Cold Climate Shelter Summary

Cold Climate Shelter Research Project
The Martin Centre for Architectural and Urban Studies
Cambridge University
6 Chaucer Road, Cambridge, CB2 1TP.

Peter Manfield
pjm29@cam.ac.uk
07967 57 82 89
01223 33 17 00

Tom Corsellis
tc205@cam.ac.uk
01223 33 17 16

Logistics

<table>
<thead>
<tr>
<th>Logistics</th>
<th>Unit</th>
<th>National Tent Ltd. ‘Winterised Tent’</th>
<th>Tested Shelter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (ex-works, ex-transport)</td>
<td>USD</td>
<td>280</td>
<td>232</td>
</tr>
<tr>
<td>Packed Volume</td>
<td>m3</td>
<td>0.28</td>
<td>0.5</td>
</tr>
<tr>
<td>Weight</td>
<td>kg</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>Maximum Lead Time for 1000 units</td>
<td>days</td>
<td>(?)</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Floor Area</td>
<td>m2</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Cross sectional Area</td>
<td>m2</td>
<td>5.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Internal Volume at Head Height (above 1.7m)</td>
<td>m3</td>
<td>1.3</td>
<td>6</td>
</tr>
<tr>
<td>Internal Volume</td>
<td>m3</td>
<td>23.2</td>
<td>20.4</td>
</tr>
<tr>
<td>Time to construct shelter</td>
<td>hours</td>
<td>(?)</td>
<td>3</td>
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Environmental Performance at the Ford Driveability Test Chamber (DTC)

<table>
<thead>
<tr>
<th>Min. External Temp (maintaining internal temp of 15 C)</th>
<th>deg C</th>
<th>(?)</th>
<th>-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed (maintaining internal temp of 15 C)</td>
<td>m/sec</td>
<td>(?)</td>
<td>12.5</td>
</tr>
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</table>

Required Heat Input kWatt (?) 2.4

Side elevation of the prototype inside the environmental test chamber
Front elevation
Acknowledgements

I would like to thank the following individuals and organisations for their support for this project:

**Project Funding**

The Sir Halley Stewart Trust

**Consultants**

<table>
<thead>
<tr>
<th>Name</th>
<th>Role and Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gordon Browne</td>
<td>Lecturer in Building Construction, Southampton Institute</td>
</tr>
<tr>
<td>John Martin</td>
<td>Department of Manufacturing Engineering, Cambridge University</td>
</tr>
<tr>
<td>Dr. Darren Robinson</td>
<td>Research Associate, Martin Centre for Architectural and Urban Studies, Cambridge University</td>
</tr>
<tr>
<td>Joseph Ashmore</td>
<td>Research Assistant, Martin Centre for Architectural and Urban Studies, Cambridge University</td>
</tr>
<tr>
<td>Dr. Rory O’Connor</td>
<td>Occupational Therapist/Physician</td>
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**Oxfam GB**

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<tr>
<th>Name</th>
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<tbody>
<tr>
<td>John Howard</td>
<td>Technical Advisor</td>
</tr>
<tr>
<td>David Cox</td>
<td>Shelter Consultant</td>
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**Manufacturers**

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</tr>
</thead>
<tbody>
<tr>
<td>John Bowdidge &amp; Martyn Holloway</td>
<td>Rockwool Ltd., Bridgend, Wales</td>
</tr>
<tr>
<td>John Tookey</td>
<td>Owens Corning Building Products Ltd. St. Helens, Merseyside</td>
</tr>
<tr>
<td>Tim Woodbridge &amp; Richard Thompson</td>
<td>Web Dynamics Ltd., Hertfordshire</td>
</tr>
<tr>
<td>Chris Mitchell, Phil Widdop &amp; Enid Runchman</td>
<td>Monarflex Ltd., St Albans, Hertfordshire</td>
</tr>
<tr>
<td>Paul Barac</td>
<td>Encon Insulation, Cambridge</td>
</tr>
<tr>
<td>National Tent House Ltd.</td>
<td>Pakistan</td>
</tr>
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<td>TriMed Ltd</td>
<td>London</td>
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**Testing Facilities**

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>The Ford Motor Company</td>
<td>Dunton Engineering Centre, Laindon, Basildon, Essex</td>
</tr>
<tr>
<td>Burton McNeal</td>
<td>Engineering Director</td>
</tr>
<tr>
<td>Richard Folkson</td>
<td>Manager-Systems/Safety, Advanced Vehicle Testing</td>
</tr>
<tr>
<td>Colin Bunting</td>
<td>Emission &amp; Environmental Test Laboratories</td>
</tr>
<tr>
<td>David Russell</td>
<td>Supervisor Environmental Laboratories</td>
</tr>
<tr>
<td>David Gustard</td>
<td>Senior Test Engineer</td>
</tr>
<tr>
<td>Alan Shrimplin</td>
<td>Test Engineer</td>
</tr>
<tr>
<td>Mick Gardiner</td>
<td>Prototype Mechanic</td>
</tr>
<tr>
<td>&amp; the team at Ford</td>
<td></td>
</tr>
<tr>
<td>Kim &amp; Beth Waterhouse</td>
<td>Clare Farm, Dullingham, Suffolk</td>
</tr>
<tr>
<td>Novacold Food Stores</td>
<td>Peterborough, Cambridgeshire</td>
</tr>
</tbody>
</table>
Martin Centre for Architectural and Urban Studies

Dr. Nick Baker  
Dr. Koen Steemers

Other Cambridge University Departments

Jim Platts  Department of Manufacturing Engineering  
Dr. Claire Barlow  Department of Manufacturing Engineering  
Kara Johnson  Department of Materials Science  
Professor Mike Ashby  Department of Materials Science  
Mick Bradshaw  Department of Architecture  
Judith Drinkwater  Department of Architecture  
David Green  Department of Engineering  
Derek Olive  Department of Engineering  
Richard Taylor  Electronics Research, Department of Engineering

Other NGO and GO Staff

Adrian Porter  Shelter Engineer, International Rescue Committee, Kosovo  
Carl Jenkins  Prizren Field Officer, International Rescue Committee, Kosovo  
Nathan Koeshall & Diane Johnson  Programme Manager, International Rescue Committee, Kosovo  
Phillip Upson  Emergency Logistics Department, Department for International Development  
Squadron Leader Ayers  Defence Clothing & Textiles, MOD  
Mike Goodhand  Logistics Dept, British Red Cross  
Annika Saalovara  United Nations High Commissioner for Refugees  
Wolfgang Neumann  United Nations High Commissioner for Refugees  
Nagette Belgacem  Protection Officer, UNHCR, Kosovo Mitrovica, Kosovo
Researchers

<table>
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<tr>
<th>Position</th>
<th>Name</th>
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<tr>
<td>Project Investigator</td>
<td>Dr. Robin Spence</td>
</tr>
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</table>

Robin Spence is a structural engineer with extensive research experience in the fields of building technology and building materials manufacture. Current interests include disaster protection strategies, environmental impact of construction, low-income housing in earthquake areas, and low-cost building materials for developing countries.

Since 1975, Robin has been a lecturer in Architecture at the University of Cambridge, with responsibility for the structures programme, and a Fellow of Magdalene College. He is also a Director of the Martin Centre for Architectural and Urban Studies, and a Director of Cambridge Architectural Research Limited.

<table>
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<tr>
<th>Position</th>
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</tr>
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<tbody>
<tr>
<td>Project Manager</td>
<td>Tom Corsellis</td>
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</table>

Tom is currently concluding his PhD on physical planning for refugee camps at Cambridge University (due for submission, end 1999). Tom has also worked on assignment for UNHCR, Crown Agents DFID, OXFAM GB, MSF France, ODI and others. He was recently Camp Planner (and later Shelter Specialist) for the Balkans for DFID and has also worked in both East and West Africa on major infrastructure design and physical planning. He has also contributed to the Sphere Project, which aims to define minimum standards for Humanitarian Response.

Tom has also worked as an architect in Japan, USA, Germany, Holland, Italy, Turkey, India and Australia.

<table>
<thead>
<tr>
<th>Position</th>
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<tbody>
<tr>
<td>Research Manager</td>
<td>Peter Manfield</td>
</tr>
</tbody>
</table>

Peter is currently studying for his M.Phil in Environmental Design in Architecture, specialising in temporary shelter. He has previously worked on assignment for UNHCR, LWF and IRC in Kenya, Kosovo and Macedonia, focusing on shelter policy and construction management. He has also undertaken design work for the new OXFAM GB Hot Climate Shelter System.
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*Acknowledgements*

*Researchers*

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Cold Climate Emergency Shelter Systems

1 Executive Summary

1.1 Aim

The remit of this project has been to present to the aid community a prototype design, or series of designs, for a stand-alone shelter system for displaced persons in cold climate environments.

1.2 Project Methodology

The limited period of this project has allowed only part of the testing procedure necessary. Cold climate shelter should be developed through a comprehensive series of social and technical tests including

- prototype construction development
- collection and evaluation of environmental performance data from:
  - field tests
  - modelling tests
  - environmental chamber tests
- shelter testing with one or several beneficiary populations over a significant time period.

The results achieved to date are based on research into a range of appropriate insulation materials and their incorporation into existing structural designs for hot climate shelter. The shelter designs were then further developed through the physical construction of several prototypes, the best of which was tested in an The Ford Driveability Test Chamber (DTC) gauge its performance under extreme climatic conditions.

1.3 Results

The shelter performed extremely well within the Ford DTC and maintained an internal temperature well above survival conditions under Gale Force 6 wind and an outside temperature of –20°C. The shelter maintained structural integrity throughout the environmental tests. The shelter in its current stage of development is not in a state to be immediately deployable as neither social nor field tests have been completed. The method of exhausting waste gases from the stove or heating unit is also not fully resolved at the time of writing.
1.4 Prototype Description and Specification

A series of prototypes were constructed (refer to Chapter 4). The most successful was later tested (Chapter 5) and is described below.

