CLIMATE RESPONSIVE DESIGN TOOLS FOR EMERGENCY SHELTER.

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INTRODUCTION

This discussion paper outlines the tools presently available to site planners/civil engineers for the design of emergency shelter in refugee or IDP (conflict or natural disaster) situations. The paper is written as part of the response to the IASC Working Group: Report of Emergency Shelter Cluster November 2005. That report sought as one of three key elements to be addressed to improve the overall effective response of humanitarian assistance to: *"… develop (and build on existing) guidelines and tools for rapid participatory shelter assessments and interventions in different climatic and geographical conditions and different contexts, including ways of supporting communities for clearing and restoration of damaged shelter immediately after the crisis"*.

This paper concentrates on the tools and guide lines that are available for the different climatic and geographic conditions encountered in emergency shelter. It is written from the perspective of a site planner/civil engineer in the field and consequently has a "technical" bias. The intention of such a bias is to outline the relevant theoretical/ academic frame work so that emergency shelter can be more effective as required by the above IASC Working Group.

There is minimal existing guidance within the humanitarian literature on tools that address climatic and geographical conditions of emergency shelter. Neither the UNHCR Handbook nor the SPHERE guidelines address such issues. Yet such issues are central to the well being and health of such refugees and victims. Shelterproject.org (Professor Robin Spence et al) are perhaps the sole source of scientific data particularly related to tents. However, there remain large gaps in the knowledge base and one noticeable gap is the design and use of natural ventilation for shelters, settlements and camps. Here, what is done during the emergency phase is difficult to change in the later stages of shelter development.

Moreover, the overall emergency shelter response adopted also impacts on later recovery phases. For example "urban" densities if not controlled in the emergency will create issues of fire risk, social issues of privacy, drainage and issues with solid waste disposal. In addition, there can be other social issues related to welfare dependency that can be traced back to how assistance was provided including the provision of emergency shelter. Thus, there is a need to "get it right" at the start and hence the need to identify appropriate tools that are robust for an emergency situation yet sufficiently precise to avoid serious consequences in later phases of recovery and reconstruction.

The basic objective of any shelter besides the important psychological aspects of identity and place is to modify the existing climate. Yet again highlighting the need for specific robust climatic and geographical tools and hence this discussion paper.

As a refugee or disaster victim emergency shelter can be sought in various ways that includes one or more of the following:

- Shelter inside the damaged house.
- Shelter along side or as close as practicable to their damaged house in tents or temporary constructions.
- Shelter with relatives or friends that is nearby.
- Shelter with relatives or friends that is distant.

- Shelter inside requisitioned buildings (formal situation).
- Shelter inside vacant or public buildings (informal situation).
- Shelter in emergency centres provide by outside national or international agencies
- Shelter in emergency camp sites provided by the Government, the military and outside national or international agencies that are located in the area or region
- Shelter in emergency camp sites provided by the Government, the military and outside national or international agencies that are located outside the area or region (evacuation).

And the assumption in this paper is that the emergency shelter will largely be tents. This is probably more the case for refugee situations and wide spread flooding disasters but may necessarily be the case for earthquakes and cyclones and perhaps also tsunami based on what was seen in the recent tsunami in Aceh and Sri Lanka and before that in PNG. In these situations victims often elected to set up temporary shelters close to their original homes. Moreover, the paper also assumes that the disaster will be in the context of a developing country rather than a developed country.

Finally, the word “emergency” is often used but there remains no “measurable” definition for such a condition. As perhaps its first recommendation this paper would suggest that a situation is in a state of emergency till 80% of the affected or accessible population have emergency shelter. Agreement by aid Agencies on this issue would have meaningful impacts for victims, field operations, Governments and donors.

THE IMPORTANCE OF SHELTER

As mentioned above, the basic objective of any shelter is to modify the outside climate and if that is not achieved (and people live “rough”) will result in medical conditions that potentially can be fatal if exposure is prolonged.

For cold climates the table in annexe 1A shows the allowable exposure times for different temperatures for workers wearing suitable cold weather clothing. This shows that exposure times drop off dramatically when temperatures are below about -8^{O}C. In an emergency people are not always properly addressed, they could be exposed longer and this increasingly places them at risk. The second table in annexe 1A lists the increasing risks and under lines the need for shelter to retain heat.

For warm/ humid and arid climates there is a similar situation. Annexe 1B outlines the medical implications of different climates of elevated temperature and humidity. It shows that a temperature of 30^{O}C and 90% humidity to 40^{O}C and 50% humidity can lead to heat stroke that can be fatal. This is offset by breezes and hence the importance of shelter to expel heat and promote natural ventilation for further cooling of its occupants.

Hence, emergency shelter must be able to modify the ambient climate to achieve livable conditions for occupants. How this can be achieved using available guidelines and tools so that shelter with “dignity” is obtained is the subject of this discussion paper.

CLIMATE DATA

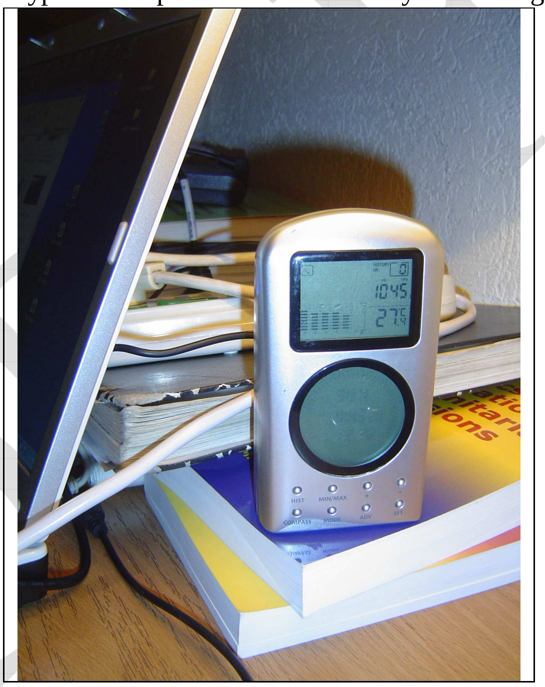
Climate data is the starting point for the tools and approaches listed below. The required data are often gathered just prior to an emergency deployment.

Documents such as the “Climates of the World” published by the Dept of Commerce USA give minimum and maximum temperatures for many cities through the world. It can be down loaded from www.ncdc.noaa.gov/climate/climatedata.html#clim . This site also has the facility to format and down load recent monthly averaged climate data for 1,600 stations outside of the USA. Thus, this is a good starting point.

Once on the ground data can also be sought from both the Public Works Departments and Government Meteorological offices. And failing that, data can be measured on site and also inferred from prevailing topographical conditions. Such data is usually not available for the precise site and when data is available from a nearby weather station (such as an airport or city) it usually requires mathematically modified for any differences in terrain, channeling, escarpments and cliffs. The required modification factors can be readily obtained from any structural loading code. Where the typology alters or modifies the climate in the area of proposed camp site such an approach of modified data from a distant station would not be appropriate and this approach should not be used.

Simple recording devices such as the digital temperature and humidity measuring device as shown in figure 1 below can be used. These give immediate readings and "validates" in an informal sense data collected earlier.

Figure 1: Typical Temperature and Humidity Measuring Device.



Temperature data are the easiest to obtain and can be extrapolate from "broad brush" temperature maps to obtain usable data. However, wind speeds (and particular wind direction data) remain problematic.

