs of the population. This includes factors such as the clothing, bedding and food available, and the health, age and metabolic rate of the occupants, factors that will vary from person to person and from one emergency to another.

2.1.3 Logistic

Cost

Spending per head of capita in a refugee crisis ranges from US$ 10 to 20 for a typical African family, to US$ 500 to 5000 in the Kurdish crisis(6). The cost of additional kit must be in proportion to the improvements made. The existing cold climate shelter costs US$200, and the standard UNHCR heater costs $200. Neumann set a target cost of US$ 400 –500 for the full winterised tent system, which was echoed by Red Cross officials who suggested a cost of US$ 60 – 80 for the liner.

Weight

The weight of the materials for transportation directly influences the cost. The weight of the existing shelter is 115kg, and the liner should not increase this significantly.

Volume

Packed volume also directly influences the transportation costs. The packed volume of the existing shelter is around $0.3m^3$, and the liner should not increase this significantly.

Production time

The winter period may only last three months, but this is the time when most people are likely to die from cold. Thus the shelter must be available to be made in large quantities (around 10 000) at very short notice (7 to 10 days), requiring several manufacturers, or must be suitable for stockpiling for immediate use.

Supply Lead-Time

Once produced, the shelter must be transported to where it is required. In order to do this as quickly as possible, the distance for transportation must be low, meaning that ideally it could be produced locally, from locally procured materials. If this is not possible, then the weight and volume of the shelter kit must be minimised for ease of transportation.

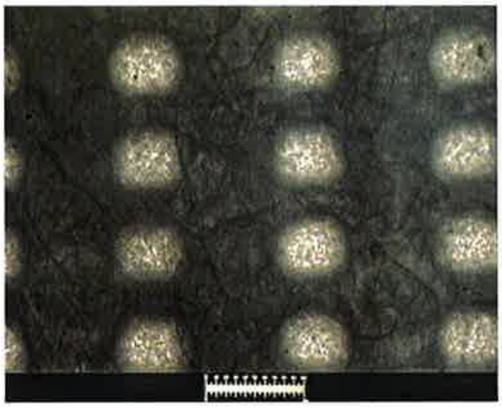
2.2 Material Selection

Previous research on cold climate shelter, carried out in Cambridge University engineering and architecture departments, working in conjunction with a materials company called Web Dynamics, has developed a material that is potentially suitable for use as a liner. Manfield's work[6] shows that the material performs well in terms of buildability, strength, and U-value for its weight and packed volume, compared to other insulation materials tested. Crawford's work[7] showed that the material was efficient at conducting moisture out of a space without condensation occurring, compared to other materials tested. Web Dynamics agreed to produce a further sample of the material for a prototype liner for the UNHCR tent.

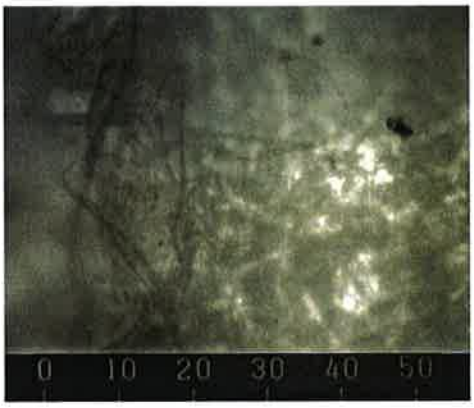
The material consists of 3 layers, the "inner" and "outer" layers being breathable, spun polymers of approximately 0.1mm thickness. The outer layer is also waterproof, similar to Gortex™. The "middle" layer is hollow fibre polyester wadding, commonly used in sleeping bags, duvets and ski-wear. It has good insulation properties due to the inclusion of air, a poor thermal conductor, both within the fibres themselves and between them.

Figure 2: Microscope Pictures of the Liner Material

Figure 2(a) Inner Layer

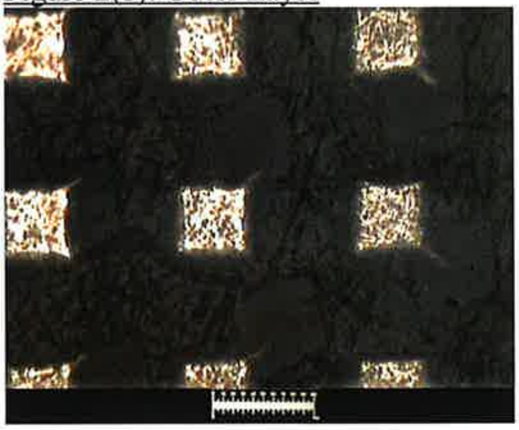


2.5x magnification (scale = 1mm)



20x magnification

Figure 2(b): Outer Layer



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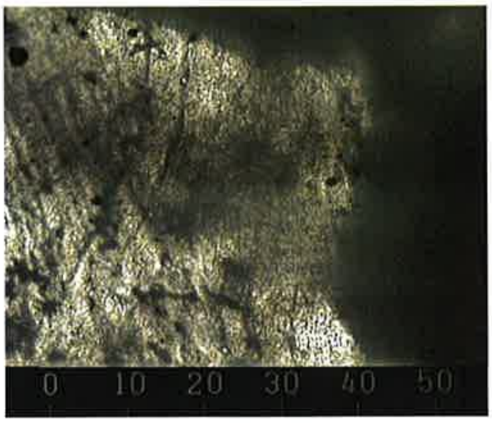


20x magnification

Figure 2(c): Hollow Fibre Wadding

2.5x magnification

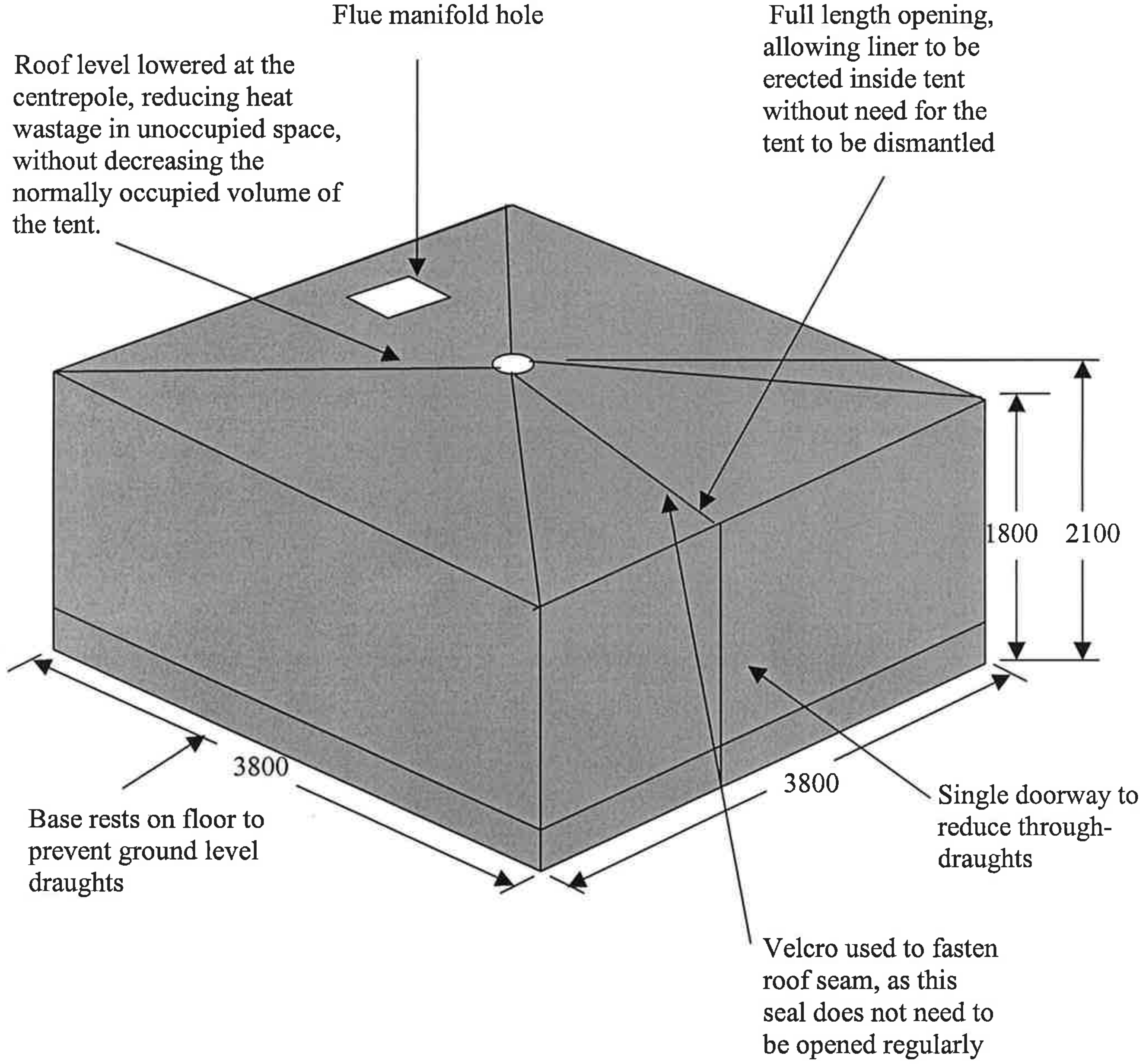
At 20x magnification it can be seen that the holes in the outer layer, allowing the passage of water vapour, are smaller than those in the inner layer, indicating that the outer is more waterproof than the inner.