Fig 1

<table>
<thead>
<tr>
<th>PROTOTYPE No.:</th>
<th>6</th>
<th>Tested Shelter</th>
<th>Materials Cost per unit*</th>
<th>Materials Cost per unit*</th>
<th>Mass per unit*</th>
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</thead>
<tbody>
<tr>
<td>PROTOTYPE Name:</td>
<td>Tested Shelter</td>
<td>£ 145</td>
<td>USD 232</td>
<td>94.5kgs</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>PART FUNCTION</th>
<th>MATERIAL ITEM</th>
<th>SPECIFICATION</th>
<th>QUANTITY</th>
<th>WEIGHT</th>
<th>COST</th>
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<tr>
<td>Skin</td>
<td>UNHCR Reinforced Sheeting</td>
<td>4 metre wide roll</td>
<td>18 metres</td>
<td>14.4kgs</td>
<td>£ 25.92</td>
</tr>
<tr>
<td>Ends</td>
<td>Monarflex T-Plus Scaffold Sheeting</td>
<td>4 metre wide roll</td>
<td>16 metres</td>
<td>12.8kgs</td>
<td>£ 23.04</td>
</tr>
<tr>
<td>Structure</td>
<td>MDPE Tubing</td>
<td>63 mm OD</td>
<td>18 metres</td>
<td>18.4kgs</td>
<td>£ 16.02</td>
</tr>
<tr>
<td>Pegs</td>
<td>Steel Re-bar</td>
<td>10mm OD</td>
<td>3.0 metres</td>
<td>1.8kgs</td>
<td>£ 1.50</td>
</tr>
<tr>
<td>Purlins</td>
<td>Alu Tubing</td>
<td>15.9mm</td>
<td>10.8 metres</td>
<td>4.2kgs</td>
<td>£ 6.16</td>
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<tr>
<td>Tensioners/ Cross bracing</td>
<td>PP Rope</td>
<td>8mm dia</td>
<td>52 metres</td>
<td>14.0kgs</td>
<td>£ 1.56</td>
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<tr>
<td>Insulated Flooring</td>
<td>Polyurethane Closed Cell Foam</td>
<td>5mm thick x 1.2m wide roll</td>
<td>10.8 metres</td>
<td>1.9kgs</td>
<td>£ 10.80</td>
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<tr>
<td>Insulated Door/Ends</td>
<td>Polyurethane Closed Cell Foam (translucent)</td>
<td>2mm thick x 1.2m wide roll</td>
<td>48.0 metres</td>
<td>3.8kgs</td>
<td>£ 24.00</td>
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<tr>
<td>Insulated Skin</td>
<td>Miraflex resin-free glass fibre roll</td>
<td>150mm thick x 570mm wide x 10.7m</td>
<td>3.0 rolls</td>
<td>23.1kgs</td>
<td>£ 36.00</td>
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| Space Heater | Canadian Heater | Kerosene/diesel fuel | 1 | 40.0kgs | £ 200.00 |
| Locally-made stove | Kosovian Bread Stove | Solid fuel | 1 | 20.0kgs | £ 25.00 |

Structure

The structure consists of 3 lengths of polyethylene (MDPE) water piping which form 3 hoops that sit on steel reinforcement pegs in the ground on a square plan of side length 3.6 metres. The hoops are joined horizontally by 3 hollow section aluminium tent poles and cross-braced internally with two lengths of polypropylene rope. The rope acts in tension against the tent poles, which are in compression.

Roof

The roof consists of expanded resin-free glass fibre sandwiched between two layers of UNHCR specification reinforced polyethylene sheeting, which are laced with polypropylene rope and tensioned over the hoops and buried in the ground at the sides.
Doors/End

The door and back end of the shelter consists of translucent closed cell foam, sandwiched between transparent reinforced polyethylene scaffold sheeting which is also buried into the ground at the bottom.

Floor

The floor consists of low density closed cell polyurethane foam under a reinforced plastic tarpaulin.

Heaters

The shelter is heated by either a folded sheet steel bread oven, which burns solid fuel and is produced the Balkan region, or a higher specification heater burning either diesel or kerosene fuel, adapted from the US army model specifically for relief purposes\(^1\).

\(^1\) Refer to Appendix 2 for details of heater suppliers and specifications.
Figure 1: Construction Axonometric
(Drawing by M. Trinder and J. Ashmore)
2 Project Background

2.1 Hot Climate Shelter Development

In May 1999, Cambridge University in collaboration with OXFAM GB concluded the development of a new shelter system for displaced people in hot climate environments\(^2\). This shelter system has been developed as a viable alternative to the expensive and often inappropriate shelter systems currently available on the commercial market. The hot climate shelter offers two significant advances on existing systems: it is assembled, rather than being fabricated, from material readily available in the construction industry. This serves two purposes: (1) reducing shelter lead-time to that needed only to purchase the material and (2) employing materials that are useful in later reconstruction phases.

This research into cold climate shelter shares a common design approach with the OXFAM hot climate shelter system. These common concerns include designing for minimal cost, volume, and weight, together with an emphasis on materials with a very short supply lead-time.

Despite the fact that shelter clearly has very different objectives in hot and cold climates, many of the construction issues, and criteria for material selection during an emergency phase, are similar. For this reason, the cold climate shelter prototypes use the hot climate shelter design and structure as a point of departure and allows for the development of a ‘family’ of compatible shelter systems that can be adapted for use in any given environment.

2.2 Current Cold Climate Shelter Provision

This project is borne out of two concerns that seem to have been overlooked by the majority of agencies and organisations within the aid community:

a) shelter for displaced people is not afforded the attention and funding that it should;

b) the resulting shelter provision, in the majority of hot and cold climate emergencies, is inadequate and invariably has a very limited life span.

\(^2\) The hot climate shelter system was developed by Howard, Corsellis, Manfield and Martin from 1997/99 and has since become the new shelter standard for OXFAM
Macedonian Case Study

The resources that shelter provision do receive is then poorly invested. This was most evident in the recent confusion in Macedonia concerning the winterisation of refugee camps. When a decision to provide winterised tents for Macedonia was finally taken, the tents took months to be fabricated and delivered to site, by which time, the majority of Kosovar Albanian refugees had returned home. The tents have since been transferred to Kosovo, but it would appear that they are not designed or insulated to cope with the extremes of cold on the Kosovan plateau, or in the highlands on the borders with Albania and Macedonia.

The implication, when considering heating any sizeable number of uninsulated tents, is that the fuel and transportation costs are likely to be enormous. The lack of a coherent and effective shelter policy for cold climates may still put thousands of displaced people at further risk and further underlines the need for more resources to be spent on shelter preparation for disasters yet to happen.

2.2.1 Existing Winter Shelter Tents

Two existing winterised tents that were deployed by UNHCR in the Balkans during the 1998/9 winter were identified for further analysis. These tents provide useful benchmarks with which to set project goals and compare built prototypes, particularly as both tents have been used for cold climate shelter assistance in the past. Unfortunately, information relating to both is incomplete at the time of writing.

i) The UNHCR Winterised Tent

This tent is made from two layers: one is made from canvas, which forms the waterproof outer flysheet; and the other from cotton, which is hung from inside the flysheet as a liner. The tent is supported by five poles, each two metres in length, one in each of the four corners of the square plan, and one larger pole in the centre of the plan. The corner poles are guyed to ground pegs and tensioned.

It has a plan area of 4x4 metres giving a total area of 16m2 and providing shelter for 3/4 people (using UNHCR shelter standards for cold climates) or 7 people (using the brief for this project). The wall height is 1.9 metres allowing standing height over the entire floor plan. The tent is designed to take a stove and flue manifold. The tent weighs approximately 100kg and has a volume of 0.3-0.5 m³.
ii) ‘National Tent’ Winterised Tent

This is a ridge tent with two layers similar in material composition to the UNHCR tent. The floor plan is also 4x4m and the only major difference is that head height and internal volume are considerably less, as a result of the lower tent wall height of 1.1 metres. Cost, volume and weight are compared with the resultant prototype from this project in Figure 1.

2.3 Project Rationale

This project focuses on one small part of shelter provision, that of stand alone, self-build shelter systems for Kosovo this winter. The design ethic has been to combat the problems with current shelter systems by providing the following.

i) Low unit cost

The aim has been to select materials with a low unit cost. Typically, sheet and roll materials from competitive markets are the cheapest.

ii) Maximise internal useable volume

Most cheap emergency shelter available on the commercial market are ridge tents, or adaptations thereof. These ridge tents have little useable headroom and, in any case, have a low cross-sectional area/material perimeter ratio, which indicates the usability of the internal space. This project seeks to use structural forms that maximise useable volume. This is especially important in cold climates, given that it is likely that occupants will have to spend long periods of time inside the shelter.

iii) Minimise running costs

A shelter system deployed in a cold climate will need a heat source of some specification in nearly all emergency scenarios. The amount of fuel supplied for the heat source will, to a large extent, depend on the thermal performance of the shelter. Thermal performance in this instance can be approximated to two parts:

a) the heat loss due to air infiltration, or how well sealed the tent is;
b) the heat loss through the tent fabric and floor, which is dependent upon the mean average insulation value of the shelter material.
Existing canvas tents have both a low insulation value and are further subject to large heat losses through infiltration. This project seeks to use both structural systems and construction techniques that minimise heat loss through infiltration. It also seeks to maximise the insulation value of all fabric faces in order to minimise conductive heat losses.

In addition, all construction materials used in the shelter should have a lifespan of at least six months in order to eliminate the need for component replacement over a winter season.

iv) Minimise the number of components

It is possible to reduce both the total cost and the total lead-time for procuring a complete shelter kit by minimising the number of components and material types. This also keeps construction techniques straightforward and reduces the potential for building a shelter incorrectly.

v) Minimise shelter supply lead time

Most industrial manufacturers that supply commercial and domestic markets for the materials used have either the production capacity or substantial stockpiles in place to cope with large demand. This means that their material can be supplied in bulk and at short notice to meet the unpredictable needs of humanitarian emergencies. Using global material standards further increases the likelihood of local production and hence local procurement. Local procurement will significantly reduce transportation time and associated costs.

vi) Employ materials that can be used in a reconstruction phase

Assuming that there are limited funds available for humanitarian assistance, especially those allocated to shelter provision, it is essential that any material provided should be useful for the longest possible time period. All materials distributed should be durable enough to last for the period of an anticipated emergency. In the case of cold climate shelter provision, this should be the duration of winter. However, the benefit is maximised if these same materials are also of use during reconstruction or care and maintenance phases of assistance. Tailored tents and other commercial and military shelters do not achieve this end.

---

3 The aim has been to minimise heat losses through infiltration whilst maintaining the minimum air change rate. This minimum air exchange is necessary for a regular supply of fresh air and in order to exhaust waste gases, such as carbon monoxide from any leakage in the flue of space heaters. Refer to Chapter 3.2.
3 Project Investigation

3.1 Objectives

- To design a stand-alone shelter system for use in the Balkans this winter, the component parts of which can be: (1) procured regionally within Eastern and Central Europe; (2) readily available in bulk with a short lead time to delivery; or (3) already stockpiled in the event of an humanitarian emergency.

- To develop these designs through the construction of several prototypes.

- To test the best of these prototypes in an environmental chamber in order to predict performance in the field, given a series of specified climatic conditions.