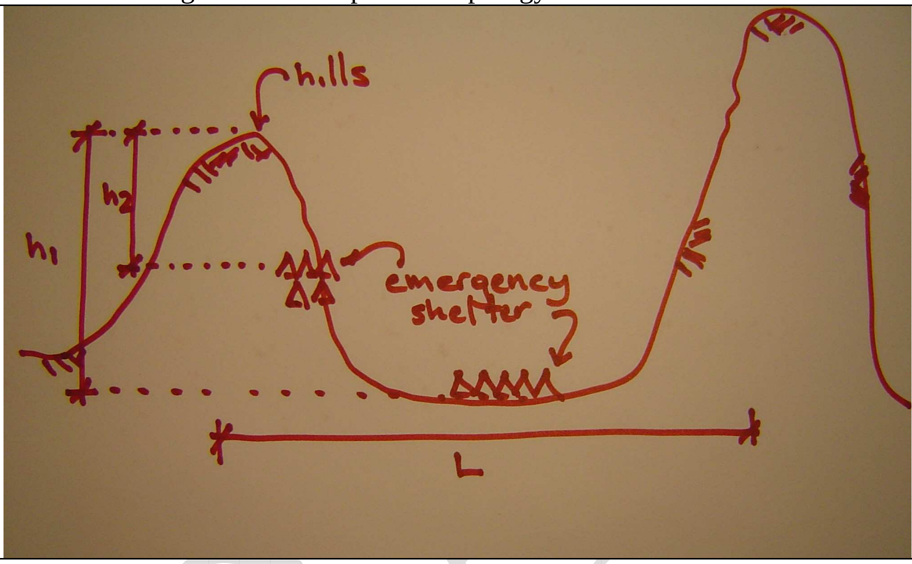
One approach is to estimate the higher wind speeds in the area by count the stones holding down roofs. This load of stones can be taken as equivalent to the wind loading generated by a 5 year return period gust and by using standard wind coefficients wind speeds can be quickly derived. Natural ventilation studies by Aynsley and Lee have shown that such wind speeds are 1.5 to 2 standard deviations above the average wind speeds for the area. Standard deviation data taken from the wind climate for the wider area can be used for this purpose.

Wind direction can be inferred from both the landscape and the topology of the local geography. For example, if the emergency shelter is located in a valley than provided:

$$h_1 > L/5$$

h_1, h_2 = the heights of the lower hills above the respective shelter site
L = distance between the hill tops forming the valley

Figure 2: The Impact of Topology on Wind Climate.



The wind direction will be predominantly along the valley. This is because the “shadowing effect of the hills forces any cross wind over the valley. If the emergency shelter is located on the side of the hills than h_1 is the height difference from that site on the side of the valley to the lower hills forming the valley.

If there are trees on the site than the Grigg Putnam Index can be used (refer to Annexe 2). This Index is commonly used in preliminary assessments of sites for wind farms. The index allows both an estimate wind direction and average wind speed for a site.

Lastly, local people can be surveyed as to what is the wind climate for the area.

But by this point the site planner should have a good sense of the climate that they are dealing with in the camp.

GEOGRAPHICAL AREAS AND BUILDING TYPOLOGIES
Geographical areas (and there associated climatic zones) can be used to classify different building topologies. Annexe 3 is an example of this and tabulates building topologies for different geographical areas that are characterised by latitude/ longitude, vegetation and cultivation found in tropical climates.

While interesting, the tables are not usually effective in the field. The existence of other “micro-climates” within an overall climatic category means that several different climate typologies can co-exist concurrently thus making it difficult to ascertain exactly which building typology is applicable. In addition, transition between the geographical areas further makes the application of such tables tenuous.

Nonetheless, they can be useful for “checking and validating” other data and assumptions used to develop a workable emergency shelter strategy intervention. Such checks are essential in an emergency where full information is not readily available, dis information apparently abounds and yet action is still expected.

RULES OF THUMB

What are perhaps more useful are the rules of thumb that have been developed for permanent shelter for different climate zones. Such rules are based on the minimising the heating of building given their thermal mass and are as follows:

Shape: The ratio of the dimensions of the building assuming a rectangular building:

- tropical zone 1:3
- arid zone 1:2
- temperate zone 1: 1.6
- cool zone 1:1

As buildings are located away from the equator (towards either pole) the form of the building moves from an elongated rectangle to a square building. This is in direct response to the change of solar angles at different latitudes and the consequent heat gain/ loss.

Orientation: The above forms need to be orientated to the sun to achieve the control of heat gains/ losses (depending on the heating requirement of the associated climate). The ideal solar axis would be as follows with the long axis aligned as follows:

- tropical zone On an axis 5^{O} north of East (north south orientation)
- arid zone On an axis 25^{O} north of east (south east orientation)
- temperate zone On an axis 18^{O} north of east (south south east orientation)
- cool zone On an axis facing south (facing south)

Layout: The layout of a house will also impact on its inhabitants. The location of “buffer” zones (or circulation such as hallways and corridors) constructed of thermal massive materials (such as mud brick) for thermal mass or insulation as required can be judicious planned as follows:

- tropical zone Buffer zones on the east and west sides of the building. This protects against a low sun but also creates a thermal buffer for those inside. Moreover, the placement of circulation in these areas means that occupants pass through the buffer zones briefly .
- arid zone Buffer zones on the east and west sides with usually only shading required for the summer.
- temperate zone Buffer zones on the north side with the provision for passive solar heat gains on the south side during winter
- cool zone Buffer zone all round with a concentration of thermal mass inside the middle of the building. Exterior wall would need to be perforated to maximise sun into the building.

Other guidance includes the following

- tropical zone Are the hardest climate types to live in. Humidity is high, so skin evaporation is limited, evaporative cooling (using fountains, ponds and water features) is not effective. Moreover, the diurnal temperatures are small so there is little cooling at night. Use natural ventilation and ensure the as much heat as possible is reflected away by using a reflective roof, venting the ceiling area and having a separate ceiling. High floor to roof heights can be used to aid ventilation and minimise radiated heat. Free standing houses are often elevated to again aid natural ventilation by stronger breezes and air flow across the bottom of the house as well. Vegetation can be used to funnel wind onto the house.
- arid zone Thermal mass very desirable due to the large diurnal temperature changes. Usually inwards looking house due to the need for protection from the hostile outside conditions of wind, dust and glare. Hence, court yards are often used. Evaporative cooling is also used such as fountains, ponds and water features. Building are usually “reflective” (typically white in colour). Building are often grouped (for shared shading) and people often occupy the insides during the day on the roof areas in the evening. Use of vegetation as a climate modifier can also be considered.
- temperate zone Similar to the cool zone but not as rigorous. Solar gains should be used where available with summer venting for any potential over heating (may require shading). Thermal mass is desirable. Use of vegetation as a climate modifier can also be considered.
- cool zone Reduce the ratio of surface area to volume, group building so they have “common” walls (and therefore greater insulation), insulate the building envelope, make windows relatively small in area with say shutters for minimising heat loss at night (rather than double glazing). The building should be sealed and air losses controlled particularly at doorways by say a double door system and vestibule.

These general rules of thumb are applicable to thermally massive structures and would not apply to tents. Nonetheless, they are listed here for instances where “rubble” and damaged houses maybe be used as an emergency shelter. Such basic information can be easily implemented at minimal or no cost.

BIO CLIMATIC CHARTS

A more effective tool than the geographic areas and the rules of thumb discussed above are bioclimatic charts (refer to Annexe 4). Such charts map passive design options against climate measurements conditions and in Annexe 4 this is against ambient temperature and relative humidity. Passive design is where “free” natural resources (such as wind) are utilised to achieve comfortable living conditions. And as such are critical in humanitarian situations. There are different charts and the one shown in Annexe 4 is more robust than other versions that require further climatic data.

The chart can be used in several ways and for shelter in an emergency are best used by plotting the 4 coordinates formed by the following:

- The maximum ambient (in the shade) temperature and minimum humidity
- The maximum ambient (in the shade) temperature and maximum humidity
- The minimum ambient (in the shade) temperature and minimum humidity
- The minimum ambient (in the shade) temperature and maximum humidity

The resulting outline area marked by these 4 points on the bio climatic chart indicates the typical passive structure/s and design/s that would be beneficial for occupants.

The above climatic data do not need to be precise and representative values can be obtained from the internet for nearby towns and cities. The conclusions should also be verified against local buildings.

The chart is particular useful in warm humid climates (by identifying the need for natural ventilation) and in arid climates (for identifying the need for thermal mass and night cooling). It should be noted that several strategies could be used for certain climatic conditions.

It should be noted that below 7^{O}C there are no passive options and a direct heating intervention will be required.