The material was provided in a 1.5m width roll and is not quilted, to avoid the compaction of the material, which would reduce its insulating properties.

2.3 Liner Specification

Consideration of the criteria listed above led to the following liner design.

Figure 3: Liner Specification (Dimensions in mm)



3.0 Thermal Testing

3.1 Experimental Method

Thermal testing was carried in the Ford Motor Company Environmental Test Chamber, where it was possible to control both the ambient temperature and the windspeed.

3.1.1 Aims

- To observe the thermal environment within the tent, for various external temperatures and windpeeds.
- To assess the improvements that can be made by use of the liner.
- To obtain data in order to create a computer model of heating requirements with and without the liner.

3.1.2 Assumptions

Previous testing of cold climate shelters [(6), (7)] has been carried out at temperatures of -20°C, based on the conditions experienced in winter in Kosovo. This temperature was repeated to enable direct comparisons between the shelter systems. In addition, testing will be carried out at a more moderate winter temperature of 2°C, enabling comparison with the UK winter field tests (Test B).

Windspeeds of up to 12.5m/s (~~Gale~~ Beaufort Scale Force 6) were be tested, in line with previous cold climate shelter testing based on Kosovan winter conditions.

The tent was aligned with the two doors on the axis of the wind direction. The liner was erected with the door on the sheltered side of the tent.

The heater consisted of electric bar heaters, housed in a metal box to mimic the radiative-convective split of a typical paraffin or wood burning stove. Power inputs of between 0.8kW, approximately equivalent to the heat energy produced by 8 people, and 5.4kW, within the UNHCR recommended heat input for the existing tent, were tested.

Occupancy of eight people per tent was judged to be a realistic estimate, based on conversations with aid workers. The occupants of the tent were assumed to be inactive, i.e. to have no effect on the mixing of the air, modelling night-time conditions when the temperatures are likely to be lowest. The tent and liner doors remained closed throughout the experiment.

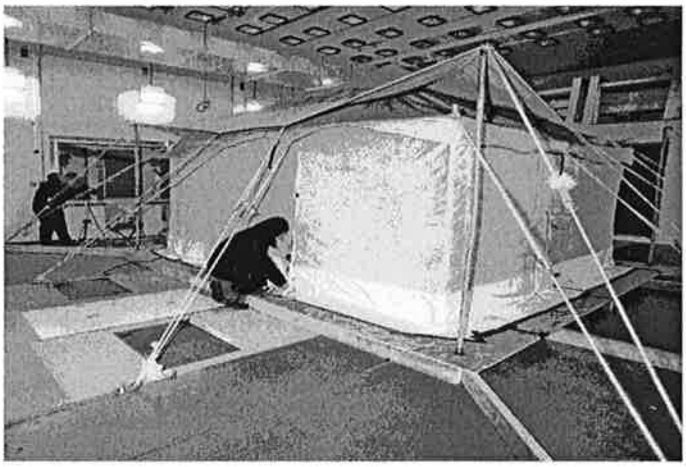
Previous testing has indicated that with the liner material used, there is little build-up of condensation and ice in the tent[7]. Thus it was assumed that the presence of moisture within the tent has an insignificant effect on its thermal performance, and was not remodelled.

Table 1: Summary of Physical Test Conditions

Temperatures	Wind Speeds	Heat inputs
-20 and 2 °C	0, 2.5, 7.5 and 12.5 m/s	0.8, 2.3 and 5.4 kW

3.1.3 Test Set-up

Figure 5: The Ford Environmental Test Chamber



A test rig was constructed, allowing the tent to be erected inside the chamber. The tent was mounted on a false floor in order that the heat loss to the floor could be recorded, and ultimately corrected for heat loss to the ground. The bottom flaps of the tent were stapled to the false floor to mimic the "digging in" of the bottom of the shelter that would occur in the field, preventing excessive air infiltration at the base of the tent walls.

An array of surface and air temperature sensors, provided by Ford, were set up inside and outside the tent, in order that the distribution of heat could be recorded.

Figure 6: Ford Test Set-up (Dimensions in mm)

Figure 6(a): Elevation

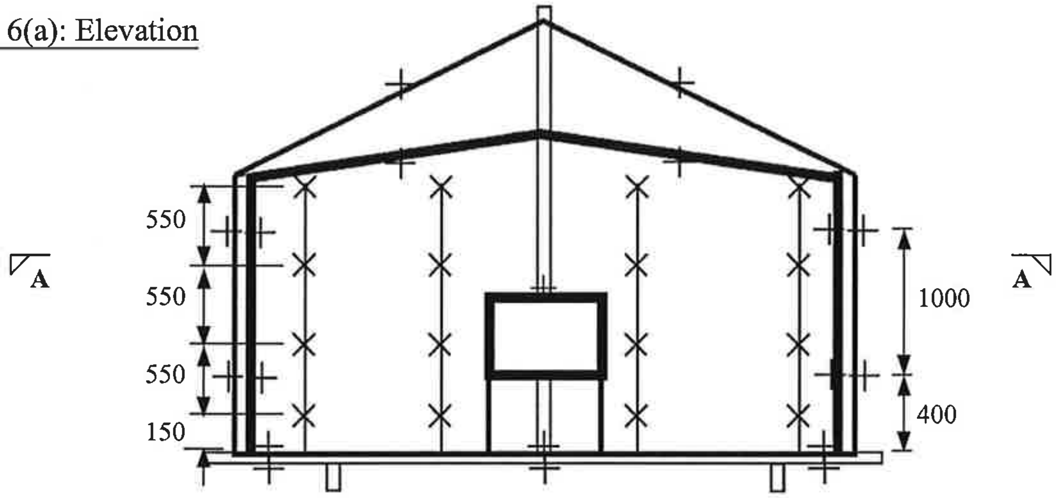
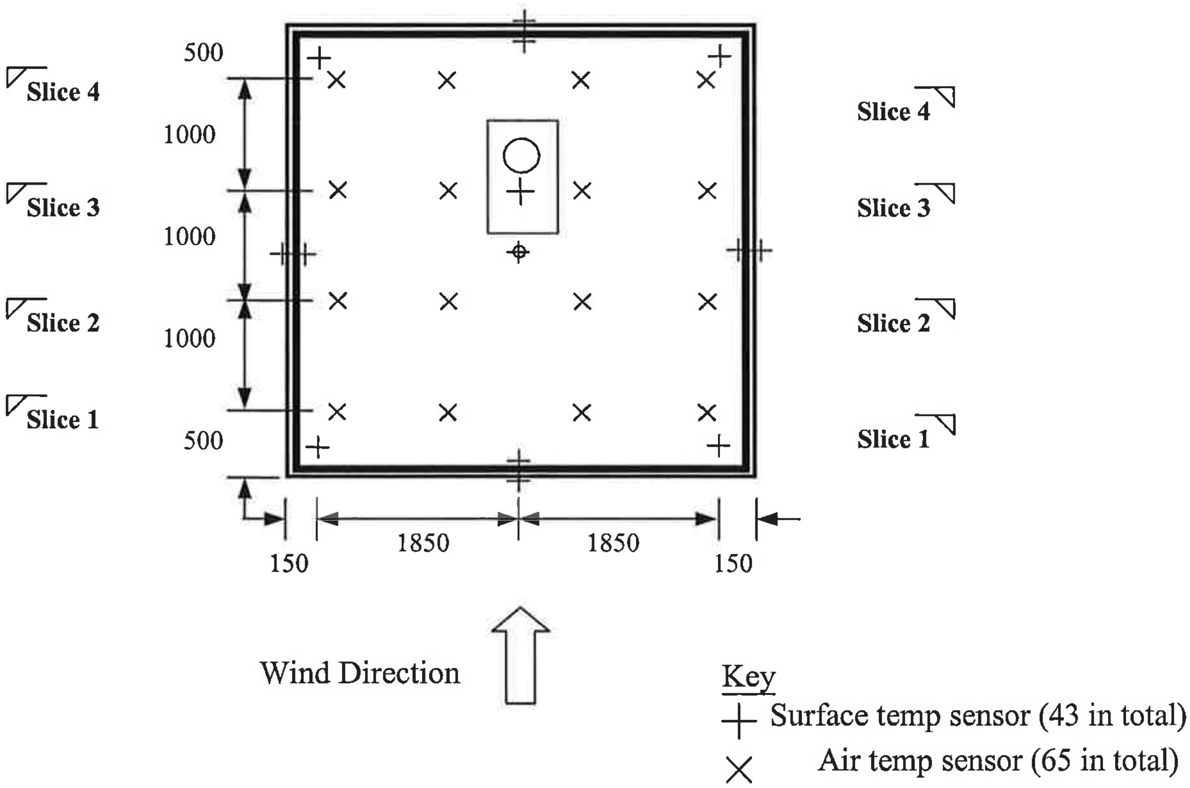


Figure 6(b): Section A-A



3.1.4 Monitoring of Test Conditions

The windspeeds and temperatures were monitored by the Ford equipment and recorded at 5-minute intervals. The real-time conditions were observed from the control room, each test case being maintained until steady state conditions were reached.

The power input to the heater was monitored by use of a power meter.

Qualitative observations were made of the temperature distribution in and around the tent, using an infrared camera provided by Ford.