- To provide a series of material specifications, costs, lead times and details of supplying agents for all component parts for a successful shelter system.

- To develop further an approach towards the implementation of emergency shelter programmes in cold climates.

3.2 Design Brief

3.2.1 Number of Beneficiaries Per Shelter

The UNHCR Shelter Standards for Cold Climates recommend 4.5m² of sheltered floor area per person. This would mean less than 3 beneficiaries could fit comfortably into a shelter using the hot climate shelter structure with its floor area of 13m². While this standard is supported fully, in reality, cost implications make this figure unlikely. Testing should proceed on the assumption of a maximum capacity of 6 people.
3.2.2 Design Temperatures

The monthly weather file for the Djakovica/Albania border in Kosovo detailed below has been extrapolated from data from the closest weather station, which is Pristina:

<table>
<thead>
<tr>
<th>Location:</th>
<th>Djakovica/Albania border</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>± 900 m</td>
</tr>
<tr>
<td>Lat:</td>
<td>42.4°</td>
</tr>
<tr>
<td>Long:</td>
<td>-20.35°</td>
</tr>
<tr>
<td>Winter months</td>
<td>Avg. daily max. temp</td>
</tr>
<tr>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>November</td>
<td>5.90</td>
</tr>
<tr>
<td>December</td>
<td>1.85</td>
</tr>
<tr>
<td>January</td>
<td>1.00</td>
</tr>
<tr>
<td>February</td>
<td>4.67</td>
</tr>
<tr>
<td>March</td>
<td>9.44</td>
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</tbody>
</table>

Kosovo is a plateau surrounded by mountain ranges to the north, south and west of the province. Temperatures on the plateau (Pristina) can reach –15°C at night in the month of December and reaches –20°C or lower temperatures at higher altitude. The average monthly minimum air temperatures detailed above are appreciably higher but can be used to predict heating and fuel requirements for the most extreme environments in Kosovo.

It was decided to test the shelter to –20°C as it would be extremely unlikely that any number of heated shelters could be maintained in more severe conditions or at altitudes where the logistics of the provision of aid becomes unrealistic.

3.2.3 Survival Temperatures

The average mean internal target temperature for the internal shelter environment was set at 16°C ± 4°C.

3.2.4 Wind speed

It would be useful to gauge the structural and thermal performance of the shelter under a series of wind speeds. The average wind speeds for Kosovo are detailed above, although it was not possible to ascertain maximum wind speeds as this is largely determined by an individual site. However, wind is only at a peak value for a fraction of the total time, and so modelling for thermal performance under these conditions is not useful. Conversely, the shelter is at greatest risk of structural failure during buffeting wind conditions where an average wind speed may be relatively low, but where there are also shorter, high speed gusts.

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4 Data obtained from METEONORM Version 3.0.
5 pers comm Rory O’Connor. Refer to Appendix 5.
It was decided that it was more useful to gauge the thermal performance of the shelter during any environmental tests to be performed within the project, rather than to measure the structural performance as structural failure would halt any further testing. Wind speeds for testing were adjusted accordingly and the shelter was tested in still ambient wind conditions and at a range of speeds up to 12.5 m/s\(^{-1}\) or Gale Force 6.

### 3.2.5 Logistics Targets

#### i) Shelter Cost

The humanitarian disaster in Kosovo received more funding that in many other emergencies in recent years. If a shelter system is to be useful beyond this specific emergency, the budgets for previous or proposed shelter programmes will have to be analysed to inform appropriate costing. This information is hard to find, largely because it remains with individuals in organisations, rather than in accessible records. To compound the problem, few Non-Governmental Organisations (or Governmental Organisations) have a specific shelter budget prior to any given emergency. As different emergencies have various budgets, it is even harder to give a realistic or ‘competitive’ target cost for a shelter system for use in any cold climate.

There are a few commercially available ‘winterised’ or cold climate shelter systems, some of which have been used in the field by experienced humanitarian organisations and these provide the best guide to target prices. The UNHCR Winterised Tent has a floor plan of 16m\(^2\) and costs around £125 sterling\(^6\). This is equivalent to £17.80 per person, assuming the same living density as those for the design brief of this project. Military tents can cost up to £500 sterling per person using the same living density assumptions\(^7\). A target cost of £200 sterling was eventually decided upon with OXFAM for a complete shelter system, inclusive of any packaging costs\(^8\). This is equivalent to £33 sterling per person. This higher cost as compared with the UNHCR winterised tent is justified by the lower running cost, shorter lead-time to delivery and material use in later assistance phases.

#### ii) Shelter Weight

The shelter should be light enough to be carried and construct within a family group. It cannot be relied upon that all six members will be fit and healthy, so it was decided that 2 to 3 people must be able to carry and erect the system. A weight of 100kg was decided upon.

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\(^6\) Cost is ex-works, ex-transport. \textit{pers comm} Wolfgang Neumann, UNHCR PTSS.
\(^7\) \textit{pers comm} Squadron Leader Ayers, Ministry of Defence.
\(^8\) \textit{pers comm} John Howard, OXFAM GB.
iii) Shelter Volume

The shelter kit should be compact enough to be carried by two to three persons and be sufficiently compact to minimise transportation costs, either by air or land. The un-insulated UNHCR tent has a packed volume of 0.28m³. A target volume of 0.5m³ was decided upon for this project.

iv) Lead Time

The time period for any one component from order date to delivery for adequate material for 1000 shelter units was fixed at ten to fourteen days.

3.2.6 Humidity Levels

Humidity becomes a health risk at significantly high or low values. Fifty percent Relative Humidity (RH) is comfortable for most humans but 20-80% RH can be tolerated, although this value range will depend to some degree on the beneficiary population⁹.

3.2.7 Air Change Rate

The necessary fresh air supply rate for a shelter containing 6 occupants, assuming there is no smoking, is 12 litres per second per person (l/s/person) and this corresponds to an air exchange rate of 0.98 ac/h. The necessary air change rate rises to 18 l/s/person for when occupants smoke and/or the stove is being used for cooking¹⁰.

3.2.8 Insulation Values

Without knowing the constituent parts of heat loss for a shelter system in high winds at –20⁰C, it is impossible to predict the insulation value needed for insulation for a shelter. It was decided that this value should be maximised using readily available materials and providing other material selection criteria have been addressed.

3.2.9 Heater Assumptions

There is greater uncertainty over the design and use of the heater than any other item on the shelter kit list. The type and size of the heater, together with the amount of fuel distributed, will depend on the type of emergency within a given environment and, to a greater extent, what is available in stockpiles and on local markets. Different heaters with the same kilowatt output have various convective/radiative percentage outputs, fuel burning efficiencies and surface

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⁹ pers comm Rory O’Connor. Refer to Appendix 5.
¹⁰ CIBSE guidelines.
temperatures, all of which will significantly affect the internal shelter environment\(^{11}\).

In order to complete the tests within the project deadline, several assumptions were made concerning the most likely options available to the aid community within Kosovo during August 1999 and the experiment apparatus was tailored accordingly. It was decided that there were two options for heating winterised shelter with a very short lead-time:

i) **Kosovan ‘Bread Stove’**

These locally built stove units burn solid fuel and come with flue pipes\(^{12}\). They are produced very cheaply (around £25 sterling per unit) and can be produced using local capacity and distributed in bulk within a matter of days.

ii) **Canadian Heater**

It will not be possible, or indeed preferable in all environments, to supply solid fuel such as cut timber for heating and cooking purposes. This heater burns diesel or kerosene fuel and is therefore useful where the political and climatic environments of the emergency are not known. The heater is considerably more expensive at £200 sterling per unit, but would be also available in bulk within a short lead-time\(^{13}\).

Assuming these two options, the heating strategy for the test was as follows:

- a 3kW electric (radiant) bar heater would be used in the chamber, which would enable accurate measurement of power input on a single 13 Amp cable;

- the electric heater would be placed in a welded steel plate box to alter the radiative/convective output ratio to that of a solid/liquid fuel stove/heater.

Once data is taken from the shelter environment with a known power input/output, it is possible to extrapolate to predict performance of other heaters with similar radiative/convective heat outputs.\(^{14}\)

\(^{11}\) *pers comm* Nick Baker, Martin Centre, Cambridge. Details are not given in this report. Please contact the author for further information.

\(^{12}\) Stove is made from TIG welded 2.5mm steel plate. Refer to Appendix 4b for details of the standard oven/heater used in Kosovo compared with that used in the test chamber.

\(^{13}\) Heater unit designed by T. Corsellis as part of DFID consultancy for the winterisation of Elbasan camp, Albania Refer to Appendix 2 for further details.

\(^{14}\) UNHCR and ICRC both have standard stove units, but data could not be found relating to these units, concerning size, kWatt output, availability, cost and production lead time. However, it should be possible to adjust the data sets to predict performance with these units when specifications become available.
3.3 Project Assumptions

3.3.1 Shelter Construction

Any construction that needs to be built in a minimum time period by non-skilled labour needs to be both simple and straightforward. This is not to say that certain individuals and ethic groups are not capable of advanced construction, rather that these skills cannot be relied upon within every family group. For the purposes of this project it was necessary to rely upon the field experience of several aid personnel in order to anticipate what construction methods and techniques are possible with a beneficiary population in Kosovo within an emergency shelter assistance programme. This is particularly important not only in terms of the viability of the initial construction process, but also in the way in which a shelter system might be maintained, or degraded, over time. As a result of many discussions, several assumptions were made about maintenance, including maintaining high tension in the cross bracing of the structure and the plastic sheets, and the extent to which a shelter would be sealed in high winds in the extremes of cold weather. Prototype development and environmental tests were altered accordingly.

3.3.2 Social Behaviour

Similarly, in the absence of detailed studies, a number of assumptions were made about the extent to which a beneficiary population might impact on their emergency shelter environment in social terms. This includes the amount of cooking within a shelter, cigarette smoking, the movement in and out of the shelter, daily routines and anticipated activities within and around an emergency shelter.

3.4 Project Methodology

Four different tests were identified as being the minimum needed to gauge the performance of a prototype shelter system:

1. **Prototype development.** As a first step to ascertain what is possible to build, it is necessary to physically construct several prototypes using a variety of pre-selected industry standard materials together with a structural system. In this way, it should be possible to eliminate inappropriate designs and materials before being tested in an environmental chamber or in the field.

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15 In the absence of data from social testing in the field, this project drew upon experience from those who have worked within shelter programmes for the British Red Cross, OXFAM GB, DFID, IRC, LWF and UNHCR.