THERMAL COMFORT MODELS

Thermal comfort is a complex and contentious issue. The relationship between the objective measurement and the subjective response is not clear and remains at the centre of an ongoing thermal comfort debate. Field studies of free running or naturally ventilated buildings supported an “adaptive” rather than the “static” approach used to date for essentially “sealed “ buildings. People were “adapting” to their environment and for example MacFarlane had found as early as 1958 that Europeans in Singapore preferred temperatures that were some 2^{O}C warmer than those in Sydney (MacFarlane, 1958).

This has led various researchers to develop algorithms for adaptive comfort models and more recently with the work of Brager and deDear in 2000 has there been consensus on what should be the adaptive thermal comfort model and their mathematical model is as follows:

$$\text{Optimum Temperature} = 17.8 + 0.31\text{x } T_{a(out)}$$

Where $T_{a(out)}$ = the average temperature of the daily maximum and minimums for the previous month.

For emergency shelter their comfort model can be simply applied by taking the lowest and highest temperature and calculating the optimum temperature with $T_{a(out)}$ being the average of these two temperatures.

Such a thermal comfort model can be used in various applications. It can be used in both a warm/ humid and in cold climates. In cold climates it can be used to calculate the optimum temperature (and hence heating requirements) inside emergency shelter/tents. In warm climates it can be used to ascertain whether the wind at the site is sufficient to provide thermal comfort by natural ventilation. Thus, thermal comfort modeling is central to providing shelter with “dignity”.

For warm/ humid climates the MacFarlane criteria would also be required to adjust for the positive cooling effects of the wind and the detrimental impacts of higher humidity. These criteria are as follows:

- For each 10% increase in relative humidity above 60% the Optimum Temperature should be decreased by 0.8^{O}K.
- For each 0.15 m/s increase of air speed the Optimum Temperature should be increased by 0.55^{O}K for air temperatures up to 37^{O}C

Thermal comfort is then achieved for 80% of the population when the actual temperature is within ±2.5^{O}C of the Optimum Temperature modified as required by MacFarlane's criteria above.

NATURAL VENTILATION

Natural ventilation is caused by either wind induced pressures or by solar induced temperature differentials. Wind pressures are dominant and "wind on skin" has a beneficial cooling effect in warm/ humid climates and conversely a detrimental freezing effect in cold climates. Thus, natural ventilation is promoted in one climatic context but mitigated in others.

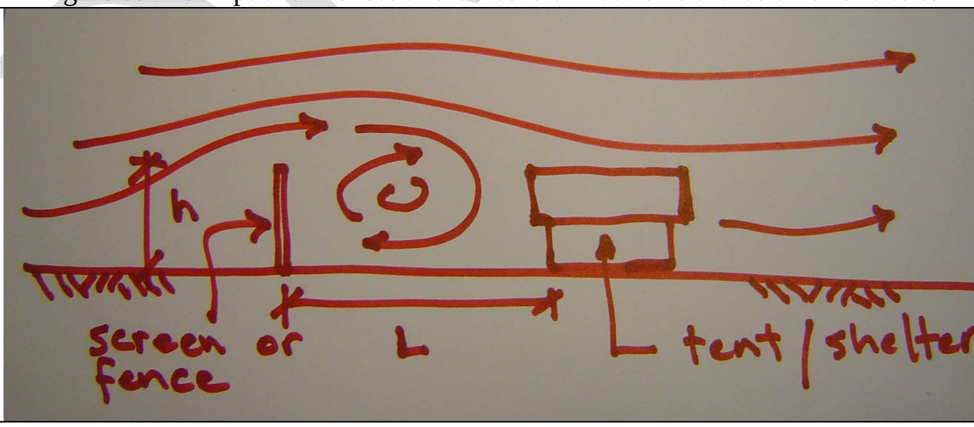
For emergency shelter located in warm humid or arid climates natural ventilation is one of the few options open to camp occupants to achieve thermal comfort with the main objective being to maximize the airflow through the tent or shelter. And the first requirement is to ascertain the wind speed and dominant wind direction and hence the earlier discussion on "Climate Data".

Consequently, in warm/ humid climates tents or vents in shelters should be within ±60^{O} (and preferably ±45^{O}) of the dominant wind direction. Tents are typical placed "along" the dominant wind direction to achieve maximum airflow (and consequently the best thermal comfort conditions for shelter occupants).

In cold climates, tents are typically placed "across" the dominant wind direction (outside the ±60^{O}). This will minimise wind chill effects for occupants inside the tent or shelter and also prevent winds blowing directly into the shelter or tent when doors are opened.

Screens and fences can be effective in both warm humid and colder climates. In warm climates the tent should be located away from the fence by at least 5 x the height of the screen or fence. This distance ensures that natural wind flows initially disturbed by the screen "re-attaches" to the ground thus re-establishing the cooling potential of natural ventilation. Where this is not spatially feasible wind catchers such as shades can be used to collect and channel wind down into the tent or shelter. And when the tent can not be placed along the wind small end walls can again be used to channel wind through the tent.

Figure 3: The Impact of Fences and Screens on natural Ventilation of Shelters.



In colder climates the tent or shelter should be preferably located within the 5 x the height of the screen zone thus offering some protection to the tent or shelter.

Interestingly, in both climates cooking could be located within that 5x height zone with a stack pipe venting smoke well up into the external airflow. (However, as discussed later it would need to be within 1.4x the height of the tent when sheltered by the tent rather than a screen or wall.)

The discussion thus far, has assumed a “cross ventilation approach” to natural ventilation that requires an opening on the windward and leeward sides or ends of the tent or shelter. The flow rate can be calculated based on the pressure differential as follows and is based on the British Standard for Natural Ventilation, BS5925:1991 (BS5925, 1991):

$$q = C_D \times A_W \times U_r \times \sqrt{(\Delta C_P)}$$

q = flow rate
C_D = discharge coefficient usually taken as 0.61
A_W = ratio of area of inlet to outlet openings
U_r = reference velocity usually to the top of the building.
ΔC_P = pressure differential.

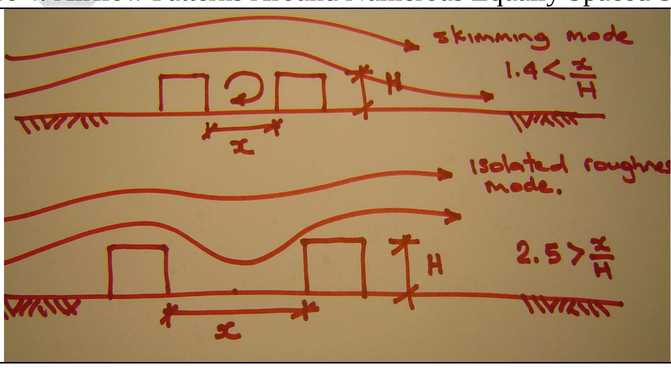
It should be noted that large increases in ΔC_P values (which are generated by the prevailing wind direction and the shape of the tent) produce relatively small increases in flow rate. For example an increase in ΔC_P from 0.1 to 1.0, a ratio of 10 produces only 3 times more wind through the tent. However, it is important to keep opening relatively the same in number and certainly in total areas on the wind ward and leeward sides.

The airflow around dispersed tents or buildings is quite different to the “infinite” or “semi-infinite” (in terms of their length to height ratio) screens or walls. Research by Lee and Soliman has shown that there are three flow patterns for separation gap between adjacent buildings. These are as follows:

- Isolated roughness: The two buildings are sufficiently far apart that the air flow reattaches to the ground between the two buildings.
- Wake Interference: As the separation between the buildings is reduced a “horse shoe vortex forms. The air flow pattern is maintains circulation in the building separation.
- Skimming mode: Finally the separation distance is sufficiently reduced that the air flow “skims” over the separation between the two buildings.

A sketch of the first and last flow patterns are shown in figure 4 below.

Figure 4: Airflow Patterns Around Numerous Equally Spaced Shelters.