3.2 Thermal Test Results

3.2.1 Definitions

The **Lower Level Temperature, T_{LL}** was defined as the average temperature 150mm above floor level, i.e. in the sleeping area of the tent.

The **Average Temperature, T_{av}** was defined as the volume weighted average temperature within the tent between 0mm and 1800mm above ground level, i.e. it is the average temperature within the occupied space.

The **Layer Temperatures, T_{L1}, T_{L2}, T_{L3}, T_{L4},** and **T_{L5},** were defined as the area weighted average temperatures of each layer of sensors.

The **Temperature Difference, dT,** was defined as the difference between the Average Temperature, T_{av}, and the external air temperature.

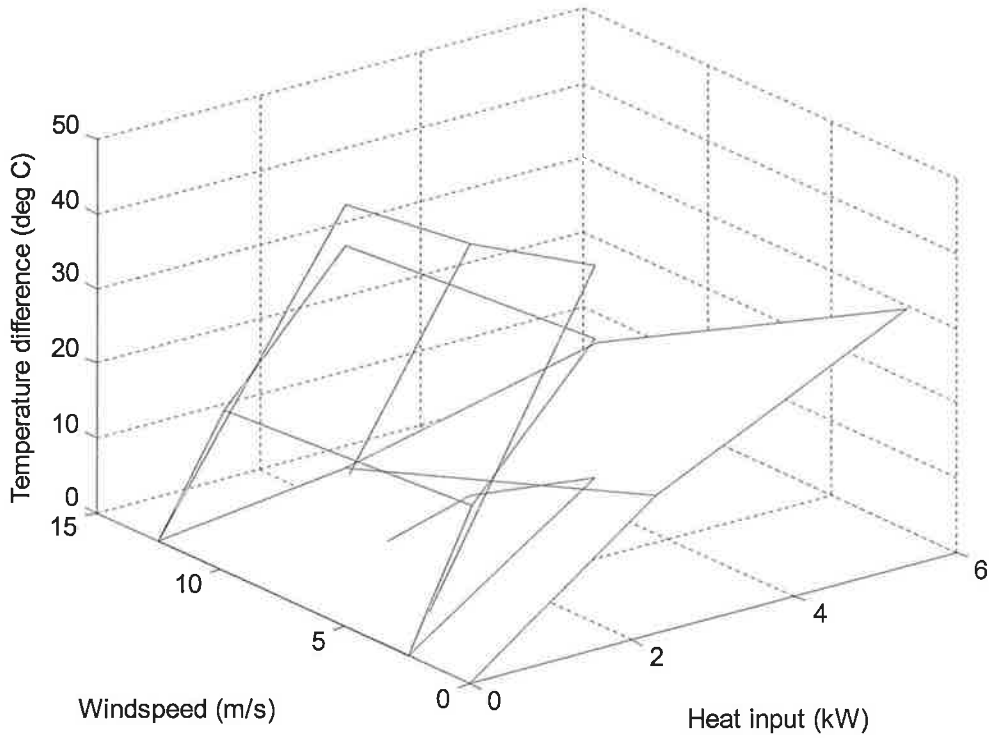
3.2.2 Air Temperature Results

The steady state temperatures recorded for each of the test case are included in Appendix D: Results.

Figure 6 [7] shows the temperature difference, dT, plotted against the heater input and the windspeed, for each of the test cases. They have been plotted as surfaces, with the actual data points marking the corners of the surface. Two distinct sets of surfaces are visible: the upper surfaces being the results for the tent with the liner, and the lower surfaces for the tent alone. Temperatures were considerably warmer with the liner, particularly at low heat inputs, reaching 30 to 40°C above external at 2.3 kW, compared with only 5 to 10°C above for the standard tent.

The two separate upper surfaces, consisting of data from the two different external temperatures tested, show good agreement, indicating that the temperature increase within the tent is fairly independent of the external temperature.

Figure 7: Variation of temperature difference with heater input and windspeed.



The graph shows a decreased rate of temperature increase with power towards higher power inputs, i.e. the more fuel is used, the less efficiently it heats the tent. With a poorly insulated tent it may be impossible to achieve reasonable internal temperatures in very cold weather, because the power demands would exceed the capacity of the heater.

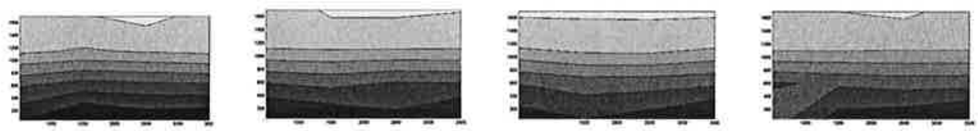
The effect of increasing the windspeed is to decrease in temperature difference, due to increased ventilation rates. This effect is considerable in the standard tent, with the temperature difference dropping from 19°C to 3°C over 12.5m/s at 2.3kW. The temperature decrease with the liner is only around half of this value, indicating that the liner seals the tent effectively against draughts.

3.2.3 Distribution of Heat Inside the Tent

Figure 8 below shows plots of the air temperature for vertical slices through the tent. The slices are labelled A-D, corresponding to the slice positions marked on Figure 6: Ford Test Set-Up.

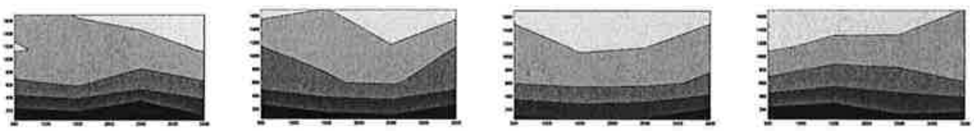
Figure 8: Vertical slices through the tent, for steady state conditions at –20° C, 2.5m/s, with a 2.3kW heat input

Figure 8(a): Without liner



1 2 3 4

Figure 8(b): With liner



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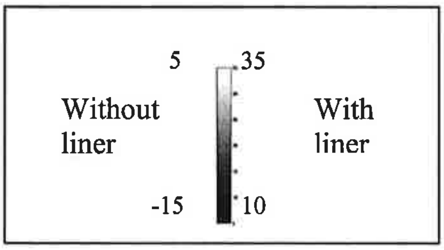
Scale:



The temperature profiles show a great deal of vertical thermal stratification within the tent, both with and without the liner, with the coldest temperatures occurring at ground level. There is actually more stratification when the liner is used, probably due to the decreased mixing of air. Without the liner, there is an almost uniform spread of heat across the tent horizontally, with temperatures being slightly higher in slices 3 and 4, close to the liner. When the liner is used, the temperatures are more variable, being lower at the walls of the tent, and more significantly higher near the heater. This difference is probably also due to the reduced ventilation when the liner is used.

3.2.4 Radiant Temperature

The radiant temperature was several degrees below the average air temperature for the tent both with and without the liner, indicating that even with the warm air temperatures measured with the liner, the thermal environment was not ideal. The radiant temperature in a tent pitched on earth may increase over time, as the top layer of earth directly beneath the tent becomes warmer.

3.2.5 Ventilation and Air Movement

The ventilation rates were calculated by use of the following formula:

$$Q = \Sigma\,[U_{fabric}A_s(T_{si} - T_{so})] + ms(T_{av} - T_{ao})$$

Where:

U_{fabric} = U-value of component part of tent, excluding surface resistances (kW/m^2K)

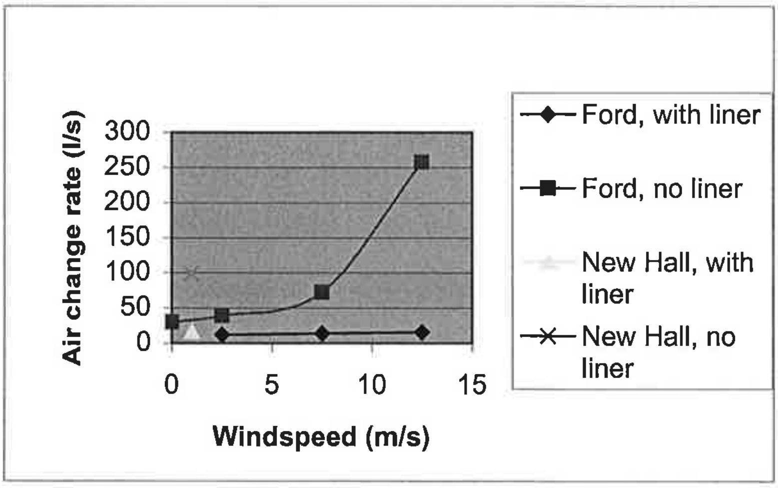
A_s = Surface area of component part of tent (m^2)

$(T_{si} - T_{so})$ = temperature difference between inner and outer surfaces of component part of tent. (°C)

m = mass flow rate of air through tent (m^3/s).

U-values were calculated based on CIBSE data, and are included in Appendix F: U-Values.

Figure 9: Variation of Air Change Rate with Windspeed



It can be seen from the Ford results that the mass flow rates of air are almost constant with increasing windspeed for the with-liner cases, indicating that the liner produces a well sealed and controlled internal environment. Without the liner, the air change rates are three to four times higher at low winds, and increase considerably with windspeed. Also plotted on the graph are the ventilation rates calculated for Field Tests carried out at New Hall, Cambridge. These tests are described later in the report. The higher ventilation rates recorded will be due to the less efficient sealing of the door and the bottom of the tent during the field testing.