16 Refer to Appendix 4 for a detailed description of prototype development and tests at Ford’s Environmental Test Chamber at Dunton, Essex.
2. **Field performance tests.** In this test, the shelter prototype, or series of prototypes, should be erected in a suitable harsh environment in order to gather empirical data. This is necessary as it is not possible to model certain environmental conditions, such as buffeting wind and true ground fixing, within a testing chamber. It also allows data to be collected over a longer time period.

3. **Environmental chamber tests.** The use of an environmental chamber allows for an evaluation of performance whilst controlling wind speed, temperature and moisture, which are the three key climatic variables in terms of testing.

   i) **Thermal testing.** Thermal testing can gauge the level of thermal comfort within the shelter under extreme conditions. In addition, it is possible to determine the thermal performance of the constituent parts of the shelter and the infiltration heat losses. This information can inform design revisions after testing.

   ii) **Condensation testing.** The aim of the cold room tests was to gauge shelter performance relative to moisture produced from respiration and cooking. This is important both from the levels of humidity produced and its affect on the thermal performance of the shelter. These tests were not possible to complete within the time period of this project, and have been pushed back to Phase Two of the project. The results to follow describe the key findings from the environmental chamber.

4. **Social tests.** Perhaps the most important test is how a beneficiary population will interact with the shelter. This is critical in terms of which construction techniques are to be employed and in terms of space use and cultural appropriateness. It can also directly inform other technical aspects such as the durability of components.

The short duration of this project has meant that it has not been possible to perform **field performance tests** (2.) and **social tests** (4.). These tests must be completed to ascertain whether the shelter can be deployed successfully.

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17 Kate Crawford, Department of Engineering, Cambridge University is currently preparing to undertake cold room testing of the shelter.
3.5 Selection of Insulation Materials

In physical terms, one of the most critical components of a cold climate shelter system is choosing an appropriate insulation material. The first part of the project was spent researching which materials are available within European and world markets that could be usefully employed to insulate a shelter in a severely cold climate. A list of criteria is given below to explain the material selection process.

<table>
<thead>
<tr>
<th>No.</th>
<th>Nominal Insulation Component</th>
<th>Selection Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>‘U’ value</td>
<td>(Insulation value)</td>
</tr>
<tr>
<td>2</td>
<td>Unit cost</td>
<td>(Cost)</td>
</tr>
<tr>
<td>3</td>
<td>Bulk purchase price</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Weight</td>
<td>(Production)</td>
</tr>
<tr>
<td>5</td>
<td>Packed volume</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Extent to which production is standardised</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Number of manufacturers world-wide</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Material familiarity</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Lead time (for supply of material for 1000 kits)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Compatibility of production dimensions</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Chemical</td>
<td>(Degradation)</td>
</tr>
<tr>
<td>12</td>
<td>Fire</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Water moisture/vapour</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Human use</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Climatic exposure</td>
<td>(Environmental Health)</td>
</tr>
<tr>
<td>16</td>
<td>Toxicity</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Tensile strength</td>
<td>(Structural Performance)</td>
</tr>
<tr>
<td>18</td>
<td>Compressive strength</td>
<td></td>
</tr>
</tbody>
</table>

Further investigation into insulation materials and manufacturers indicated that materials fell into two categories: (1) those that were industry standard; and (2) those that could be tailored to specific requirements. The question was then asked whether the shelter should be fabricated in kit form, from specially fabricated materials, or whether the material selection criteria described above should be rigidly adhered to. The latter course of action was...

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16 It should be noted that this selection process was not exhaustive and the search for cheaper, more effective industry standard material is ongoing.

19 This is a nominal list that has been adhered to as closely as possible. In reality, it has been extremely hard to ascertain accurate values for certain criteria without data from laboratory and field testing. However, it is interesting to note that excluding the first two criteria, all others criteria can be usefully applied to every other component part of a shelter system.
decided upon. Some material manufacturers are in a position to alter standard products specifically for aid purposes whilst keeping costs low. This presents some useful material for shelter in cold climate, but implies a departure from the brief set at the outset of the project. Specially fabricated products are, by definition, not industry standard and will therefore increase supply lead-time. For these reasons, tailored or modified materials have not been developed further or tested as part of this project.

It is noteworthy that specially fabricated materials do have their place in emergency assistance, and provided there is adequate lead-time or ability for limited stockpiling, they may well be the preferred choice in some emergencies. As a parallel project, shelter development was started with a manufacturer with abilities to modify standard products specifically for aid purposes\textsuperscript{20}.

\textsuperscript{20} Details of shelter development using specially fabricated materials are given in Appendix 3.
4 Prototype Development

Following the investigation into appropriate materials, five designs were identified for prototype construction. This phase of the project was not so much a comprehensive series of tests, but more an exploration of what was possible with the design brief and the variety of materials on the market. The following chapter describes the prototypes built and the conclusions drawn from the development process.
4.1 Prototype 1

Ventilated Monarflex ‘Universal’ Sheeting Sandwich

Monarflex universal sheeting with poly toggles/snap-fitted to eyelets

20mm pipe spacers push fit over the poly toggles

Resin free glass fibre is rolled between the spacers

Insulation is taped to sheet to minimise differential movement during construction/

Top sheet toggles are snap fitted to the pipe spacers
Aim

The aim of this design was to examine whether it was possible to create an insulated cavity that was also ventilated.

Roof Design

This prototype uses a double layer of Monarflex Universal reinforced plastic sheeting for the roof with 150mm expanding glass fibre sandwiched between the sheets.

The two sheets were kept apart using lengths of 20mm diameter Medium Density Polyethylene (MDPE) water piping as spacers. These plastic pipes attached to the sheets by push fitting over Monarflex plastic toggles that snap fit into eyelet patches already welded to the sheet during manufacture.

End/Door Design

It was not possible to construct a door using expanded glass fibre due to the weight and bulk of the insulating material. Resin free glass fibre has very low tensile strength and will fall apart over time with gravity and constant movement from everyday use. No other door/end designs were attempted in this prototype.

Floor Design

Polyurethane closed cell foam was placed on the floor. The foam comes in rolls 1.2 metres wide and is 5mm thick. Lengths were cut and taped together before being placed on the shelter floor and covered with a UNHCR tarpaulin to protect it from wear and tear.

Advantages

- The glass fibre used in this prototype, ‘Miraflex’, is resin free and expands to some ten times its packed volume, thus achieving the highest insulation value of any material used during prototype development.
Disadvantages

- The spacers do not maintain a sufficient or consistent cavity across the roof. In fact, only small cavities formed around each spacer. In addition, the spacers tended to displace the toggles from the eyelets where there was sufficient compression caused by the tension in the two sheets. As soon as the toggles are displaced from the eyelets, the roof sheet is no longer watertight.

- The entire roof with integral ‘spacers’ had to be made on the ground and then hauled over the structure. This was difficult to achieve with two people and impossible to then sufficiently tension the sheeting to maintain effective internal volume.

- Monarflex Universal sheeting does not appear to be as suited to this application as the UNHCR specification sheeting in terms of strength and UV degradation.

Verdict

- Rejected ventilation strategy.

- Rejected method of construction on the ground.

- Retained resin free expandable glass fibre as the preferred insulating material.

- Retained closed cell foam as the only realistic floor insulation available.
4.2 Prototype 2

Mineral Fibre Rockwool 'Duct Wrap' Sandwich

- Mineral fibre duct wrap is easy to cut but difficult to join.
- Insulation comes in 1x4 metre rolls.
- Shelter construction is straightforward.
- Four lengths of mineral fibre cover the roof with overlap joints to prevent cold bridging.
- Constructing doors with mineral fibre duct wrap and UNHCR sheeting.
Aim

The aim of this prototype was to investigate how mineral fibre products could be used to provide insulation.

Roof Design

This prototype sandwiches 40mm thick, reinforced foil backed mineral fibre wool between two layers of UNHCR specification sheeting. Each roll is four metres long and allowed six metre lengths to be cut and taped together.

End/Door Design

The door and end design for this shelter used mineral fibre Duct Wrap enclosed between two sheets of UNHCR plastic sheeting. The mineral fibre and plastic sheets are then laced together using polypropylene rope and laced over the end hoops of the shelter structure and buried in the ground.

Floor Design

High-density mineral fibre batts were placed between two UNHCR tarpaulins.

Advantages

- The shelter was relatively easy to construct and the rolls of mineral fibre were manageable in size.
• Mineral fibre Duct Wrap usefully retains its nominal thickness, and hence the maximum insulation value, between the plastic sheets in all parts of the roof except for when it passes over the structure. This is made possible because the inner plastic sheet bearing the load of the insulating material sags more than 50mm below the position of the supporting hoops whilst the top sheet is at high tension with no dead loading and does not sag to the same degree.

Disadvantages

• The fact that the roll had to be gaffer taped to make efficient use of two rolls was not ideal and would almost certainly pull apart in use in the field21.

• The weight and volume of the mineral fibre Duct Wrap necessary to cover the roof were too great for one person to carry22. These represent a cause for concern in terms of transportation costs.

• The self-weight of the mineral fibre Duct Wrap caused significant deformation of the plastic water pipe structure after a period of several weeks. This structural deformation highlights the inherent weakness of the structure employed, but also implies that this mass per unit area of insulation may be nearing the maximum loading capabilities of the 63mm hooped piping structure.

• The high-density floor batts are unsuitable due to their high mass per unit area. There were also doubts raised as to their structural performance on rocky ground, as any panel system will fragment on uneven ground if it not of sufficient strength or flexibility.

• The mineral fibre easily fell away from the plastic foil backed reinforcement if not handled with care.

Verdict

• Rejected mineral fibre products used in this test due to higher volume and mass per unit area and its lower structural strength, as compared to equivalent products using glass fibre.

• Retained the construction process used for this prototype.

21 Rockwool later confirmed that there is a European product made in Germany called Klimarock in 6 metre lengths of a comparable insulation value to the material used in this prototype. They also confirmed that this material would be available in bulk with a short lead-time. Refer to Appendix 2 for further details.

22 Refer to Chapter 3.2.
4.3 Prototype 3

Inverted Monarflex ‘Universal’ Sheeting, with Suspended Insulation

**Aim**

The aim of this prototype was to investigate the feasibility of suspending insulation from the inside of a shelter using a single reinforced tarpaulin, rather than sandwiching it between tensioned sheets of roof plastic. This would enable ventilation of the insulation and reduce the risk of interstitial condensation within the insulating layer.

**Roof Design**

This method of construction uses only one Monarflex Universal sheet with proprietary ‘poly-toggles’, snap fitted to the eyelets facing inside the shelter. A network of plastic rope is then fed through the toggles to form attachment points for rolls of insulation. The insulation would then be ventilated between the living area and the plastic roof sheet and would enable one roll to form a complete loop, covering roof wall and floor.