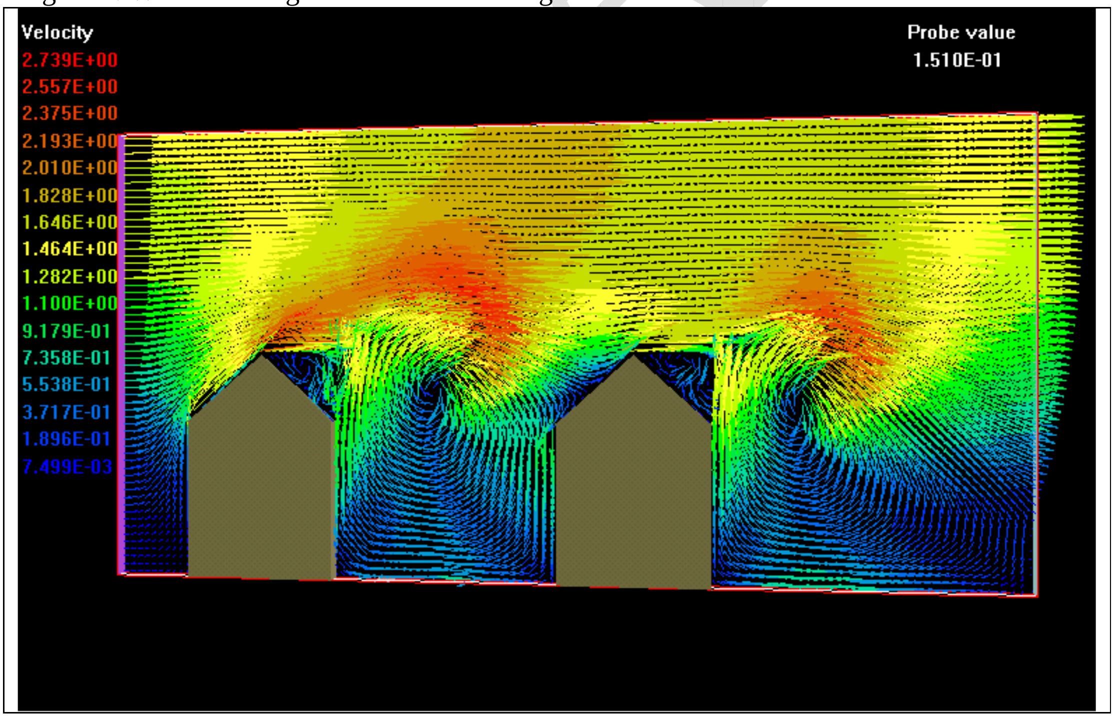
Their research showed that this skimming pattern occurs when the ratio of the building separation distance “x”, and the building height “H” is less than or equal to 1.4. In this instance the wind flow simply went over the top of the shelters and did not touch the ground in between. Between 1.4 and 2.5 they found a wake interference flow pattern and here the wind flow increasingly started to reach down into the gap between the shelters. At 2.5 an isolated roughness flow pattern developed and the wind flow finally re-attach to the ground between shelters producing similar wind conditions as up stream of the shelters. Mathematically this is represented below as:

$$1.4 < x/H < 2.5$$

x = the building separation distance
H = the building height

Consequently, the separation distance between tents or shelter should be at least 2.5x tent height or around 5 metres. Conversely, in cold climates it would suggest that tents should be closer than 1.4x tent height or around 2.80 metres? While this would place tents in an area out of the wind it could also be an area of “stale” air with little flushing from prevailing winds. Hence, in cold climates spacing tents ate between 1.4 to 2.5x tent height (approximately 3 to 5 metres) is desirable. A sense of this can be also seen from figure 5 from a computational fluid dynamic (CFD) mathematical simulation of air flow around and between buildings (in this case a school in Singapore). The velocity of the wind flow is represented by its colour with red being around 2.7 metres/second and dark blue around 0.0075 metres/second. Wind flows in between the buildings are small and are of the order of 1/300 of the main wind flow (and essentially zero) as would be expected for a x/H =1.00.

Figure 5: Wind Flushing out between Buildings.



Natural ventilation has been the only mechanism that has provided cooling to previous emergency shelter programs. Yet it remains essentially “uncharted”. More research is required to develop specific design guidelines for commonly used planning typologies such as the "U" shaped layout advocated by UNHCR.

THE HEATING OF TENTS

The heating requirements for tents (in cold climates) are based around the Heat Loss Equation which is as follows:

$$Q = UA(Tin-Tout),$$

Q= rate of heat loss
U= the U value or thermal transmittance. It is also the inverse of the thermal resistance
A= surface area of tent
Tin= Temperature inside the tent
Tout= temperature outside the tent.

Thus to reduce heat loss requires one or more of the following:

- Lowering of the U value (or conversely increasing the thermal resistance of the sides, roof and ends of the tent). This is achieved by better insulation and is discussed in practical details later in this paper.
- Minimizing the surface area of the tent. This not a real option given the practical constraints on tent dimensions.
- Rationalizing (and hence increasing) the outside design temperature. If tents are in frost areas than an outside temperature of $-2^{O}C$ would be appropriate. Moreover, if the presence of a nearby river means that temperatures would only reach say $0^{O}C$ than a lower heating loss would be achieved.
- Lowering the inside temperature. This should be set by the thermal comfort model discussed above.

These are now discussed in more detail.

INFILTRATION LOSSES FROM TENTS

The heat loss equation above assumes that the tent is air tight. This is not the case and the canvas material used for many tents is "porous" allowing hot air to leak out. This process is referred to as infiltration.

This loss increases when there is wind on the tent which creates areas of "suction" on the leeward side of the tent and positive inward pressures on the wind ward side. This results in air inside the tent being "sucked" out by these pressures in addition to the natural movement of hot air upwards (and outwards) from inside the tent. The actual extent of this increase depends on the orientation of the tent and the spacing between tents. The fly only marginally mitigates this loss and in many cases increases it by creating higher negative suction pressures between the fly and the inner tent. Plastic is significantly less permeable and the installation of "plastic sheeting" over the inner tent (as opposed to the fly) significantly reduces loss by infiltration.

In the field it is usual for the fly to be covered with plastic sheeting firstly because it is easier to install but primarily because it is perceived as reducing dampness inside the tent. The design concept of a fly covering an inner tent means that higher negative pressures are developed on the inner tent than if there were no fly at all. These pressures result in the inner tent making contact with the outer fly. And where this occurs water is transferred to the inner tent and thus inside the tent.

However, a plastic sheet installed between the fly and the inner tent (with the plastic hard as practical against the inner tent) would prevent this dampness while at the same time eliminating infiltration losses. Installation of the plastic sheet would only require the removal of the fly, then the positioning and edge sewing (using bagging twine and needles) of the plastic sheet to the inner tent and finally the reinstatement of the fly.

One significant advantage of this installation is that it will not require tent occupants to move out nor would any access (and hence disruption) inside of the tent be necessary.

Typical figures for infiltration (using a pressurized approach intended to simulate wind effects) are shown in table 1 below and are taken from a study by Spence, Ashmore and Manfield. Their liner was apparently on the inside of the tent and not on the outside as suggested in this paper. This difference should not be significant but could result in condensation if the thermal gradient through the tent is not adequately controlled. Nonetheless, table 1 below shows that the inclusion of the plastic sheet potentially reduces permeability by 50% in still conditions and by 25% in windy conditions. Looked at another way the figures also show that in still conditions most if not all the heated air in a typical tent will have dissipated within 30 minutes in still conditions and 10 minutes when there is a breeze. The temperature inside the tent would then be the same as the ambient (outside) temperature. In addition, if someone opens the flap of the tent to enter than these times will be shorter. These leakage times underline the permeability of canvas and the speed of cooling of a tent. Later tent designs are minimizing infiltration losses by adopting impermeable and water proof polyester fabrics.

Table 1: Comparative Infiltration Rates.