During the "no liner" tests, the front of the tent partially collapsed in the 12.5m/s wind, breaking the seal at the bottom of the tent, and causing the very high ventilation rates seen in the graph for this condition.

Table 2: Recommended ventilation rates for buildings[8]

Purpose	Fresh air required (litres/s/person)
Normal use	8
Rooms with smoking	12
Requirements for breathing	2

For the assumed occupancy of eight people, the tent with the liner only just meets the physiological requirements for ventilation in the New Hall tests, and fails in the Ford test. There is a definite need for vents or windows to allow increased ventilation. One would not expect such an overcrowded space to be able to meet the upper bounds of the ventilation requirements on a continuous basis – the freshening of the air could be achieved by opening the doors and/or lifting the walls of the tent for a complete air change, during the day when the external temperatures are highest.

3.2.6 Heat Loss from the Tent

The U-values for each of the constituent parts of the tent were used to calculate the distribution of heat loss for the temperature profiles recorded. The U-value used for the heat loss to the floor is that of an earth floor, not the suspended floor that was used in the Ford tests. This is not strictly correct, as the temperature profile would also be altered for different pitching conditions, but it enables an approximate analysis to be made of the real-world performance of the tent. Further discussion of the ground conditions are included in the following Section: Analysis.

Figure 10: Heat loss from the tent, for steady state conditions at –20° C, 2.5m/s, with a 2.3kW heat input

Figure 10(a) : Without liner, 2.5m/s

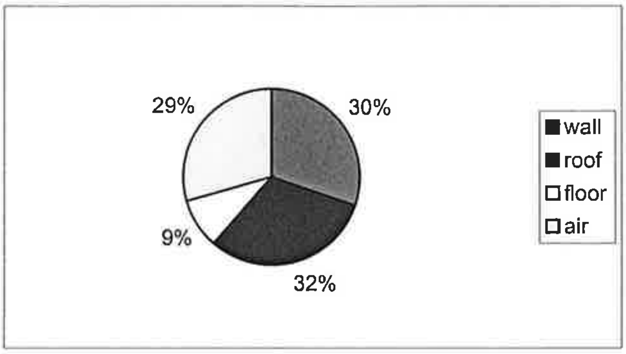


Figure 10 (b): Without liner, 12.5m/s

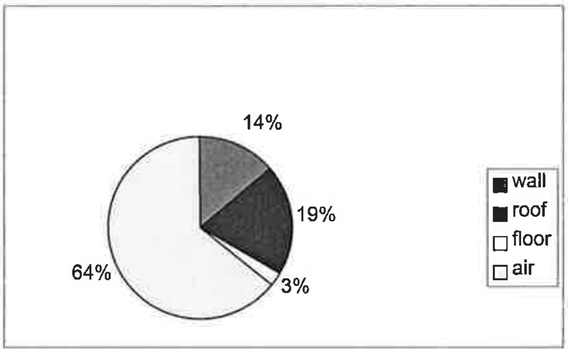


Figure n (c) : With liner, 2.5m/s

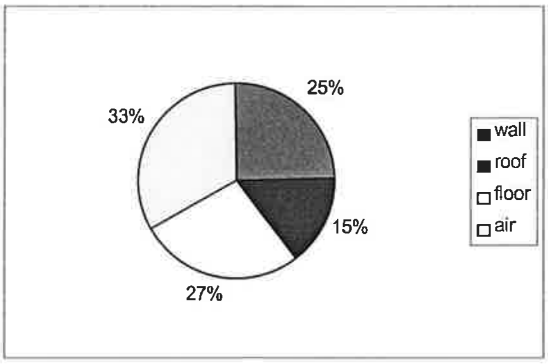
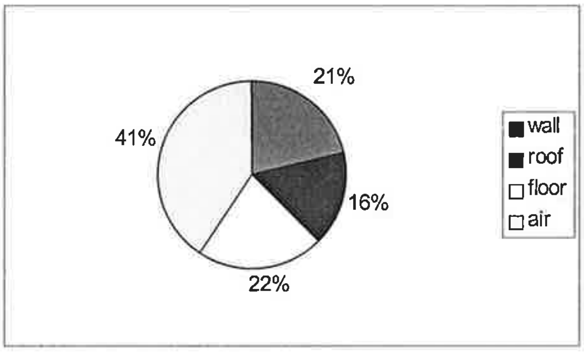


Figure n (d): With liner, 12.5m/s



4.0 Analysis: Modelling of Fuel Consumption

4.1 Modelling of the Power Requirements

A Matlab program was written, to calculate how much power would be required to maintain a certain temperature inside the tent, with and without the liner, given the weather conditions. The program was run using Afghan weather data, to calculate the fuel savings that could be made by use of the liner.

The test results show that the internal to external temperature difference, dT, depends on three factors:

(i) The heater power input, Q.
(ii) The external windspeed, v.
(iii) The use, or lack of use, of the liner.

It was observed that there is an approximately linear relationship between dT and v:

$$dT = a - bv \text{ (for constant Q)} \quad \text{.................................(1)}$$

The constants, a and b, were calculated from the test data for two particular heater inputs for both the with and without liner cases.

A power law relationship was fitted to the variation of temperature difference with heater input, Q:

$$dT = cQ^{\alpha} \text{ (for constant v)} \quad \text{.................................(2)}$$

The desired internal temperature was defined, and the external temperature was read from a file of weather data, in order to calculate dT. Equation (1) was used to calculate dT for two different values of Q, for the relevant windspeed read from the weather data. This enabled the constants c and α to be evaluated for each particular windspeed:

$$\alpha = \{\ln(dT_1/dT_2)\} / \{\ln(Q_1/Q_2)\}$$

$$c = dT_1 / Q^{\alpha}$$

Rearrangement of Equation (2) then enabled the required heater input Q to be calculated for the relevant temperature difference, dT.

If the external temperature was higher than the internal temperature, then Q was set to zero. Otherwise, Q was adjusted to allow for the difference between the test chamber tests and real-world conditions, as described in the following section.

4.2 Adjustments to Model for Real-World Conditions

During the Ford tests, the tent was mounted on a suspended floor of known U-value, and the internal and external surface temperatures monitored in order that the heat loss could be recorded. For the Matlab model, it was assumed that an equivalent temperature could be maintained in real life conditions (i.e. with a solid floor) if the heater provided the difference in heat loss between the solid and suspended floor conditions. This energy difference was calculated using the following formula:

$$dH = A(T_{LL} - T_{ao})\ (U_{susp\ floor} - U_{solid\ floor})$$

where:

A = Internal surface area of floor

T_{LL} – Tao = Internal to external air temperature difference at 150mm above ground level.

$U_{susp\ floor}$ = U-value of the chipboard floor, including the surface resistances.

$U_{solid\ floor}$ = The U-value for the ground in a four metre square building, as given by the CIBSE Guide.

The thermal resistance of the solid floor, calculated as described below, was higher than that of the thin suspended floor, so less energy would be required for a given temperature than was measured in the Ford tests.

A similar adjustment was made for the conduction losses through the flue manifold hole. During the Ford tests, no flue manifold was included in the liner, but in reality there would be a hole in the roof of the liner and tent, containing sheets of steel to separate the flue pipe from the fabric. In the Matlab model, the U-value of the steel sheets was used to replace the U-value of the liner for a $0.12m^2$ area of the roof.

4.3 Modelling of Afghan weather conditions

Many of the Afghan refugees were in camps in near Peshawar, just over the Eastern border of Afghanistan in Pakistan. Detailed weather records were not available for this location, but data was found for the town of Ghazm in Afghanistan, situated relatively near to Peshawar in a similar physical landscape. The data consisted of hourly average temperatures and windspeeds for one year.