**End/Door Design**

None attempted.
**Floor Design**

The floor and roof design was combined in this prototype so that the insulating material forms one continuous envelope for both roof and floor.

**Advantages**

- The construction method is both easy and straightforward.

**Disadvantages**

- The foiled-backed products tested are not sufficiently durable to be inside a living space and cannot cope with damage from live loads on the floor.

- Glass and mineral fibre products cannot be used as floor insulation as the live loading compresses the roll to a thickness with a negligible insulation value.

- Both products readily absorb moisture, which pose further hazards in region such as the floor, which are especially susceptible to moisture ingressation.

- Glass and mineral fibre products may pose a risk to inhabitants if they are exposed within a living area and ingested through breathing\(^\text{23}\).

- Insulation roll widths are restricted to the spacing of the Monarflex eyelets, which are at one-metre centres, where the supporting rope attaches to the sheet.

- Monarflex Universal sheeting does not appear to be as suited to this application as the UNHCR specification sheeting in terms of strength and UV degradation.

**Verdict**

- *Rejected design in its entirety as no suitable insulation material could be found.*

\(^{23}\) Manufacturers of both glass and mineral fibre insulation assured us that their products posed no health risk, but acknowledged that they could be an irritant to some people. There was not sufficient time to confirm these assurances with an independent expert.
4.4 **Prototype 4**

Owens-Corning ‘Miraflex’ Glass Fibre Ducting Insulation Sandwich

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**Aim**

This prototype investigates the use of glass fibre ducting insulation as a material for the ends, doors and roof.

**Roof Design**

This prototype was constructed in an identical manner to prototype No. 2 where mineral fibre ducting insulation is sandwiched between two layers of UNHCR sheeting, except in this case, 50mm thick glass fibre duct wrap replaces that of 40mm mineral fibre. The glass fibre rolls come in 1.2 metre widths and so three widths cover the length of the roof.

**End/Door Design**

The door and end design for this shelter used 25mm thick glass fibre duct wrap enclosed between two sheets of UNHCR plastic sheeting. The glass fibre and plastic sheets are then laced together using polypropylene rope and laced over the end hoops of the shelter structure and buried in the ground.

**Floor Design**

None attempted.

**Advantages**

- The low density of glass fibre ducting insulation makes it easier to handle during construction.
• The relatively low mass per unit area of 20mm thick glass fibre ducting insulation reduces the dead load on the doors. Only a small structural deformation was recorded after several weeks.

• This material compresses to a greater extent than the equivalent thickness of mineral fibre. Higher compression means lower packed volume.

• As with the mineral fibre rolls, glass fibre ducting insulation retains its nominal thickness in all parts of the roof between the plastic sheets, except for when it passes over the structure. Hence it retains its maximum insulation value.

Disadvantages

• As with the mineral fibre equivalent, it is not possible to effectively tape pieces of glass fibre ducting insulation together in the field, so production roll lengths must exactly fit the shelter design.

• Glass fibre readily absorbs moisture and at a higher rate than mineral fibre. Moisture ingression into fibrous material will reduce its insulation value.

• Glass fibre ducting insulation is not translucent and so will not allow light into the shelter.

Verdict

• Rejected 20mm glass fibre ducting insulation for roof due to relatively low insulation value.

• Rejected 20mm glass fibre ducting insulation for ends and door as material is not translucent.
4.5 Prototype 5
Web Dynamics Composite Spun-Polymer/Polyester Quilt

doors and roof are made of the same composite material with

the material is lightweight and easy to build

seam stitching could prove to be a weak point

material translucency gives better lighting conditions

Roof Design

This shelter is constructed from a composite layered fabric. The top layer consists of a spun polymer which is water-resistant yet allows water vapour to permeate. Polyester wadding insulation is woven into the underside of the fabric with a polymer breather layer forming the inside face.

End/Door Design

The end and doors for this prototype use the same material as described for the roof design.

Floor Design

None attempted.

Advantages

- The material is lightweight which means it is easy to handle during construction.
• The entire roof fabric is made into one piece. This makes the construction process simple and straightforward.

• The material is translucent which allows adequate lighting within the tent.

Disadvantages

• Only a few manufacturers can produce composite, quilted products using spun polymers. This may not produce competitively priced products.

• Composite products for specialised use involving several manufacturing procedures and not necessarily all within a single company or country, all contribute to a longer lead-time than that for a shelter system using only industry standard material.

• It is only possible to provide a minimal insulation thickness within a single quilted product. This is not adequate for the most severe cold climates.

Verdict

• Rejected composite material as it does not answer the project brief criteria.

• Retained concept and continued development with an industrial manufacturer\(^{24}\).

\(^{24}\) Refer to Appendix 3.
4.6 Prototype 6

Prototype Design Selected for Testing in the Ford DTC

Roof Design

150mm thick expandable resin free Owens-Corning ‘Miraflex’ glass fibre loft insulation, sandwiched between two UNHCR tarpaulins.

Door/End Design

Two layers of 2mm thick, translucent closed cell foam sandwiched between two sheets of transparent, reinforced low density polyethylene scaffold sheeting. The doors were tied to the structure using polypropylene rope and proprietary eyelet patches welded onto the scaffold sheeting during manufacture.

Floor Design

A single layer of 5mm closed cell polyurethane foam was cut to length and taped together. Another UNHCR tarpaulin was placed over the top of the insulation.
5 Results from the Environmental Tests at Ford DTC

A series of tests were designed to be undertaken inside both at Ford's DTC and a cold room facility:

**Thermal Testing**

Within the Ford DTC, it was possible to manipulate both temperature and wind. Hence, the aim of tests were to gauge the thermal performance of the shelter whilst in an environment at minus twenty degrees Celsius and whilst experiencing various wind speeds up to a maximum of 12.5 metres per second (Gale Force 6). An array of 56 thermocouples, 3 globe thermometers, and 8 surface thermocouples were placed: (1) inside the shelter on metal stands, to form a three dimensional grid; (2) on the shelter surfaces, both inside and outside; and (3) on the heater. In addition, a thermal imaging camera was used to produce graphical data to substantiate findings from the thermocouple readings. This test was undertaken at the Ford DTC at Dunton in Essex. The results are detailed in section 5.1.

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25 Refer to Appendix 4 for Testing Methodology.
26 Globe thermometers measure both air temperature and the radiant environment to give an overall reading of thermal comfort.
5.1 Internal Temperature Gradients with and without wind

The graph above shows how heat is dispersed within the shelter environment using a 2.4 kW heat source, with no wind, and when the wind is at Gale Force 6. The first point on the x-axis (0.2 metres) represents the level from the ground at which occupants would sleep. This is critical as it likely to be the coldest part of the tent and also the zone in which occupants are at the greatest risk of perishing. The graph shows that in both still and gale force conditions, the lowest part of the tent maintains a minimum of 15.6 °C (±0.7 °C) which is comfortably inside the survival temperature for the majority of humans, and adequate for vulnerable groups including the elderly \( ^{27} \). In the absence of wind, there is a 15 °C temperature difference from head to foot.

\( ^{27} \textit{Pers comm}} \) R. O’Connor, Cold Climate Physician, British Antarctic Survey.
5.2 **Global Conductance/Wind speed graph**

![Graph showing the relationship between wind speed and global conductance. The equation is $y = 0.094x^2 + 0.632x + 53.035$ with $R^2 = 0.997$.]

The shallow gradient indicating that heat loss is not greatly affected by wind speed, even at gale force speed. This would indicate that the shelter is effectively sealed against drafts\(^{28}\).

5.3 **Component parts of shelter heat loss with no wind\(^ {29}\)**

![Pie chart showing the percentage contribution of each component to shelter heat loss. Door/Ends: 36%, Ventilation/Infiltration: 35%, Roof: 13%, Floor: 16%]

\(^{28}\) Several assumptions were made concerning the extent to which low-level shelter sealing would be performed in the field and the test rig was altered accordingly. Refer to Chapter 3.3.

\(^{29}\) Data relating to the floor condition have been normalised to model average Kosovan winter ground temperature rather than the steel decking of the test chamber. Appendix 4 shows the original data before normalisation.
After adjustments were made for the heat losses to the test chamber floor, it was possible to disaggregate the overall thermal performance of the shelter into its constituent parts. The pie chart indicates where in the shelter heat losses are occurring for still air and ambient conditions at –20 °C. The fabric floor and roof combine to represent just under a third of heat losses whilst the ends of the shelter account for another third. The remaining third is lost through air infiltration occurring in still, ambient conditions due to the thermal convection currents inside the tent.

### 5.4 The Dependence of Infiltration Rate upon Wind Speed

The graph above indicates that the shelter provides a minimum air change rate of 2.8 air changes per hour (ac/h) without wind (refer to y-axis intercept). If the occupants smoke, the minimum supply rate should be 1.47 ac/h and the air change rate is still satisfactory.
6 Project Conclusions

6.1 Conclusions from Prototype Development

6.1.1 Roof Design

‘Miraflex’ expandable glass fibre proved the best compromise between ease of handling and absolute insulation value. This was in preference to the foil backed mineral and glass fibre alternatives. ‘Miraflex’ is used for insulating lofts and expands from a packed thickness of 15mm (in roll form) to a nominal thickness of 150mm when unpacked. This material comes in 10.7m rolls and three rolls cover an entire shelter roof. After several designs and techniques were tested, it was decided that the easiest way to construct an insulated roof was to throw over rolled material on top of a tensioned polyethylene sheet and then to sandwich this with another plastic sheet on top.

Some concerns were raised as to the structural integrity of ‘Miraflex’ over time. The fibres are only held loosely together within a thin plastic bag and whilst this is adequate during the construction process, it is possible that the material may be pulled down by gravity towards the edges of the tent over time.

6.1.2 Door/End Design

A closed-cell polyurethane foam was chosen due to its thinner section, lower weight and better than average insulation value. ‘Miofol’ is a thin closed cell foam, which also has a higher tensile strength than ‘Miraflex’ glass wool. This means that it is better placed to cope with wind loads and a greater human use, such as at the door. Door construction presented more demanding construction problems. It proved too difficult to use a similar thickness insulation material to that of the roof and also be able to fix it to the MDPE water pipe structure. This forced a compromise in the choice of material in terms of weight/volume versus absolute insulation value.

The material is also translucent, which drastically improves lighting levels within the shelter. This was a significant development in terms of realising the importance of light versus the need to insulate as well as maintain sufficient privacy within a shelter. The combination of ‘Miofol’ and Monarflex T-Plus scaffold sheeting effectively diffuse light entering through the door and closed end of the shelter as well as providing privacy and a degree of insulation. However, 4mm of closed cell foam has a substantially lower insulation value than any other part of the shelter and so conductive heat losses were relatively high as compared with other surfaces. Condensation will inevitably form on the colder inside surfaces of the door ends but this will run off to the base of door on the inside of the shelter30.