	Air permeability at 50Pa ($m^3/hr/m^2$)	Air permeability at 5Pa ($m^3/hr/m^2$)
Damp canvas	45.6	9.56
Dry canvas	41.4	13.4
Liner, dry canvas	32.6	7.01

*from University of Cambridge, dept. of Architecture, 6 Chaucer Road, Cambridge, CB2 2EB Comparative European Field Testing Of Differing Strategies For Insulating Tents

INSULATION OF TENTS

Canvass, as well as being permeable, is also not a good insulating material. This means that heat inside the tent is quickly dissipated by conduction through the fabric to the outside. And its thermal conductivity is so high (or conversely its insulation resistance value (R) is so low) that heat inside the tent is quickly dissipated to the outside colder temperatures. Table 2 below gives typical thermal conductivity values for different materials. A higher value indicates that the material conducts heat away faster and hence canvas at 27 is only half that of steel at 50 and thus is conductive. On the other hand plastic with a value between 0.04 to 0.05 is more than 50 times less conductive than canvas. However, canvas is typically thicker than plastic sheeting but a 250 thick micron plastic (which is thin) would be equivalent to12 mm thick canvas. Interestingly, diamonds are one of the most conductive materials available.

But perhaps the most significant value from table 2 is that air (in the form of an air gap) has one of the lowest thermal conductivity values and therefore is an excellent inexpensive insulating material. And when combined with plastic sheeting provides a cost effective, logistically light solution to tent insulation.

Table 2: Conductance Values for the Tent Roof.

Material	Thermal Conductivity w/m^{O}C
Diamonds	1,000-2,600
Steel	50
Canvas	27
Ice	1.6
Wood	0.4-1.2
Plastic sheeting	0.04-0.05
Fibre glass insulation	0.04
Polystyrene	0.03
Air	0.026
Styrofoam	0.01

The effectiveness of different insulating options is best compared using an EXCEL spreadsheet based around the heat loss equation above using calculated "U" values for each option. The U value is the summation of the complete system rather than just one material and typical options for say possibly upgrading a non winterized tent could be as tabulated in table 3 below. Note that some of these options achieve better insulation values than the winterized tent. However, the canvas options in table 3 below consider only the roof area with the tent in a tent approach also including the side and back walls. They do not involve the front wall (but could) and for a complete comparison one should refer to table 4 below.

Table 3: Conductance Values for the Tent Roof.

Material	Conductive "U" Value (^{O}C /m^2/w)
Standard non winterize tent (consisting of a canvas fly and inner tent)	4.3
Canvas fly and inner tent + plastic sheet + inner cloth type liner.	1.8 – 2.7(37-58% improvement)
Canvas fly and inner tent + plastic sheet + sewing edge for air gap.	1.3- 1.8 (58-70% improvement)
"Tent within a tent" approach	1.3- 1.8 (58-70% improvement) but also includes the end walls.
UNHCR Winterised tent	1.6 but note that this is over roof and walls of the tent.

One "popular" option is to line the inside of the tent roof with another "cloth" type material. This approach is often suggested with the idea of using blankets attached to the inside of the tent. Such an approach relies solely on the insulation properties of the blanket and does not exploit the potential offered by "air" gaps as discussed earlier. Lowering the head room across the tent would partly provide such an air gap but would hamper movement inside the tent and make living in the tent impractical. However, it does potentially result in a 37% to 58% reduction of heat conduction from inside the tent. It should be noted that a cloth fabric is preferably inside the tent rather than a plastic sheet because of the potential for condensation forming on the plastic sheet and dripping directly onto tent occupants.

Another variation of this approach could be adding plastic sheeting to the outside fly from its bottom edge to the ground and to the ends of the fly and with the bottom edge buried in the soil directly around the tent would in effect create a “tent within a tent” approach. This has the advantage of not impacting on the inside area of the tent while at the same time reducing its U value by 58-70%.

There are many options encountered in the field and the setting up of the heat loss equation as an EXCEL spreadsheet provides a comparative test bench for different options

HEATING

Moreover, such a tool allows calculation of the required heating as the first step to comparing and accepting suitable heaters/ stoves. This approach also checks the many “pet” theories of how to keep warm and whether heating is required at all? Examples of such pet theories include that you can keep warm with one candle, that painting your tent in kerosene water proofs it and that people are tough and don’t require heating anyway.

For example, the heating requirement for the standard 4x3 non winterized UNHCR subjected to an outside temperature of -2^{O}C (frost conditions outside) while maintaining an inside temperature of 16^{O}C (based on the thermal comfort model discussed earlier) requires 4.2 kW of heat. This represents two large domestic electric heaters at maximum output. Further more, if the suggested alterations for infiltration and insulation are completed on the standard non winterized tent the heating requirement drops from the 4.2 kW mentioned above to 2.4 kW and still further down to 1.7 kW for the “tent in a tent” approach. Allowing 0.1 kW for each of 5 people typically in a tent means that the required heating loads are around 1.9kW and 1.2 kW respectively. And this will need to be provided by some form of heating in the tent. These figures are tabulated below in table 4.

Table 4: Heating Requirements Inside the Different “Tent” Options.

Material	Calculated Heating (watts)	Heating Provided by People (watts)	Required Supplementary Heating. (watts)
Standard non winterized UNHCR tent (consisting of a canvas fly and inner tent)	4,178	500	3,678
Canvas fly and inner tent + plastic sheet + inner cloth type liner.	2,826	500	2,326
Canvas fly and inner tent + plastic sheet + sewing edge for air gap.	2,430	500	1,930
“Tent within a tent” approach	1,724	500	1,224
UNHCR Winterised tent	1,581	500	1,081

From this point a discussion of exactly how this heating will be provided can be initiated.

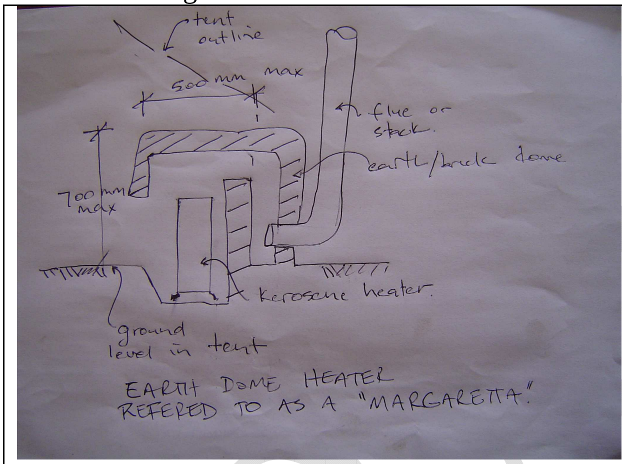
FIRE SAFETY

One critical issue with providing heating in tents has been the risk of fire. Previous experience of site planning teams in Kuram Agency in NWFP during 2001-2001 with kerosene heaters/ stoves indicated a risk factor of around 0.1 deaths/10,000 people/day due to tent fires. Initially there were issues of faulty soldering of kerosene tanks and once these were resolved this risk was much lower. However problems did persist and the main causes of tent fires were the following:

- Stability of the stove (with a pot of water on top)
- Problems encountered during refilling the kerosene tank.
- Accidentally knocking the stove/heater while people are asleep in the tent..

The construction of what has been termed a “Margaretta” has been suggested as one way to reduce the risk of fire inside the tents while at the same time increase the thermal efficiency of the heaters inside the tents. It would also include a damped flue arrangement that would prevent heat escaping up the stack while still providing adequate ventilation. This was sketched up and several were constructed as prototypes. It is interesting to note that vernacular versions of this are also used by local people in their homes (refer to figure 6 below).

Figure 6: The “Margaretta” for Fire Safety and Thermal Efficiency Inside Tents and the “Local” Version of the “Margaretta”.



It consists of a mud brick surround in which the kerosene stove/heater would be placed. As such it would not be able to be knocked over in a crowded tent. In addition the thick 150mm surround would store heat and release it back in to the tent. The provision of the wall section at the back of the heater would further radiate heat back into the tent and the provision of the stack pipe behind (and at a lower level) would provide ventilation for soot and kerosene fumes.

This could also be considered as part of a skills or vocation initiative within the camp

DIGGING DOWN INSIDE THE TENT.

The option of digging down inside the tent has several heating and comfort advantages which could be enjoyed in either a warm/ humid or arid climate as well as colder climates.

The ground 300 mm below ground level has a smaller diurnal (the difference between nigh and day) temperature change of around 2.5^{O}C as compared to 12-14^{O}C experienced at ground level in cold climates. The research literature also suggests that ground temperatures at this depth would be of the order of 20^{O}C in warmer climates and around 10-12^{O}C in colder climates. Consequently, digging down is cooler in warm climates and warmer in cold climates and thus does increase/ reduce the heat loss through the floor of the tent depending on the respective climate. The construction sequence for this as used by Afghan refugees is shown in annexe 5A.