4.4 Results

Figure 11: Temperature Data for Ghazm, Afghanistan, for one year

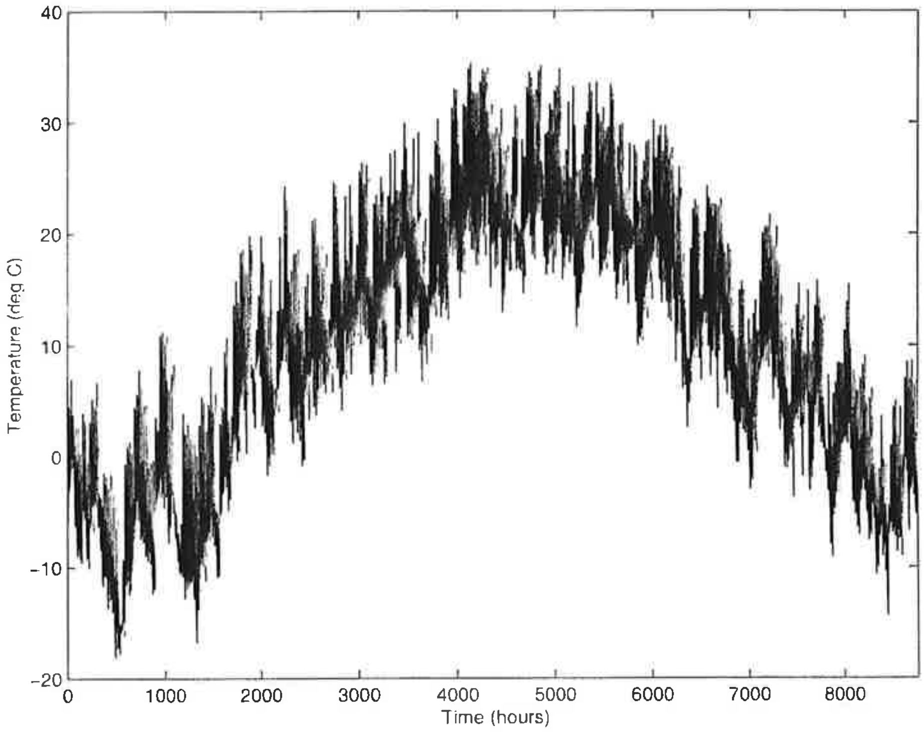


Figure 12: Windspeed Data for Ghazm, Afghanistan, for one year

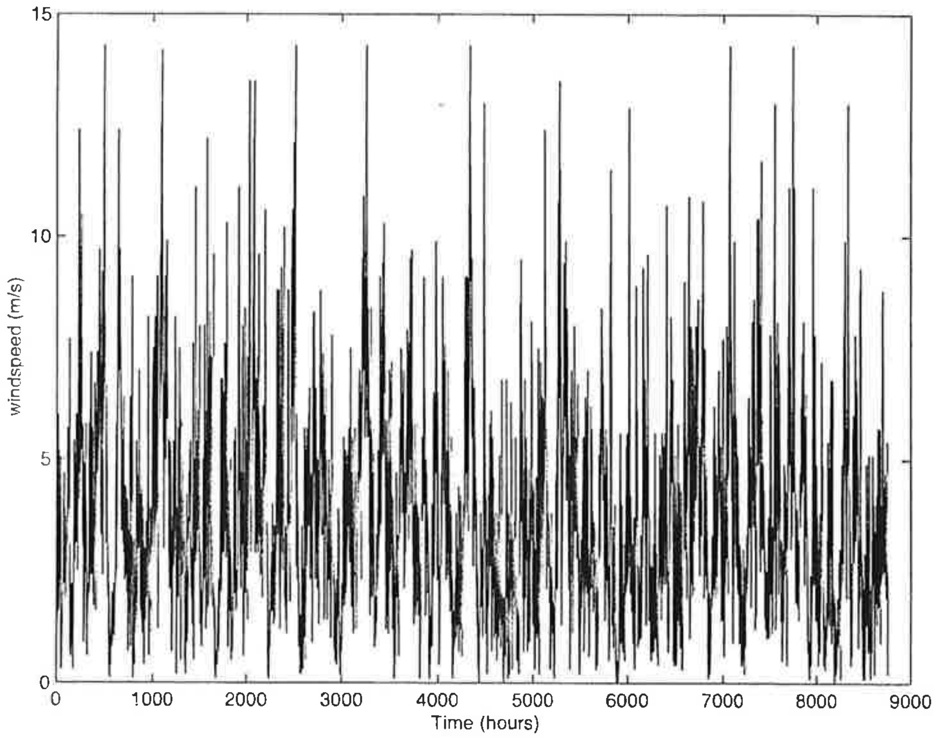


Figure 13: Power Required to maintain a Minimum Internal Temperature of ~~16°C~~ 12°C

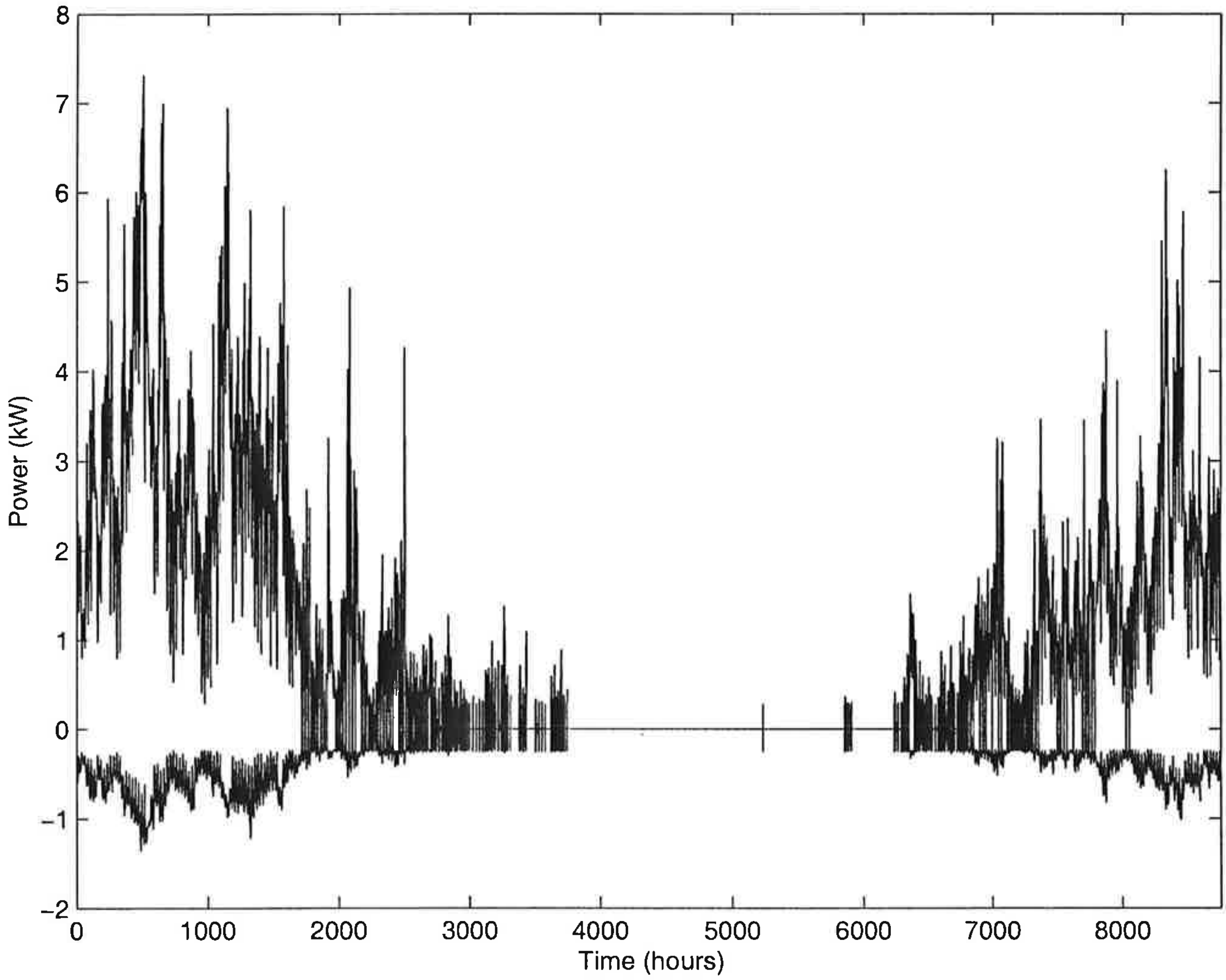


Figure 13 shows the power requirements with and without the liner, the with-liner case being plotted negative in order that the two power inputs can be compared on one graph. Comparison of the two mean power inputs, 0.24kW with the liner, and 1.01kW for the standard tent, shows a predicted annual fuel saving of 76%. This is a reduction in the whole-year energy requirements from 45000 MJ to 11000 MJ. For much of the year, the power requirements with the liner are sufficiently low that casual gains from the occupants may be sufficient to heat the shelter. The maximum power recorded with the liner is 1.3kW, meaning that the heating of the tent is efficient, and the demands on the heater are low. For the standard tent, the maximum recorded power is 7.3kW, possibly beyond the capacity of the heaters that are used.

Figures 11 and 12 show the temperature and windpeed data that was used for the analysis, with the means for the year, of 10°C and 3.7m/s, marked on the plots. , For several months heating is only required at night, due to the large variation between daily high and low temperatures. In these relatively mild conditions the liner may enable the tent to retain the heat absorbed during the day, again reducing the need for heat from fuel. The liner may also be useful for keeping the tent cool in very warm weather conditions.

The power requirements have been converted to fuel quantities, in order to calculate the savings that could be made in terms of weight, volume and cost. The stove efficiency is assumed to be 65%[9]. The fuel quantities have been calculated assuming zero casual heat gain from occupants.

Table 3: Calorific values and costs of various fuels

Fuel Type	**Calorific Value (MJ/kg)**	**Volume/unit mass (m^3/tonne)**	**Cost**
Kerosene*	32	1.2	-
Wood*	14	2.6	-
High grade charcoal*	29	5.5	-
Low grade charcoal+	7	5.5	US$ 120/tonne

* Based on CIBSE data[8].

\+ Based on figures quoted by Jo Hegeneuer[2] for fuel supplied to refugees in the Balkans.

Table 4: Fuel savings per tent, for a minimum internal temperature of 16° C.

Fuel Type	Annual Cost savings	Annual fuel volume savings (m^3)	Annual fuel weight savings (kg)
Kerosene	-	2.01	1670
Wood	-	9.9	3820
High grade charcoal	-	10.1	1850
Low grade charcoal	US $ 920	42.1	7650

Table 5: Liner Statistics

Unit Cost	Unit Volume (m^3)	Unit Weight (kg)
US$ 100*	0.5	20

* Target cost as stated by Web Dynamics(10)

When Kerosene fuel is used, the figures show that over four times the volume, or eighty times the weight, of one liner could be saved annually per shelter, for the weather conditions considered. For the low grade charcoal, this increases to around eighty times the volume, four hundred times the weight, and nine times the cost of a liner.