30 Refer to results for the condensation tests, when available.
6.1.3 Floor Design

The foam used in the test was 5mm thick, low-density polyurethane. This foam comes in 100 metre rolls and is typically used for acoustic insulation in floors. Floor insulation not only has to isolate the living space from the low temperature of the ground but also has to cope with a live loading of occupants and belongings. The material at this surface has to be resilient as there are higher rates of degradation from wear and tear due to everyday use. In addition, the material will be compressed at critical points such as where occupants lie down. Compression reduces material thickness and hence the insulation value of the material is reduced. This means that expandable materials, such as low density mineral and glass fibre products, are effectively useless and leaves only closed cell foams as the remaining alternative.

Closed cell foams are more expensive to transport as they have a low density and a high volume and will not compress appreciably for packing. However, this material is relatively robust as compared with the other insulation materials tested. Closed cell foam repels moisture and this reduces the risk of the insulation value of the floor being affected by moisture as well as reducing the risk of water entering the inhabited area.

6.1.4 Heater and Flue Design

For the purposes of the test, we did not model the effects of the flue inside the shelter, but simply capped the flue pipe up-stand with a short section of sealed steel pipe.

The model heat source used in the tests performed well and was reasonably close to the anticipated performance of the heater options described in Chapter 3.3. When more data concerning likely deployable heater units becomes available, it will be possible to extrapolate the data sets from the Ford DTC tests to predict the likely thermal performance of the shelter.

The issue of exhausting heat from the shelter was unresolved at the time of testing. The waste gases from both solid and liquid fuel heaters must be exhausted from the internal environment, but how and where a flue should puncture the skin of the shelter presents some construction problems. The greatest risk is that any suggested design or plan would not necessarily be adhered to by individual families in the field. Whilst incorrect construction is also a problem for other elements in the shelter kit, the implications for fitting a flue incorrectly are potentially fatal. Several designs have been suggested including fixing a simple manifold to the back end of the shelter in order to hold the exhaust flue pipe away from the plastic sheeting, but field testing is needed to confirm whether this is effective.

6.1.5 Structural Assessment

A jointed system using 50mm MDPE plug sections with 63 mm pipe sections is unsuitable for an insulated cold climate shelter system. The prototype construction phase led to several conclusions concerning the durability of the
structural system. All prototypes using mineral and glass fibre experienced structural deformation to varying degrees over a period of weeks and months at the test site. In the case of the shelter using mineral fibre Duct Wrap, the joints in the system failed completely due to the self-weight of the insulating material on the roof. The strain on the joints was worsened when the shelter was placed on a sloping site, which caused slow plastic deformation over a period of months. To investigate this problem further, several tests are needed to ascertain the maximum possible weight of roofing insulation. It may also be worth testing a variety of guying strategies, especially for sloping sites.

The aluminium pole section compression members also showed some evidence of deformation, but did not fail in any of the built prototypes.
6.2 Conclusions from the Test at Ford’s DTC

6.2.1 Structure

Un-segmented pipe sections performed well under wind loading inside the Ford DTC and no deformation was recorded.

6.2.2 Roof Design

Image taken with a thermal imaging camera in the test chamber

The roof is proportionally the region of lowest heat loss per unit area. The photograph above taken with the thermal imaging camera indicates that there is no cold bridging between the rolls of insulation on the roof. This means that a loose method of construction, such as that described in Chapter 4, can ensure excellent thermal performance. This is aided by the fact that ‘Miraflex’ expanding glass wool continues to expand for some 30 minutes after unrolling from the packaging and so filling any unintentional gaps left during the construction process.

6.2.3 Door/End Design

A higher insulation value is needed in the door/end construction whilst maintaining a low value for mass per unit area in order to keep the shelter ‘buildable’. The ends of the tent accounted for a third of total heat losses whilst only representing a quarter of the surface area. The temperature gradient within the shelter is not critical, as human occupancy will further increase air mixing and so lower the temperature differential.

6.2.4 Floor Design

Heat loss through the floor area constituted an unacceptably high proportion of total heat loss. This indicates that a higher insulation value is needed in this component part of the shelter.
6.3 Recommendations

Structure

- Use un-segmented 6 metre MDPE sections for primary structure
- Use 12mm steel reinforcement bar rather than hollow section aluminium tent poles as compression members
- Cross-brace internally using 8mm diameter polypropylene rope (see Figure 1)

Roof

- No alterations

Door/ends

- Increase the insulation thickness to 10mm of translucent polyurethane closed cell foam

Floor

- Double the thickness of polyurethane closed cell foam to 10mm
6.4 Recommended Shelter Specifications

Structure

3 x 6 metre lengths of MDPE water pipe (63mm diameter) joined by 3 x 12mm steel reinforcement bar cross braced with 8mm polypropylene rope.

Roof

3 x Miraflex 150mm resin free glass fibre roll sandwhiched between two 7 x 4 metre UNHCR specification tarpaulins.

Door/End

10mm thick translucent polyurethane closed cell foam sandwhiched between a single folded piece of Monarflex reinforced transparent T-Plus scaffold sheeting

Floor

10mm thick polyurethane closed cell foam under a UNHCR specification tarpaulin.

Heater

Either Kosovan bread stove or the adapted US army model heater described earlier in Chapter 3.2.9.
6.4 **Further Development**

*Structural Design*

Following the failure of the jointed MDPE pipe system in several prototypes, a comprehensive structural review is needed to improve on the results of this project. The extent to which a shelter can, or should, be braced with rope guys needs further investigation. Several tests need to be performed to further inform a design choice, including: (1) live loading the structure to simulate snow loading; (2) comparative testing on sloping sites with guyed and non-guyed shelters; and (3) with shelters with joints and those without joints.

The method of jointing might also be re-examined\(^{31}\). Several adapted designs were suggested after results had been analysed. The sketches in figure 2 below suggest directions for future testing and experimentation.

*Figure 2* Sketches of Structural and Insulation improvements explored on paper following testing in the Ford DTC

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\(^{31}\) OXFAM GB began re-examination of the Hot Climate Shelter Structure in October 1999.
Roof Design

In terms of insulation value, the roof was the best performing part of the shelter, accounting for approximately one third of the total heat losses, despite representing just under half of the total surface area of the shelter. The insulation value was so good, that it may well be possible to reduce the amount of insulation for less demanding environments in order to save on shelter cost, weight and volume. Alternative insulation materials that may warrant testing in an environmental chamber are mineral and glass fibre ducting insulation, similar to those used during the prototype development phase of this project.

It would be useful to examine in more depth the extent to which gravity and continual movement under wind loading causes resin-free glass fibre products, such as Miraflex, to pull apart under their own weight. This could be achieved through a series of simple laboratory tests to measure elongation to complement field tests. The elongation test could be performed within a university department, independently by manufacturers or the responsibility could be passed to commercial testing firm.

Floor Design

There is a need to source wider rolls of closed cell foam, up to 3.6m widths, and from producers of higher density foams similar to those producing camping carry-mats. Wider and denser foam rolls would be used in preference to those which was used in the test prototype.

The use of standard timber ‘universal’ forklift pallets to raise the floor should be investigated. Using pallets will substantially reduce conductive heat losses from human bodies lying or sleeping on the ground without the need for thicker closed cell foam, which adds significantly to both the purchase cost and the transport volume of the shelter. Using pallets will also marginally raise the sleeping zone to a region of higher average temperature\(^3\). Pallets are widely available and are relatively inexpensive although it is acknowledged that their use will not be a possibility in the emergency phase of many humanitarian disasters due to the uncertainty of supply lead-time.

Door/End Design

There is substantial room for improvement in terms of basic design for doors and ends of the shelter and the construction problem of trying to fill a ‘round hole with a square plug’ using materials from a roll remains. The construction method used in the prototype tested in the environmental chamber is not particularly straightforward, nor does it seal the tent as well as it might. An architecture student in his final undergraduate year at Cambridge University is focussing on this issue and it may be included as part of a Phase 2 shelter

\(^3\) Test results predict that the use of pallets will raise the mean average temperature in the sleeping zone to 20°C (as opposed to 15.7°C without the use of pallets) in still ambient conditions at minus 20°C.
project proposal. As with the structural system, several suggestions have been proffered for future development, including a study of commercial tents used in the Antarctic.
6.5 SWOT Analysis

Strengths

The results from this ten week project point to a qualified success. Construction tests have confirmed that it is possible to build a shelter appropriate for use in cold climate using a minimum of cheap material and tools. Test results from Ford's environmental chamber indicate that with a very minimal heat input, the interior shelter environment can be kept at well above survival temperature in extremely harsh conditions. In addition, this report lays out a methodology with which to test other existing shelter systems as well as future designs.

Weaknesses

The extent to which shelters are ‘buildable’ or culturally appropriate is beyond the remit of this project. Nevertheless, lessons learnt during this project indicate that cold climate shelter systems using industry standard material is likely to stretch to the limits what is possible under self-build assistance programmes.

Linked to the concept of ‘buildability’ is that of ‘cultural acceptance’. Little has ever been formally documented concerning this issue and is as important as any of the technical considerations covered in this document. It is noteworthy that is cannot be included in this analysis of cold climate shelter performance.

Opportunities

It has been possible to make contact with an enormous number of individuals and organisations that are interested to participate in the future development of an appropriate, cheap and durable solution to cold climate shelter for displaced people. These include insulation manufacturers, test facilities, a number of universities, departments of the university of Cambridge as well as Non-Governmental and Governmental Organisations, one of which is interested in supporting field testing in the near future.

The overwhelming success of this project has laid excellent groundwork for a second phase project as well as longer-term development over several years. Currently, there are ongoing discussions with a number of manufacturers who are interested in arranging a substantial trust fund to continue such humanitarian research work.

Research funding over the longer term will allow for the gaps to be filled within the testing methodology laid out in this preliminary report and support the formation of shelter guidelines for the aid community to compliment the limited literature currently available.
Threats

There is a danger that this cold climate shelter system may be exposed too soon to the field. Shelter systems that are assembled from cheap components, rather than being tailored or prefabricated, represent a significant departure from the status quo and will require a higher level of participation from implementing organisations and greater awareness among aid personnel. Obviously, shelter is critical for survival in cold climates and product development should not be at the risk of human life. Field and social testing requires well designed tests in collaboration with, and with the full support of NGO’s and GO’s and all other concerned parties. This not only necessitates adequate funding, but also a sufficient time to allow the long-term tests to produce valid results and conclusions.
Selected Bibliography


Appendix 2
Shelter Material Specifications and Supplier Details

Structure

- MDPE pipes (63mm OD)
- Aluminium tube sections

For details of UK suppliers contact:

John Howard
Technical Advisor
OXFAM Emergency Logistics Department,
274 Banbury Road
Oxford

Steel reinforcement bar and polypropylene rope is widely available.