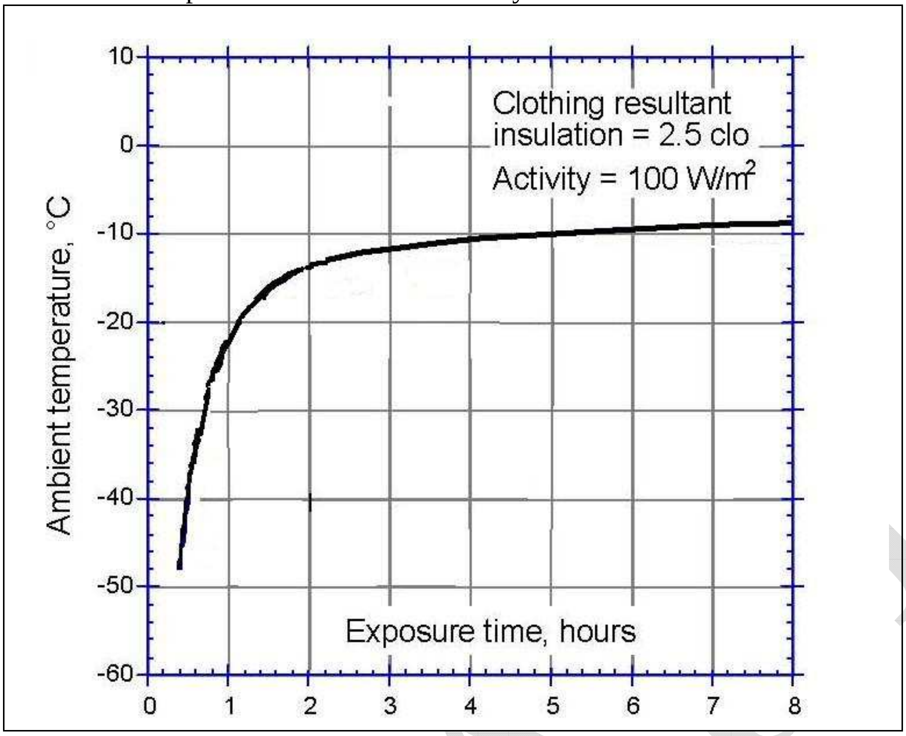
The presence of moisture reduces this benefit slightly but not significantly (refer to annexe 5B for comparative figures). And where there is a high water table digging down would not be feasible. However, it the site has such a high water table than the camp would have significant problems with latrines, washrooms and water not to mention drainage. It would suggest that the site is not suitable for a camp in the first place. Similarly, rocks also reduce the benefits gained by digging down but not significantly. Rocks should be removed from the dug down floor for thermal as well as walking comfort and where there are too many rocks digging down will not be practicable. The approach as outlines in annexe 5A includes other benefits such as the following:

- Tent occupants are lower and out of any wind
- The mud can be used to build up walls along the sides and ends of the tent
- Fire proofing of any heater or stove is easier through mud walls than canvas tent sides.
- Mud walls retain heater better than canvas tents.

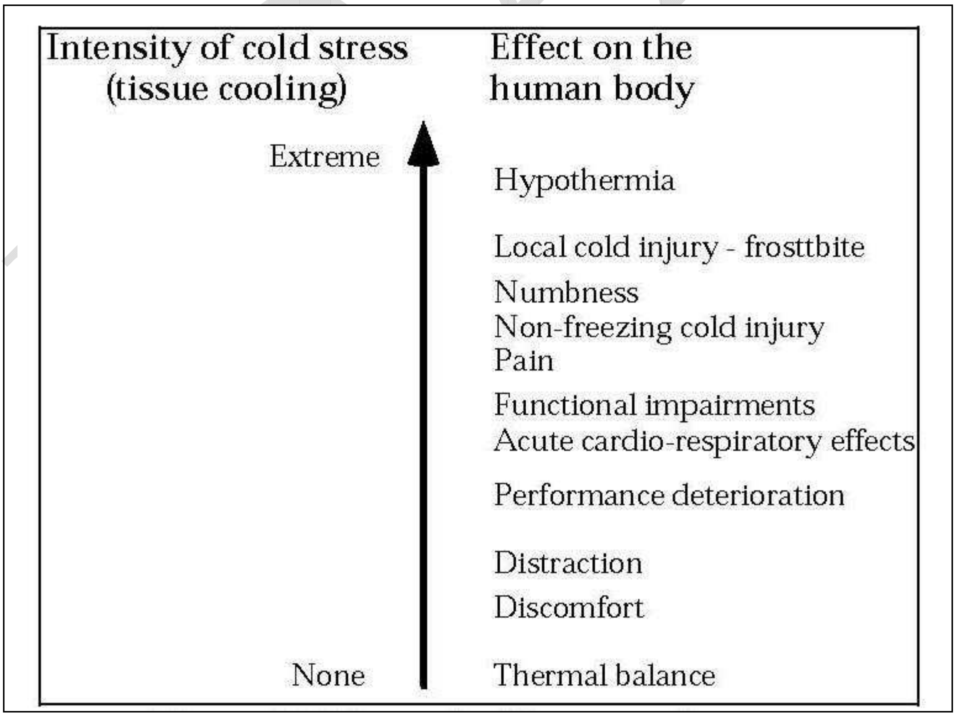
RECOMMENDATIONS
This discussion paper would recommend the following:

- The definition of an emergency should be up till when 80% of those affected and accessible to aid have been given assistance.
- The link between emergency shelter and comfort should be explored so that better "exposure" guidelines other than the work place charts that are presently available.
- A register of climate data for areas of concern should be maintained as an accessible web site.
- A guide on the use of natural ventilation in emergency shelter and site planning should be actioned. This could be connected with further CFD research related to the air flow through typical camp typologies such as the UNHCR "U" shaped layout.
- Data bases for thermal resistance values (and other thermal data such as clo values) should be set up again as an accessible web site.
- In addition, a spreadsheet version of the heat loss equation should be formulated and made available.
- Skill sets and competences covered in this report should become part of the Site Planning training provided by different agencies. This should include more "hands" on learning modules and using some of the heaters/stoves that we supply to our beneficiaries.

Annexe 1A: The Importance of Shelter to Modify Climate in Cold Climates



*adapted from Evaluation of Thermal Stress in Cold Regions -a Strain Assessment Strategy, I. Holmér, Problems with cold work Proceedings from an international symposium held in Stockholm, Sweden, Grand Hôtel Saltsjöbaden, November 16–20, 1997 pp34.



*adapted from Evaluation of Thermal Stress in Cold Regions -a Strain Assessment Strategy, I. Holmér, Problems with cold work Proceedings from an international symposium held in Stockholm, Sweden, Grand Hôtel Saltsjöbaden, November 16–20, 1997 pp32.