4.5 Validity of the Model

During the Balkans crisis, the UNHCR supplied families with 3 to 5 tonnes of low grade charcoal per winter(2). Comparison with this figure shows that the predictions are of the right order of magnitude for cold climate conditions.

The predictions made for fuel use with the standard tent may be a little high for large windspeeds, due to the partial collapse of the tent during the testing at 12.5m/s. The predictions for the requirements with the liner may be a little low, due to the very low ventilation rates during the tests with the liner, which would have to be increased in real world conditions. These two factors mean that the predicted savings may be slightly high. No allowance was made for the orientation of the tent in relation to the wind, which again, due to the nature of the tests, may reduce the actual savings from those predicted.

5.0 Field Testing

5.1 Experimental Method

Field tests were carried out by a group of students sleeping in the tent in Cambridge winter weather conditions.

Figure 14: Field Testing

5.1.1 Aims

- To assess the usability of the tent, with and without the liner.
- To obtain subjective responses to the level of thermal comfort within the tent, with and without the liner.
- To obtain temperature data for "real-world" pitching conditions, for comparison with the test chamber results.

5.1.2 Assumptions

The exact external conditions were determined by the weather. An attempt was made to carry out both tests under similar conditions, with temperatures of around 2° C and light winds of around 1m/s.

The tent was pitched in sheltered conditions, in the same position for each test. The heater used was the bar heater housed in a metal box, with power inputs of 0.75 or 1.5 kW. In addition, the body heat of the occupants was taken to be 0.5kW per person.[8] The tent was occupied by between 1 and 8 people.

5.1.3 Test Set-Up

The tent was erected in Orchard Court, New Hall. It was not possible to "dig in" the tent, so the bottom flaps were held down with pallets placed around the outside of the tent. Occupants slept on the groundsheet that is provided with the tent, and were advised to bring as much additional bedding in the form of sleeping mats, duvets and sleeping bags, as they thought they would need for comfort.

Eight air temperatures sensors were used, arranged in a reduced version of the set-up for the Ford tests, with one sensor used to record the external air temperature. Tests were carried out overnight, with occupants entering the tent at around 10.30pm, and leaving from 7.30am.

5.1.4 Calibration of Equipment

The thermocouples were calibrated at the steam point and the ice point before use. They were found to be accurate to within ± 0.3°C at the ice point, and within ± 0.7°C at the boiling point, which was judged to be sufficiently accurate for the purpose of this experiment.

5.1.5 Monitoring of Test Conditions

A portable Squirrel datalogger was used to log the thermocouple temperatures, at 15-minute intervals throughout the night.

Occupants completed a questionnaire after each test, recording their clothing and bedding levels, their thermal comfort, and their general satisfaction with the shelter.

5.2 Field Test Results

5.2.1 Physical

The field tests provide data on the thermal performance of the shelter with time.

Figure 15(a): Field Test Air Temperatures, Without Liner

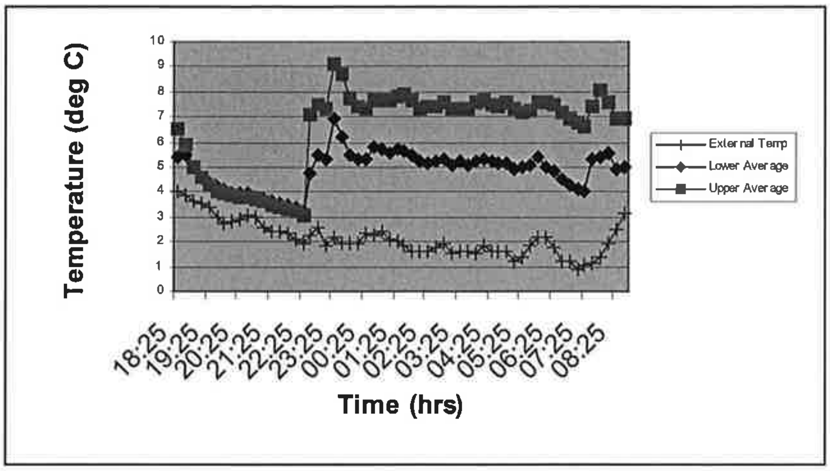
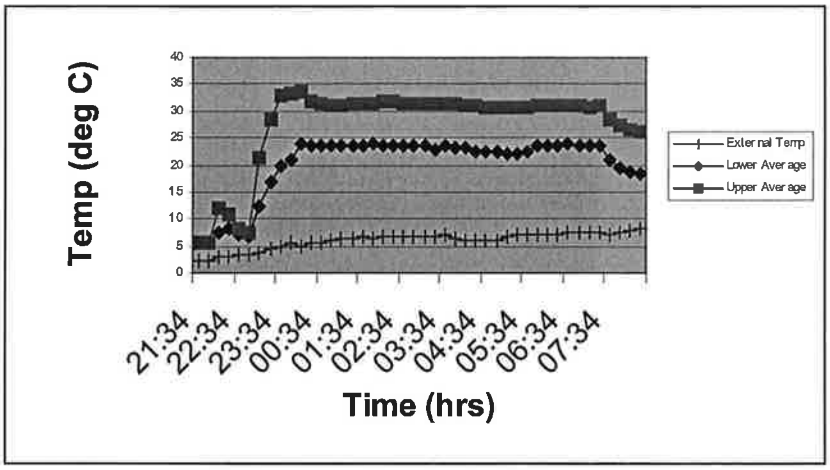


Figure 15(b): Field Test Air Temperatures, With Liner



The temperatures in the without-liner test slavishly follow the external conditions, indicating that the tent has little thermal mass. There is little apparent change in internal temperatures caused by the opening and closing of the tent door during the night, indicating that the air change rate in the tent is very large normally. Temperatures inside the tent increase rapidly when people enter the tent, and again when the heater is switched on, peaking and then falling when the occupants got into their beds, themselves against heat loss to the rest of the tent. Temperatures stabilise at around 3 °C above external at the lower level, and 6°C above on average.

The with-liner test shows smoother temperature plots, with some time lag in response to the external temperatures, indicating a more independently controlled environment.

Note that the heater was reduced to half its initial input of 1.5kW, due to uncomfortably warm conditions, at around 23:30.

Without the liner, draughts were noticeable near the doors and windows. With the liner, the tent did not seem unduly stufffy, despite the low calculated ventilation rates.

5.2.2 Social

The questionnaire and occupant responses are included in Appendix B: Subjective Responses from Field Tests.

Thermal Comfort

Occupant responses indicated that for the standard tent without the liner, outdoor clothing and excessive quantities of bedding were required, and that even then comfort was not achieved due to the low temperature of the air on the face. The personal insulation used would not be practical for daytime use as it would inhibit movement. With the liner, the warmer temperatures meant that outdoor clothing could be removed during the night, important as this allows the washing of clothes. Thermal stratification was noticeable, with standing occupants experiencing a warm head and cold ankles.

In both tests, those occupants who did not have sufficient insulation from the ground felt discomfort. This is a very important factor, as poor ground insulation means that condensation forms in the bedding where it touches the ground, reducing its insulation value further and facilitating direct conduction losses into an infinite heat sink, from all parts of the body that are in contact with it. If occupants are to sleep at ground level, then the liner is rendered almost useless if ground insulation is not available.

6.0 Fire Testing

Communication with the material manufacturers indicated that no previous fire testing has been carried out on the liner fabric. The British Standard, "BS 5438: Flammability of textile fabrics when subjected to a small igniting flame applied to the face or bottom edge of vertically orientated specimens[11] for sleepwear, blankets....tentage, etc.", details tests that can be carried out to assess the flammability of fabrics. These tests are highly specified in terms of the test set-up and method requirements, to a level that was not possible to achieve within the scope of this project, given the time and facilities available. However it was decided that testing along the lines of BS 5438 would be valuable in providing a benchmark for the flammability of the material, given the lack of previous testing.

6.1 Experimental Method

6.1.1 Aims

- To determine the ignition time for the fabric.
- To observe the rate of spread of flame.
- To observe the behaviour of the fabric when burning.

6.1.2 Test Set-Up

Each test was carried out on the full three-layer liner fabric: on the outer face in one orientation only, and on the inner face oriented with the warp of the fabric in both the vertical and horizontal directions. The specimens were mounted on a frame, as specified in BS 5438.

The ignition source was a Camping Gaz™ blow torch, with a 16mm internal diameter burner tube. The flame was adjusted to a 40 ± 5mm length. Tests were carried out in a fume cupboard, with the cupboard door open and no fan during testing. The ambient room temperature was 22° C.

Figure 15: Test Apparatus

Test C1(a): Face Ignition Time (based on BS 5438 Test 1A)

Samples were prepared of size 90mm x 210mm, and mounted on the test frame. The flame was applied horizontally to the face of a specimen for periods of 1, 2, 3, 4 and 6 seconds, until the specimen was seen to ignite. Ignition was defined as flaming occurring for more than 1s after the removal of the flame. A fresh specimen was used for each flame application.

Test C1(b): Edge Ignition Time (based on BS 5438 Test 1B)

As for Test C1a, but for a flame application at the bottom edge of the fabric.