Roof Sheeting

- UNHCR Specification braided/woven LDPE sheeting.

Several manufacturers now produce at, or near to, UNHCR/MSF 1997 standards\textsuperscript{33}. In UK, Monarflex and Protective Technologies International provide braided and woven sheets respectively, both of which would be appropriate for cold shelter, although there may well be others.

Monarflex 200C reinforced braided LDPE sheeting:

Phil Widdop
Monarflex Ltd.

HDPE woven tarpaulin sheeting:

Protective Technologies International Ltd.

\textsuperscript{33} Consult UNHCR Technical Division for further details.
Roof Insulation

- Miraflex resin-free glass fibre (150mm nominal expanded thickness)

John Tookey  
Owens Corning Building Materials Ltd.  
PO Box 10  
Stafford Road  
St. Helens  
Merseyside  
WA10 3NS  
Tel: 0802 216866  
john.tookey@owenscorning.com

Floor

- Quiet Zone Floor Foam (5mm thick)

John Tookey  
Owens Corning Building Materials Ltd.  
PO Box 10  
Stafford Road  
St. Helens  
Merseyside  
WA10 3NS  
Tel: 0802 216866  
john.tookey@owenscorning.com

Door/Ends

- Monarflex T-Plus Scaffold Sheeting

Phil Widdop  
Monarflex Ltd  
Lyon Way  
St. Albans  
Hertfordshire  
AL4 0LB  
Tel:01727 830 116  
enq@monarflex.co.uk
• **Miofol (2mm translucent closed cell foam)**

Tim Woodbridge  
Web Dynamics Ltd.  
Batchworth Lock House  
99 Church Street  
Rickmansworth  
Hertfordshire WD3 1JJ  
Tel: 01923 498 001  
Fax: 01923 498 004

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**Heaters**

• **Canadian heater**

Len Fleming  
International Thermal Research Ltd  
4-1411 Valmont Way  
Richmond  
BC  
Canada  
V6V 1Y3  
t. +1.604.278-1272  
f. +1.604.278-1274  
itr@intergate.bc.ca

• **Kosovan Stove**

Contact agencies in Kosovo for further details.
Appendix 3
Shelter Development with Modified, Composite Products
Letter to Web Dynamics Ltd, Hertfordshire

25th August 1999

Useful Properties of Quilted Membrane

1. Very light. One person can carry the quilt and doors. There is potential to increase wadding thickness to max U value whilst not exceeding manageable weight and volume.
2. Ventilated insulation. Product looks well placed to cope with internal and interstitial condensation dilemma.
3. Translucent. Psychologically important and functionally essential.
4. Colour and texture. Both contribute to ‘thermal comfort’ more than polyethylene sheeting although hard to quantify. A contact I have at the British Antarctic Survey said yellows and greens were proven to be most popular with those spending long periods of time in tents in cold climate.
5. Construction. Easy and believable to build and construct.

Problems

1. Insulation value. I would be very interested to see if the MOD report that you commissioned is accurate and that sheet does indeed perform at –5 C with 10.85 Togs, with no heat source, medium clothing and a light sleeping bag or equivalent. In any case, for our brief, it is likely to be inadequate for minus twenty celsius even with a heat source.
3. Stitching. Stitching is potential weak point and allows moisture through.
4. UV stabilisation. Nylon tents used at altitude in Greenland are chucked after 3 trips due to degradation. I would like to see data relating to strength testing after an accelerated UV exposure test similar to one performed by MSF/UNHCR PTSS in 1997 on PE reinforced sheeting.

Modified Quilted Fly Sheet (using Web 95)
Breather Flysheet

i) Web 95, 4.5m wide x 7m long
ii) Is it possible to make in one piece? What is the maximum width?
iii) If there are seams, they are to be waterproofed and reinforced to cope with (say) a person falling into side of shelter.
iv) Add reinforcement strips (50mm wide) and/or metal (galvanised) eyelets (15 to 20mm dia.) along short side at 250mm centres starting and ending 500mm from the edges.
v) Add diagonal reinforcement as per diagram below
vi) Print white line along the 7m length at 500mm from the edge both sides
vii) UV stabilised for say 5% loss in tensile strength under ISO1421 after 1500 hours UV exposure under ASTM G53/94 (UVB 313 nm peak).

Polyester wadding

i) increase to maximum thickness
ii) loose quilt stitch to maintain a maximum mean thickness
iii) fireproof

Inner Breather Layer

i) fireproof
ii) strong as possible to cope with human use/abuse
iii) aluminise the inside face (?)
**Roll materials.**

If you provide a breather sheet and a fly sheet, the insulating material can be flexible in terms of thickness and type.

Flysheet

As described for Breather Flysheet in (1.)

Breather Layer

As described in (1.) plus additional eyelets or reinforcement strips for attachment and tensioning (ref diagram below)
Flysheet as in (1.) and (2.) (or HCR PE reinforced Tarpaulin)
Liner to be 7 m x 4.5 m with attachment webbing at 1.5 m centres (long side) and 1.8m centres (short side).
Polyester wadding at max thickness. Material to cope with vapour transmission and to have vapour check on cold side which will allow any dripping condensation from inside face of cold flysheet to run down outside of liner.
Appendix 4a

Testing Methodology and Results from the Ford DTC
Dr. Darren Robinson, Senior Research Associate, Martin Centre for Architectural and Urban Studies

1. Thermal analysis
This section describes the results from an experiment that was designed to determine whether the shelter and initial heater rating were capable of providing a habitable environment under extreme winter conditions. This begins by setting out the experimental rationale and equipment used and continues to describe the results obtained. A procedure for applying the results to other shelter/heater combinations to test for habitability is presented within the Appendix.

1.1 Experimental design
There were two principal objectives for the thermal performance experiments;
1. Determine the thermal properties of the shelter and generalise the findings to enable performance ‘in the field’ to be predicted
2. Determine the extent of indoor environment variability and the likelihood of comfort from being achieved.

The indoor climate monitoring was designed to address the extent of thermal stratification and the occurrence of draughts within the comfort zone due to air leakage. Radiant temperature is also important for human comfort. To address this issues, the following instrumentation was fitted (Figure 1). Using the results from this monitoring, in conjunction with known power input to an electrical heat source, it is possible to derive heat loss coefficients (or more correctly conductances) under a range of test conditions.

Figure 1 Indoor climate measurements

Steel stands supported thermocouples, at 0.45m increments above floor level, except the first which was 0.15m above floor level (i.e., within the ‘sleeping zone’).
Surface temperature sensors were placed on each main plane. For essentially vertical surface, these were at the mid-height. Globe temperature sensors were positioned on one central stand (near to the door). All air and surface temperature measurements were recorded at 15s intervals. The numbers of sensors that were required is tabulated below. Use was also made of an infra-red thermograph, also kindly donated by the car manufacturer.

| Table 1 Sensor types and numbers |
|---------------------------------|------------------|
| Sensor type                     | Number           |
| K-type thermocouples for air / surface temperature | 48 / 12 |
| Globe thermocouples             | 3                |
| Electrical power consumption recorded | 1            |
| Infrared thermograph camera     | 1                |

The following six experiments were conducted (seven were planned but lack of time prevented completion);
1. Warm-up without wind to evaluate shelter thermal time constant.
2. Normal orientation (rear of shelter facing wind), preconditioned (structure already heated) and light wind (2.5ms⁻¹).
3. Normal orientation, preconditioned and medium wind (7.5ms⁻¹).
4. Normal orientation, preconditioned and heavy wind (12.5ms⁻¹).
5. Preconditioned and no wind.
6. 45° orientation, preconditioned and medium wind.

2. Experimental results
Temperature / time graphs for each test are shown in Figure 2.
Note that the heater achieves 75% of its maximum operating temperature within 28 minutes. However, it takes 77 minutes for the tent to reach its equilibrium air temperature of 26°C from a starting temperature of 4°C. This equates (assuming linearity) to 3.5 minutes for every degree of temperature rise.

It is difficult to gain and further meaningful indication of indoor comfort and microclimate variability from these charts. Therefore, Figure 3 describes vertical temperature variation. In the absence of wind, there is a 15°C temperature gradient from ankle to head height. Not only would this cause discomfort, but it also indicates that much of the heat is not useful. This is because, due to thermal stratification, much of the heat is retained at high level, which is beyond the occupied zone. This problem is less pronounced under windy conditions, because the wind-driven infiltration mixes the air quite effectively, such that the height of stratification has risen from approximately 0.9m to 1.3m. The temperature at floor level is 15.6±0.7°C.

**Figure 3** Vertical temperature gradients with and without wind

This vertical temperature gradient is exemplified by infrared thermograph images (Figure 4). Light colours represent warm surfaces.

**Figure 4a** i.r. thermograph – rear  
**Figure 4b** i.r. thermograph - front
The vertical temperature gradient can be clearly visualised in the image of the rear of the shelter. It is less noticeable at the front, largely because the image was erroneously recorded using a different, less sensitive, scale. Also because the heater is further away (it is just 0.9m from the rear end) and the 0.4m overlap causes a slightly improved thermal resistance. However, cold bridging due to compressed insulation in the vicinity of the corner support pipework is clearly discernible.

Due to a lack of time, none of the tests had reached full convergence (i.e., internal temperature profiles had not flattened). Regression analysis (based on the least squares fit of a quadratic equation) was used to predict the converged internal temperatures. With this information it was then possible to calculate conductance. Figure 5 shows the dependence of the shelter heat loss upon wind.

**Figure 5** The dependence of conductance upon ambient wind

![Figure 5](image.png)

Furthermore, with a knowledge of material thermal properties, it is possible to disaggregate this global thermal conductance into its constituent parts (Figure 6). It is noteworthy that, by normalising the results to account for difference in ground temperature (12°C in test chamber as compared to approx. 5°C in Kosovon winter climate), a further 0.54 kW of heat input is required to maintain the same internal temperature. Alternatively, for the same heat input, the mean internal air temperature falls by 8.4°C.

**Figure 6** Heat loss split for tested shelter (right) and normalised to represent winter ground conditions (left)

![Figure 6](image.png)
A useful extension of this analysis is to determine infiltration rates under different wind conditions (Figure 7). Although the infiltration rate increases by a factor of more than two from still to very windy (12.5 m/s) conditions, the gradient of this curve is particularly shallow. This indicates that the shelter is well sealed.