Annexe 1B: The Importance of Shelter to Modify Climate in Warm/ Humid and Arid Climates

From the National Weather Service

General Heat Stress Index

Danger Category	Apparent Temp. (°F) (Humiture)	Heat Syndrome
IV. Extreme Danger	**>130°**	**Heatstroke or sunstroke imminent**
III. Danger	105°-130°	Sunstroke, heat cramps, or heat exhaustion likely. Heatstroke possible with prolonged exposure and physical activity
II. Extreme Caution	90°-105°	Sunstroke, heat cramps, or heat exhaustion possible with prolonged exposure and physical activity.
I. Caution	80°-90°	Fatigue possible with prolonged exposure and physical activity

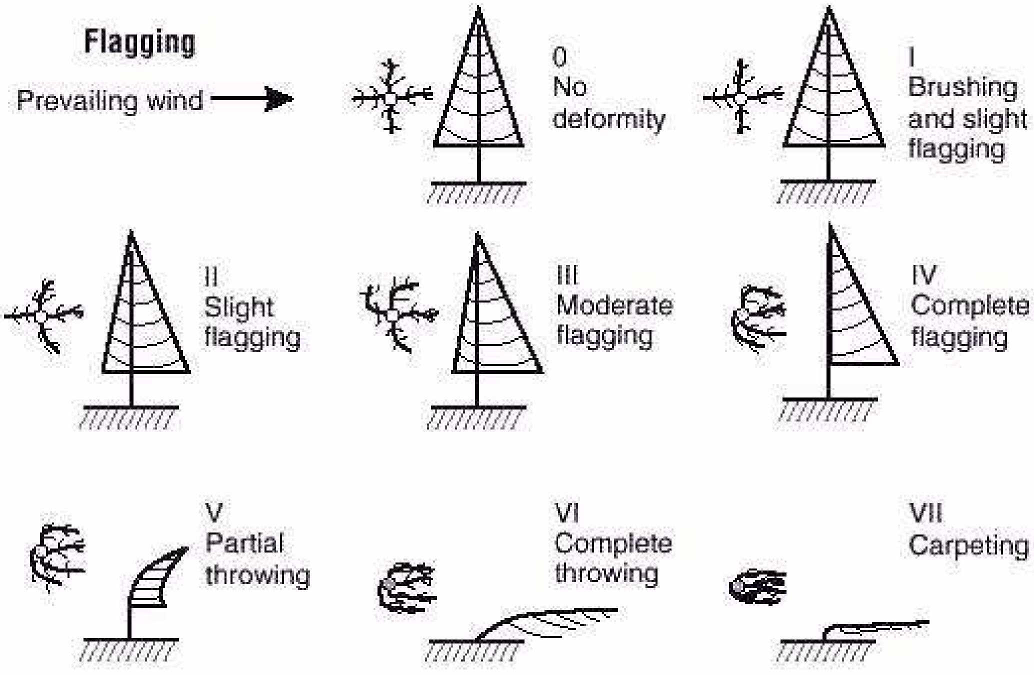
***Note: Degree of heat stress may vary with age, health, and body characteristics**

		Relative Humidity								
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
Temp °F	**104**	98	104	110	120	>130	>130	>130	>130	>130
	102	97	101	108	117	125	>130	>130	>130	>130
	100	95	99	105	110	120	>130	>130	>130	>130
	98	93	97	101	106	110	125	>130	>130	>130
	96	91	95	98	104	108	120	128	>130	>130
	94	89	93	95	100	105	111	122	128	>130
	92	87	90	92	96	100	106	115	122	128
	90	85	88	90	92	96	100	106	114	122
	88	82	86	87	89	93	95	100	106	115
	86	80	84	85	87	90	92	96	100	109
	84	78	81	83	85	86	89	91	95	99
	82	77	79	80	81	84	86	89	91	95
	80	75	77	78	79	81	83	85	86	89
	78	72	75	77	78	79	80	81	83	85
	76	70	72	75	76	77	77	77	78	79
	74	68	70	73	74	75	75	75	76	77

Example: The temperature stands at 94°F and the RH is now 62%. The heat stress temperature is over 111°F, in the **Danger** area

*from MSU Employee Guidelines For Working In Hot Environments, The Office of Radiation, Chemical and Biological Safety May, 1999 pp6.

Annexe 2: Griggs Putnam Estimate for Wind Speed and Direction.



Griggs-Putnam Index of Deformity

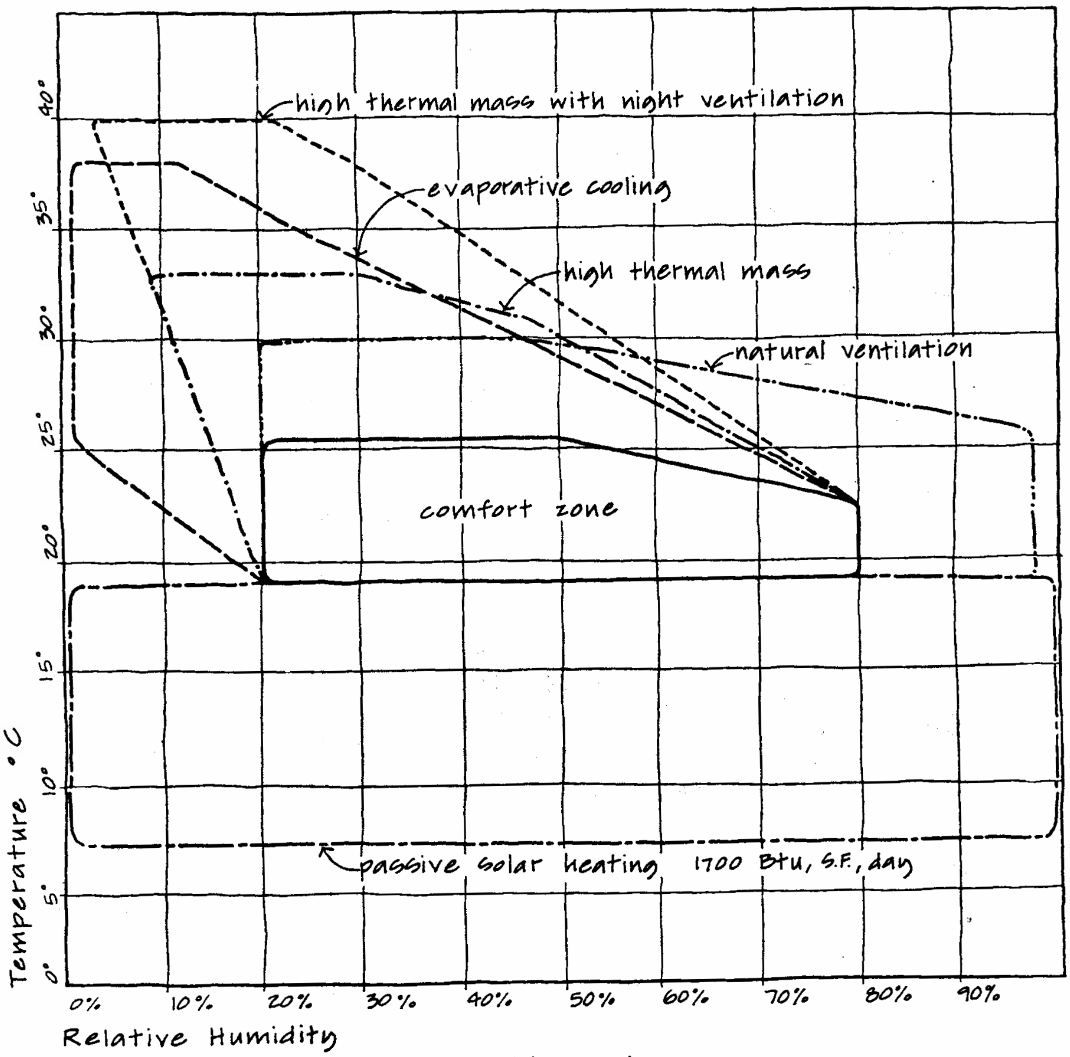
Index	I	II	III	IV	V	VI	VII
Wind, mph	7-9	9-11	11-13	13-16	15-18	16-21	22+
Speed, m/s	3-4	4-5	5-6	6-7	7-8	8-9	10

Annexe 3: Occurrence and Characteristics of Main Climatic Zones in the Tropics.