Test C2: Ad-Hoc "Roof Burning" Test

A sample was prepared of size 90mm x 210mm and mounted on the test frame. The test frame was tilted so that the sample lay at 15° to the horizontal with the "inside" layer on the lower face, similar to the orientation of the roof of the tent liner. The flame was applied to the face of the specimen for the ignition time of the fabric, as determined in Test C1(a).

Test C3(a): Flame Spread Time: Face Ignition (based on BS 5438 Test 3A)

Samples were prepared of size 50mm by 170mm and mounted on the test frame. The flame was applied to the face of the specimen for 10 seconds. On removal of the flame, the duration of flaming, and the time taken for the top edge of the burnt material to break each of the lines marked on the sample, was recorded.

Test C3(b): Flame Spread Time: Edge Ignition (based on BS 5438 Test 3B)

As for Test C3(a), but for a flame application at the bottom edge of the fabric, as shown in Figure n.

6.1.3 Monitoring of Test Conditions

The flame application time and flame spread time was monitored by use of a stop-clock or wrist-watch. The tests were recorded on video.

6.2 Fire Test Results

Figure 16(a): Examples of Fabric Melting away from flame

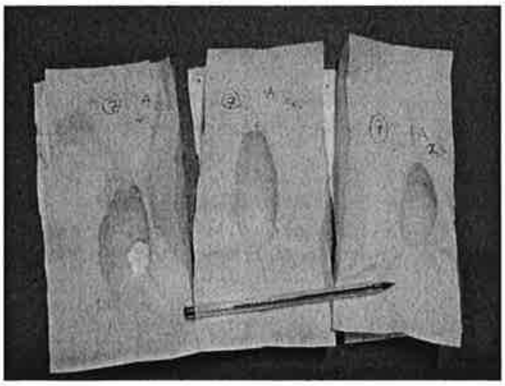


Figure 16(b): Example of Burned Sample

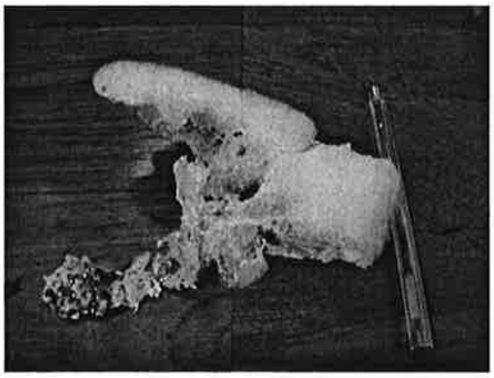


Table 6: Ignition Time Test Results

Test Type	Sample Type	Ignition time (seconds)
1A: Face Ignition	Inside, warp vertical	1
	Inside, warp horizontal	2
	Outside	5
1B: Edge Ignition	Inside, warp vertical	3
	Inside, warp horizontal	3
	Outside	2
1C: Ceiling Ignition	Inside	2

Table 7: Flame Spread Time Test Results

Test Type	Sample Type	Time taken to Marker 1 (s)	Time Taken to Marker 2 (s)	Time taken to Marker 3 (s)
3A: Face Ignition	Inside, warp vertical	25	40	70
	Outside	10	30	-
3B: Edge Ignition	Inside, warp vertical	-	-	-
	Outside	20	-	-

General Observations

Before ignition, the samples tended to melt away from the flame. Once lit, they generally self extinguished, except where the sample came in contact with the metal pins, which were heated by the flame. Burning was preferential when the middle layer was ignited. Extensive dropping of burning molten material was observed in all tests. The material continued burning on hitting the ground, often for seconds or minutes after the sample had self-extinguished.

There appears to be a large element of randomness in the nature of burning and the time taken for ignition to occur. These tests indicate that the "inside" layer is more inclined to burn than the "outside", but further tests would have to be carried out before any definite conclusions could be drawn. Ad-hoc tests simulating the liner itself may be more useful than strictly controlled laboratory testing on material samples.

7.0 Further Add-On Improvements to the UNHCR Tent and other Cold Climate Emergency Shelter Options

7.1 "Air-Lock" Porch

Heat could be conserved within the tent if an air-lock porch was available, such as is used in many houses in the UK. The possibility of using the existing door as a roof for such a porch was investigated, as the door is designed to be used as a canopy roof. The porch walls could be made from an extra section of the bamboo-reinforced canvas wall that is used in the rest of the tent, or from locally available materials.

An estimate can be made on the price by comparing the area and detailing of extra fabric required to the area and cost of the existing tent. The additional fabric amounts to ~8% of the total fabric area, and requires no ropes or poles, so the extra cost would be expected to be around 5% of the standard UNHCR tent, i.e. US$ 10.

Figure 17(a): Use of the door as a canopy roof

Figure 17(b): Creating a porch

7.2 Windows

The tent windows are currently positioned very low in the tent walls, at around 0.4m height. Calculations using the BRE Daylight Protractor show that moving the bottom of the windows up to 1.2m above the ground would result in a doubling of the daylight factor inside the tent.

7.3 Tent Erection Instructions

Neumann indicated, when interviewed by Peter Manfield, 1999[(4)], that it would be useful to have pictorial instructions for the erection of the UNHCR tent, for supply with the tent. A set of sketches for this purpose has been begun in the project log-book.

7.4 Liner Erection Instructions

A similar set of instructions would be useful for the liner, as its success of the liner is partially dependent on its correct erection within the tent. A short animation has been created, using the model tent and liner. This could potentially be used for agency staff training before they go to the field, but a set of pictures that could be photocopied onto A4 paper and issued with the liner would be more useful.

7.5 Development of an insulating fabric for use as a building material

Several of the aid agency staff spoken to in Geneva indicated that it would be useful to have a waterproof insulating material available in rolls for use as an un-tailored liner for tents, and as emergency temporary building repairs. In order for a material to be supplied for use in this way, a standard specification would have to be produced, similar to the specification for plastic sheeting: defining aspects such as the insulation properties, durability, flammability, tensile and tear strength, and roll width required. Creating a specification would also have the benefit of opening up the production of the material to the wider market, and may result in a better, cheaper product becoming available.

8.0 Conclusions and Recommendations for Future Work

8.1 Physical

The liner is able to significantly improve the thermal environment within the tent for cold weather conditions, by creating reasonable thermal conditions with relatively small heat inputs, and removing the need for any additional heat source in mild conditions. This is achieved by both the increased overall U-value of the tent, and the decreased ventilation rates. However the thermal stratification within the tent remains a problem, and the ventilation rates are currently undesirably low when the liner is well sealed. Flapped windows are required to allow the option of ventilation and light in the tent.

The liner material has proved to be reasonably durable, although some ripping has already occurred. No tests have been carried out on the U.V. stability of the liner, an important area for future work.

The fire safety of the liner material gives most cause for concern, as it has been seen to ignite and burn rapidly with flame applications of only a few seconds, such as could be inflicted by a stray cigarette or match. The dropping of burning molten fabric could cause spark further fires, and the fumes from the burning plastic could prove highly toxic. Future work must investigate the possibility of safely flame proofing the existing fabrics, or using other materials.

8.2 Social

The liner has proved successful at being erected inside the tent. This enables the liner to be provided as an add-on component without occupants having to dismantle the tent and take all their belongings outside during the liner erection. The protection provided by the outer tent also means that erection is made easier because gloves can be removed. The harness system has only been tested on the model, so needs to be tried on a full-scale liner to ensure that it will work.

The liner itself is fairly inflexible as it is tailored to suit one particular tent. However the suggested development of the insulating material for provision in sheet form would lead to a more versatile product.

The liner had little negative impact on the usability of the tent: light levels were decreased but it was not impossibly dark, and the internal space was not reduced significantly. Future liners should include flapped windows for light and ventilation, and further work should look at the method of fastening the door of the tent.

Thermal comfort within the tent is much improved by use of the liner, but it is vital that sufficient floor insulation is provided, possibly in the form of 10mm hollow cell foam as recommended by Manfield [(6)], if people are to be sleeping on the floor.

8.3 Logistic

The principal virtue of the liner is the economic and logistic savings that can be made on fuel: for the Afghan weather conditions considered, around 7 tonnes of charcoal, costing US$ 900, or $2m^3$ kerosene, could be saved per tent, per year.

Web Dynamics have stated a target cost for the liner of US$100, which would fit well with Neumann's recommendation of US$500 for the whole shelter system. The Red Cross indicated that they would prefer a slightly lower price, but suggested the option of reducing the thickness of the insulation, which may make a lower price feasible.

The weight of 20kg is excellent, being only a 20% addition to the weight of the existing tent, and making the liner possible to be carried by one person. The packed volume is less good – it is estimated that it could be reduced to $0.5m^3$, a volume that the agency staff seemed to think was reasonable. Future work could investigate the possibility of vacuum packing, or using a stuff-sack as used for sleeping bags.

No figure has yet been quoted for the production time – this is an area that will have to be confirmed with the materials company, and may depend on the quantities that are required. The material is highly specialised, meaning that it is unlikely to be produced locally to the disaster. The tent producer, National Tent, are currently looking for an alternative source in Pakistan, and the liner material producer, Web

Dynamics, have recently proposed the formation of a consortium of companies to work on materials for humanitarian aid, at the 2001 Techtextil Symposium. With more companies involved, the work-load could be spread out, enabling more rapid production.