**Figure 7** The dependence of infiltration rate upon wind speed

![Graph showing the relationship between wind speed and infiltration rate.](image)

\[ y = 0.014x^2 + 0.093x + 2.682 \]

\[ R^2 = 0.997 \]

2.3 **Recommendations**

From this thermal analysis the following recommendations are offered, with a view to further improving the shelter’s thermal performance:

- The response time of the shelter is extremely long, when heated using a combined convective / radiant source. It is recommended that this type of heater be retained, but that during start-up this should be capable of outputting mostly convective heat.
- Much of the internally generated heat is lost through the poorly insulated floor and the ends. Floor heat loss can be minimised using a floating floor arrangement to preserve mechanical durability and end heat loss can be reduced by insulating the upper 600 mm. In this way a translucent bottom will provide a source of daylight.
- Infiltration losses should be minimised by diligently sealing joints between the various membranes during construction.
- Within the shelter, the efficacy of the heat source / shelter combination could be significantly improved by encouraging air mixing, to de-stabilise stratified air.

To assist with applying the results from this thermal analysis to other heater / shelter combinations refer to the procedures presented within the appendix.
Calculations
For the case in which floor heat loss has been normalised to account for approximate Kosovan winter ground temperatures, the following conductances were calculated.

<table>
<thead>
<tr>
<th>Heat loss element</th>
<th>Conductance (C), W/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric floor</td>
<td>20.19</td>
</tr>
<tr>
<td>Fabric wall/roof</td>
<td>7.00</td>
</tr>
<tr>
<td>Fabric edges</td>
<td>19.16</td>
</tr>
<tr>
<td>Infiltration</td>
<td>18.62</td>
</tr>
<tr>
<td>Total</td>
<td>64.97</td>
</tr>
</tbody>
</table>

For the case of no wind, the average internal temperature ($T_i$) was 25.6°C, the outdoor temperature ($T_o$) was –20°C and the average heater output ($Q$) was 2981W (after normalisation).

Average internal temperature can be predicted using the following equation:

$$T_i = T_o + \frac{Q}{C}$$

By re-arranging this equation, it would be possible to predict, for similar conductances, the heater output required to maintain a predefined internal air temperature:

$$Q = C(T_i + T_o)$$

Likewise, for a given heater output, the Conductance required to maintain a pre-set internal temperature can also be derived:

$$C = \frac{Q}{T_i - T_o}$$

In each case $C$ is the total conductance. The values in the table above can be substituted with, for fabric conductance, the product of the composite’s U-Value and Area. Infiltration is seldom possible to redefine. However, infiltration conductance can be calculated by multiplying the air exchange rate ($n$) by the volume ($V$) and a constant (1/3) to account for the thermal capacity of air.
Appendix 4b

Heating units used in Kosovo and at Ford’s DTC

2 electric radiant heaters (1.7kW) were placed inside the model steel heater box

the model steel heater and steel exhaust flue pipe

TIG welded Kosovan bread stoves  P. Manfield, Feb. 99
Appendix 5  
Communication with Cold Climate Specialist

Dear Peter,

I have had some time now to look at the project proposals for the winter shelter. It is certainly an interesting area and I am happy to be involved. There is little accurate information for temporary buildings as I have discovered with my conversations with the British Antarctic Survey. However I have looked through some of my occupational health/ hygiene information and hopefully found some useful information for you.

1a. At what stage does humidity become a problem for humans to breathe? I am assuming that each tented family will produce between 5/6kgs of vapour in each 24 hour period inside a tent volume 20m3 (13m2 floorplan).

The target humidity of buildings has often been stated as 50% with a range from 30 – 70%. Below 30% there is a significant drying action on the eyes (gritty sensations, corneal drying) and the skin (drying of the epidermis and subsequent irritant dermatitis). There is also impairment of the secretion of mucus in the respiratory passages and impairment of the function of the ciliated epithelium. This predisposes to a dry cough initially and an increased risk of infection.

The nose will humidify the inspired air to 100% saturation in virtually all circumstances as a normal physiological process. Therefore to have an atmosphere that is 100% saturated does not pose a problem in breathing. However in supersaturated conditions eg fog there may be some irritant effect of the larger droplets on the respiratory mucosa producing cough especially in the more susceptible – chronic airways disease or asthma.

At temperatures below 10°C there is little loss of heat via evaporation from the skin i.e. sweating therefor having a high resident humidity will not affect normal thermoregulation.

The quantity of water vapour in the air is not a linear relationship with regard to temperature. At lower temperatures there is proportionately less water in the atmosphere to equate to 100% saturation i.e.  
At 37°C 100% saturated air contains 0.044 kg of water / kg of air  
At 0°C 100% saturated air contains 0.004 kg of water / kg of air  
To convert the 9000 – 10000 litres of expired air produced at 37°C at 100% saturation per day into the weight of water produced equates to about 0.5kg per person. In lower temperatures it is obvious that the air cannot contain the same amount of water so that there will be precipitation against cooler surfaces.

In confined areas at low temperatures therefore for a little increase in vapour producing activities ie cooking will rapidly saturate the atmosphere.

1b. Can people withstand brief periods of extremely high humidity (eg during cooking periods)?

In short yes. See above.
1c. Are children and the elderly at a higher health risk and to what extent?

In general humidity has a small part in peoples perception of thermal comfort. High ambient humidity ie above 70% will contribute to precipitation of vapour in the immediate surroundings creating the damp conditions. Prolonged exposure to this level will encourage microbial growth on surfaces and increase for example fungal skin infections, ear infections and mild respiratory illness.

1d. What would be my 'target' humidity level?

It seems sensible to aim for the oft quoted value of 50% allowing the range of 30 – 70%.

2a. If we assume each occupant inside a shelter has a winter jacket and two blankets (in addition to a heat source at around 5kW, 50% radiative, 50% convective heat, plus floor wall and roofing insulation and assuming a reasonable calorific daily intake) what would be the minimum ambient temperature that people could survive at?

There is an ISO guide to the determination of thermal environment for comfort. It deals mainly however with moderate environments but has some useful background information. From most studies it seems that the achievable result is based on subjective personal ratings to thermal sensation. People will rate a particular environment from hot through warm etc to cool and then cold. A neutral rating would mean that people are satisfied with their immediate environment. In reality this would equate with about a >80% approval rating. The rating is dependent on factors such as:

- Metabolic rate – activity, food intake, ambient temp, age, gender
- Clothing
- Air temperature
- Mean radiant temperature
- Air velocity
- Air humidity

There is a useful chart in the ISO guide that correlates metabolic rate (in terms of output for a specific activity) and thermal rating of the clothing against the optimal operative temperature. If we make certain assumptions:

- that most people inside the shelter will be sedentary or light activity
- thermal rating of the clothing / blankets is moderate to good

then the optimal temperature would be 16 °C with a variation of + / - 4°C. This then is the ideal based on >80% acceptance, with no draughts or air velocity higher than 0.1m/s and a relative humidity of 50%. This is the suitable value for a UK workplace. Temperatures which are given for comfort in the UK workplace are approx 2°C higher in the US.

In a working model and from personal experience I think that a figure of 7 – 8 °C as the ambient temperature would be an acceptable minimum. This is based on reasonable practicalities:

- sufficient heater output and fuel
- insulative properties of the shelter
- adequate clothing / sleeping materials
- possible cold acclimatization in the displaced population already

In the confines of a shelter this temperature would readily increase with the effect of body heat / cooking etc. and fall with draughts / heat loss via the conduction, convection and radiation.
Anecdotally living in a snow cave where the ambient temperature is little above zero is certainly survivable but is not conducive to any other activity apart from lying in a sleeping bag. Thermal comfort is also dependent on factors other than that of an acceptable temperature or the minimum temperature:
- draughts through ill fitting joints (increasing dissatisfaction with decreasing temperature of the moving air – wind chill idea)
- local cooling or heating of parts of the body i.e. next to the door / window or heater
- high vertical temperature difference inside the tent (cold feet and warm head) this was particularly noticeable from my experience in the Antarctic. In the old huts there was daytime cold feet and those people who were in the top bunks were roasted by the warm air.

For the ventilation of the shelter and thermal comfort the figure often quoted for air velocity is less than 0.15m/s. This is basically a little more than still air and is probably compatible with the convective movement from body heat and any additional heating equipment.

2b. What would be the 'ideal' or 'target' temperature?

2c. Again, how much must I compensate for the young and the elderly?

The young especially infants have a high surface area to body ratio. This means that they have higher heat losses by the usual processes. They must have either higher rated insulative clothing or higher ambient temperature. Studies have shown that the bedroom temperature values are often around 14°C in European countries. However there is also a high degree of thermal stability for the infants across temperature ranges if there is adequate clothing / bedding.

For the elderly many studies have shown increased mortality with extreme conditions (outside temperatures below freezing). For men there was an increased risk of death from cardiac problems and for women an increase from respiratory and cerebrovascular causes.

People with chronic airways disease (bronchitis or asthma) have measurably lower lung function in colder weather leading to exacerbations of the condition or infections.

There also seems to be a higher metabolic demand in the elderly to maintain the normal core temperature in cold environments compared to a younger population.

Therefore it would be preferable to aim for the optimal shelter temperature of greater than 16°C for this group of people. A study from Finland showed average room temperatures for their elderly of 21°C.

I have read a study from the Polar Record (a journal on polar research) on a review of the design and use of field tent shelters. The team used a questionnaire to determine the occupants satisfaction of various parameters. However there was no actual measurement of any of the indices. The conclusions were
- that moisture build up was not too much of a problem
- air quality was good
- noise insulation was poor
- night temperature was too cool
- depression and other psychological problems (close confinement, lack of sleep, safety concerns, lack of privacy)
From my own experience of field camping in the polar regions the high moisture buildup from cooking is a problem and this was always done in the bell end of the tent to allow direct ventilation outside rather than in tent. Moisture build up from breathing was not immediately apparent during the day but readily so as a build up of frost on the tent inner in the morning and as damp sleeping bags. However there was no auxillary heating at all apart from the time spent during cooking and the tent temperatures would fall to -20°C. the frost was brushed off in the morning and emptied out of the tent to avoid it melting.

From all the literature I have read I think what is written above can only be taken as a guideline and that this can be revised while the shelters are actually being used in the appropriate settings – either with the questionnaires like many previous studies and / or the measurements you mentioned in your email.

I hope I have answered some of your questions here. Don’t hesitate to contact me if there are further areas that need expansion or explanation.

I am also keen to look at the shelters themselves and what is involved in the testing process if this is possible.

Best regards
Rory O’Connor