Zone	Approx. Lat. Range	Natural Vegetation	Typical Cultivation	Climate	Problems	Requirements
Warm Humid Equatorial	7.5^{O}N- 7.5^{O}S	Tropical Rain Forest	Banana, Palm Oil	Warm with high humidity and rainfall.	Humidity prevents sweat evaporation, hot nights makes sleep difficult, high rainfall and glare from other cast sky, sun on east and west facades	Air movement from the fans or cross ventilation, low thermal capacity construction, sloping roofs and large overhangs, windows facing north and south.
Tropical Island	$5\text{-}30^{O}$N $5\text{-}30^{O}$S	Rain Forest	Sugar Cane	Warm, humid but less cloud than warm humid zone	Similar to warm humid equatorial, but clear skies and bright sun more frequently	Similar to warm humid but with additional care in the design of shading the south facing windows (vice versa in the southern)
Hot dry Tropical	$15\text{-}32^{O}$N $15\text{-}32^{O}$S	Desert, Steppe	Palms, Grazing (nomadic)	Hot and dry with high annual and daily variation of temperature	High diurnal range, very hot days in summer, cool winter days, low rainfall, very strong solar radiation and ground glare, sandy and dusty environment	High heat capacity construction, shading devices which allow solar heating in winter, small windows, flat roofs (often used for sleeping), small courtyards to give shade and protection.
Maritime Desert	$15\text{-}30^{O}$N $15\text{-}30^{O}$S	Desert	Palms, Grazing	Hot, humid with low rainfall	Similar to hot dry climates but with higher humidity causing discomfort by preventing sweat evaporation	Similar to hot dry but air movement is desirable at times.
Intermediate composite or Monsoon	$5\text{-}20^{O}$N $5\text{-}20^{O}$S	Monsoon Forest, Dry Tropical Forest	Paddy Rice, cane, Millet	Warm humid and hot dry seasons	Combines the problems of warm humid and hot dry climates	Compromise between the requirements of warm humid and hot dry climates or ideally (but more expensively) two buildings or parts of buildings for use at different times of the year
Equatorial Upland	10^{O}N- 10^{O}S	Broadleaf Forest, Mountain Vegetation	Millet	Temperate to cool depending on the altitude	Combines the problems of the warm humid and hot dry climates with those of a temperate or cold climate for all or part of the year	Designed to take advantage of solar radiation when cool or cold. Heating and additional installation maybe required
Tropical Upland	$10\text{-}30^{O}$N $10\text{-}30^{O}$S	Steppe, Cedars	Wheat	Hot summers, cold winters	As above	As above
Mediterranean	$32\text{-}45^{O}$N $32\text{-}45^{O}$S	Mediterranean Scrub	Vines, Olives, Citrus Fruits	Hot dry summers, cool wet winters.	Summers have some of the problems of a hot dry climate while winters are cold and humid with moderate rainfall.	Design with high thermal capacity, medium to small openings, and courtyards to give shade and protection.

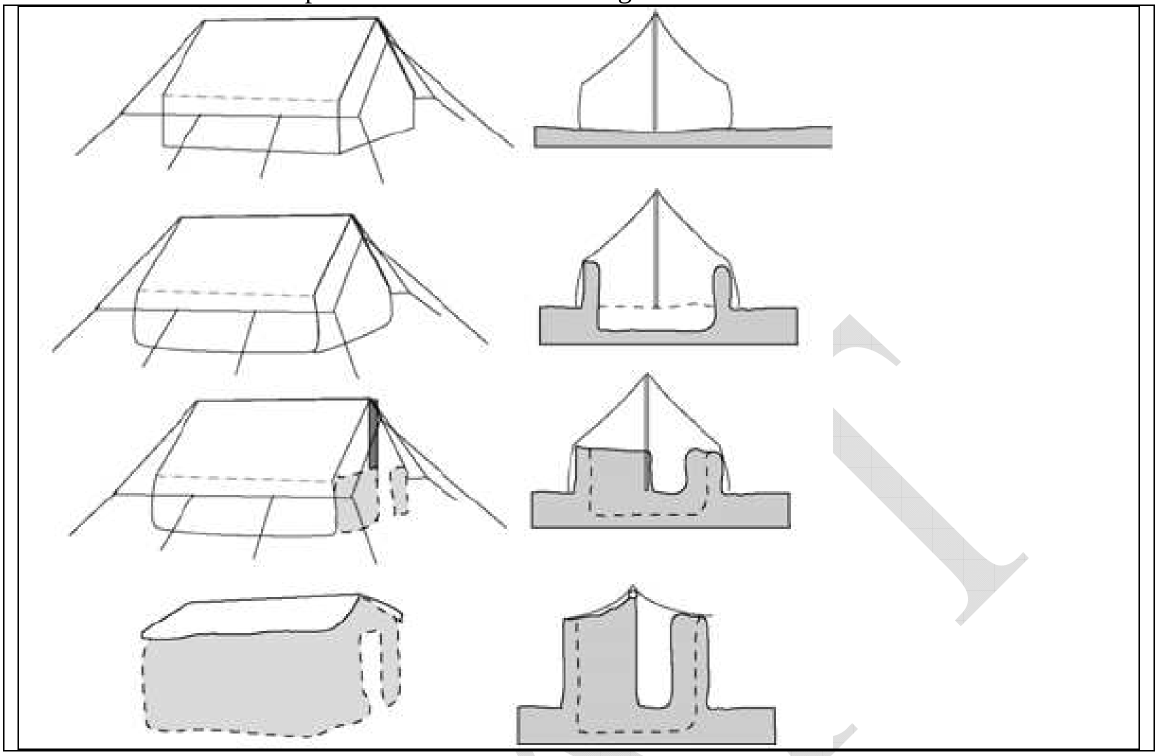
*From Adler D, 1999, 2. Metric Handbook: Planning and Design Ed Adler D pub. Oxford Press pp 37-1

Annexe 4: Bio Climatic Chart



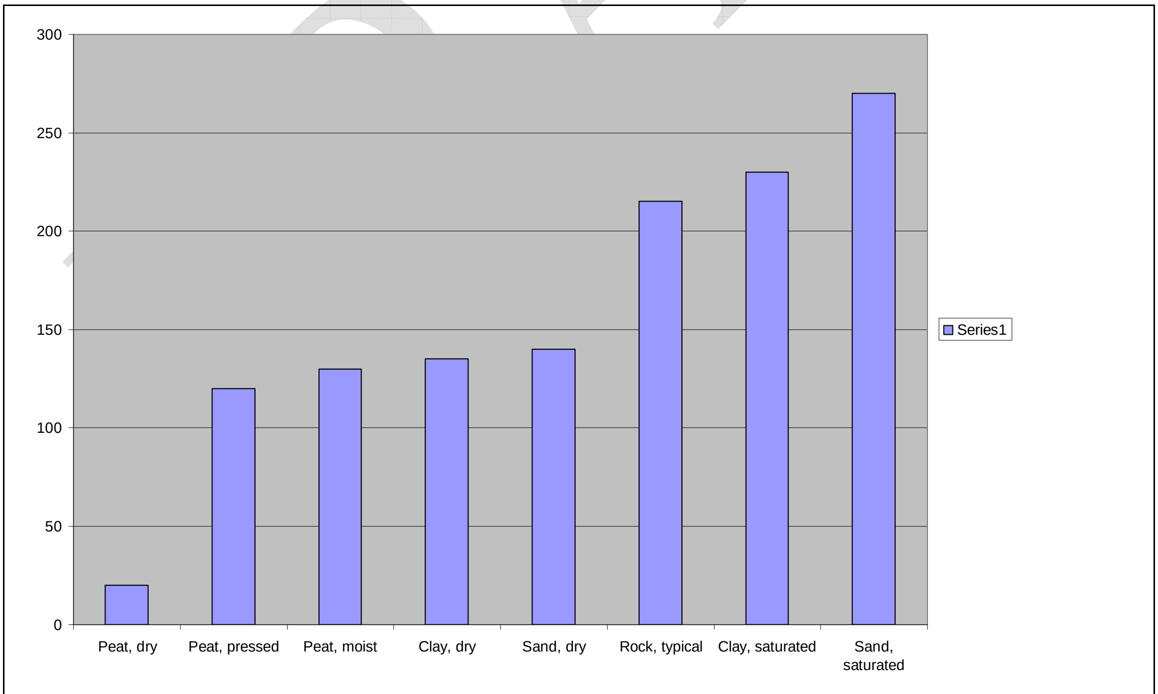
Bioclimatic Chart with Design Strategies

Annexe 5A: The Development of an Adobe Building from a Tent



*from Overview of shelter in 6 refugee camps in Herat Province, Afghanistan, march 2002 Shelterproject.org

Annexe 5B: Ground Heat Fluxes



*adapted from Comparative European Field-Testing of Differing Strategies for Insulating Tents Spence R, Ashmore J, Manfield P, Baker N, Battilana R, Cochrane R, Corselis T, Crawford K, Grisaffi C, Youlten Y Clarke S, Shelterproject.