8.4 Agency Support for Refugee Camp Field Tests

In April 2001, the liner was taken to Geneva, where the work to date was presented to senior disaster relief and technical specialists from various aid agencies. Details are included in Appendix A: Agency Responses to Geneva Presentations.

The Red Cross, who are operational in the Afghan refugee camps, indicated that they would be prepared to support field-testing of liners for their own tents in camps. This would be the final stage before agencies will consider using the liners on a large scale. It is hoped that the necessary work on flame-proofing will be completed in time to provide liners for testing in camps this winter.

Appendix A: Agency Responses to Geneva Presentations

The purpose of the trip to Geneva was to show the liner and present test results to officials at the UNHCR and the Red Cross, in order to make them aware of the work and to try to initiate the use of insulating liners in tents in refugee camps. Several other aid agencies were also visited because, although only the UNHCR has a specific mandate for shelter, it is an area that involves all aid agencies in some way.

United Nations High Commissioner for Refugees (UNHCR), Emergency Response Service (ERS) and Engineering and Environmental Support Services Section (EESS)

Confirmed the need for products such as the liner. Showed interest in the raw material for temporary building repair, and enquired about exact physical specifications and cost, with the idea of finding a cheaper producer in Asia. Enquired about the fire safety and general non-combusting safety of the material. Commented on the difficulty of ensuring that both liners and tents reached the same place, if supplied separately.

International Committee of the Red Cross (ICRC)

Suggested a target climate of –5 to –15°C for the liner, with possible reduction in volume of insulating wadding. Suggested target price of US$ 60 – 80. Indicated that they would be interested in liners made for their own tents, and that they would be prepared to buy liners for field testing in camps. Again enquired about the fire safety, physical make-up and pricing of the fabric, and showed interest in its use as a building material.

United Nations Children's Fund (UNICEF), Organisation for Migration (IOM), Medicins Sans Frontieres – Switzerland (MSF-CH), Registered Engineers for Disaster Relief – International Secretariat (RedR), United Nations Development Programme (UNDP)

These agencies all indicated the importance of appropriate and sufficient shelter for refugees in cold climates and expressed an interest in being informed of future developments with the liner material.

Appendix B: Subjective Responses from Field Tests

Questionnaire, given to all volunteers after each test

1. What clothes did you wear?
2. What bedding did you have: a) Under you? b) Over you?
2 What was your level of thermal satisfaction? i.e. were you too hot, too cold, just right, too cold on the toes, too draughty on the face, too damp, cold seeping up from the ground, etc?
3 Do you have any suggestions for improvements to the tent (inc. liner)?

Summarised Responses

	Without liner	With liner
Clothes	Largely 1.0 clo: tracksuit trousers, T-shirt, jumper, fleece, socks, some hats.	Largely 0.5 clo: pyjamas or tracksuit trousers and T-shirt. PM: 1.0 clo: tracksuit plus fleece.
Bedding	Sleeping bag or duvet plus blanket	Single layer sleeping bag or duvet.
Floor Insulation	Largely ~10mm foam mats plus a blanket or sleeping bag. One person: lilo. Two people: blankets/duvet only	Largely ~10mm foam mats plus a blanket or sleeping bag. One person: lilo. Two people: blankets/duvet only
Comfort	- Generally warm enoughs, except for face which was exposed to the air. - Cold and damp where in contact with the ground, particularly for candidates without a foam sleeping mat.	- Too hot initially, generally warm enough throughout the night decidedly chilly at ground level an hour after the heater was switched off. Several comments that the ground was cold and condensated. - RB and MB: cold and damp underneath. - Concern was expressed before the test that the tent might become stuffy, but only two comments were received, one surprised it wasn't stuffy and one complaining that it was.
Suggested Improvements	- Easier to use door: The loop and toggle fastenings are extremely difficult to do without pliers, resulting in the door being left partially open, despite the uncomfortably cold temperatures. - The low level windows lead to draughts at ground level and increased ventilation in an already draughty tent.	- Floor insulation - Flapped windows to increase contact with outside world and provide optional light and ventilation. - Easier to use door – suggested a "proper opening" rather than just a flap, and that inner door could be attached to outer for ease of use.

Appendix C: Interview with Gareth Davies, Head of MOD Clothing and Textiles Division, Colchester

During the NATO presence in the Balkans in 1999, British troops lived in heated tents throughout the winter months. The army has considerable experience with cold weather temporary accommodation, although on a larger budget than a typical refugee camp. They were contacted in order to compare the army response with that of the aid community, and possibly learn from their experience.

Shelter and insulation: 6m x 8m cotton-polyester pitched roof frame tents were used, housing 8 people and costing £2500 per tent. The sod cloth was increased from 3" to 12" to minimise rotting on this trip. The insulation was modular silvered foam, providing no fabric permeability, but ventilation between sections. Doors were fastened with heavy duty zips which were "cheap" (no price was given) and had an expected 5 year lifespan. 50mm interlocking plastic floor was used, on top of which were polythene mats (4 tog).

Heaters: 15-20kW Dantherm diesel heaters were used externally, pumping warm air into the tents. Supply of diesel was logistically difficult. During extreme cold weather, air is re-circulated through the heaters.

Other Thermal Equipment: Occupants slept on campbeds, fully clothed, in 11 tog sleeping bags costing £37 to them, £120 in shops. Food supplies are increased in cold climate conditions.

Conditions Achieved: The desired internal temperature recommended for the army is 25 °C. The 15-20kW heaters were generally capable of raising the internal temperature 15 °C above the external temperature. Condensation was not found to be a problem inside the tent, but occurred on the inside of the outer wall.

Testing: Testing is usually carried out by troops living in tents in the Norwegian Arctic. The Americans use wind tunnels, but in this is of little value, particularly for structural testing as the performance of a tent is dependent on ground anchoring.

Conclusions: Insulation, of both tents and people, is a better approach than relying on high power space heaters, as supply of fuel is difficult and expensive. He recommends that the windows on the UNHCR tent should be placed higher to avoid excessive ventilation due to the stack effect.

Appendix D: Ford Test Results

Figure n: Steady State Temperatures

ambient temp (deg c)	wind-speed (kph)	Heat input (kW)	TLL (deg c)		TL2 (deg c)		TL3 (deg c)		TL4 (deg c)		TL5 (deg C)		Tav (deg C)	
Liner (yes/no):			y	n	y	n	y	n	y	n	y	n	y	n
-20	0	2.3	/	-8	/	-4	/	3	/	4	/	6	/	-1
-20	2.5	2.3	14	-9	24	-5	30	1.5	32	2	35	4	25	-3
-20	7.5	2.3	10	-15	20	-14	25	-12	27	-10	30	-9	21	-13
-20	12.5	2.3	7	-17	18	-17	22	-17	25	-16	27	-13	18	-17
-20	0	5.6	/	1	/	8	/	25	/	26	/	28	/	15
-20	12.5	5.6	/	-11	/	-11	/	-8	/	-5	/	-4	/	-9
2	2.5	2.3	27	/	35	/	43	/	45	/	49	/	38	0
2	12.5	2.3	24	/	33	/	40	/	41	/	46	/	35	0
2	2.5	0.8	16	/	19	/	22	/	22	/	25	/	20	0
2	12.5	0.8	13	/	15	/	20	/	20	/	23	/	17	0

Appendix E: U-values

Description	Area (m2)	Thickness (m)	Conductivity (W/mK)	Resistance (m2K/W)	U-Value (W/m2K)
Walls					
Rsi				0.1200000	
Liner*		0.03	0.03	1.0000000	
Ventilated Airspace*		0.02		0.1800000	
Cotton		0.0003	27	0.0000111	
Air		0.003		0.1000000	
Canvas		0.00076	27	0.0000281	
Rse				0.0600000	
TOTAL WITH LINER	23.4			1.4600393	0.68
TOTAL WITHOUT LINER	24			0.2800393	3.57
Skirt					
Rsi				0.1200000	
Liner*		0.03	0.03	1.0000000	
Ventilated Airspace*		0.02		0.1800000	
LDPE		0.00028	0.33	0.0008485	
Rso				0.0600000	
TOTAL WITH LINER	4.7			1.3608485	0.73
TOTAL WITHOUT LINER	4.8			0.1808485	5.53
Roof					
Rsi				0.1000000	
Liner*		0.03	0.03	1.0000000	
Ventilated Airspace*				0.1700000	
Cotton		0.0003	27	0.0000111	
Air		0.003		0.1000000	
Canvas		0.00076	27	0.0000281	
Rso				0.0700000	
TOTAL WITH LINER	15.3			1.4400393	0.69
TOTAL WITHOUT LINER	17.8			0.2700393	3.70
False Floor					
Rsi				0.1400000	
Chipboard		0.015	0.12	0.1250000	
Rso				0.0800000	
TOTAL WITH LINER	15.2			0.3450000	2.90
TOTAL WITHOUT LINER	16			0.3450000	2.90
Earth Floor					
Solid earth floor					
TOTAL WITH LINER	15.2				1.22
TOTAL WITHOUT LINER	16				1.22
Insulated floor					
Closed cell polyurethane foam		0.005	0.035	0.1428571	
Solid earth				0.8196721	1.22
TOTAL WITH LINER	15.2			0.9625293	1.04
TOTAL WITHOUT LINER	16			0.9625293	1.04

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