Design Information Review Summary

		All		Loh Kat		Concrete blocks		Fired Brick		Adobe with fired brick		Adobe/layered mud	
		No	%	No	%	No	%	No	%	No	%	No	%
Completeness	Is the drawing set complete? (Does it include a dimensioned and annotated foundation plan, floor plan, roof plan, sections, elevations, and details? Alternatively 3D drawings containing the same level of information?)	1	10%	0	0%	0	0%	1	33%	0	0%	0	0%
Material	Are materials stated?	8	80%	2	67%	1	100%	2	67%	2	100%	1	100%
	Are material strengths stated?	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Detailing	Has the ring beam been drawn?	6	60%	3	100%	1	100%	1	33%	0	0%	1	100%
	Has the ring beam been drawn? (excluding Loh Kat)	3	43%			1	100%	1	33%	0	0%	1	100%
	Is the ring beam buildable? (Is all of it shown, does it include all dimensions, corner connections, connections from the wall to the ring beam and from the ring beam to the roof and is the material defined?) (excluding Loh Kat)	1	14%			0	0%	0	0%	0	0%	1	100%
	Have lintels been drawn? (excluding Loh Kat)	3	43%			0	0%	1	33%	1	50%	1	100%
	Are the lintels buildable? (Are they dimensioned, is the extension into the wall dimensioned, and is the material defined?) (excluding Loh Kat)	0	0%			0	0%	0	0%	0	0%	0	0%
	Is there a brick bond shown? (for masonry shelters)	1	14%			0	0%	1	33%	0	0%	0	0%
	Is a corner connection shown? (the brick bond around the corner for masonry shelters, the connection of members at the corner for Loh Kat shelters)	1	14%	1	33%	0	0%	0	0%	0	0%	0	0%
	Is a roof to wall connection shown on drawings?	3	30%	2	67%	0	0%	0	0%	0	0%	1	100%
	Is the roof to wall connection buildable from drawings?	2	20%	1	33%	0	0%	0	0%	0	0%	1	100%
	Are there connections between roof (and wall and base in the case of Loh-Kat) members?	1	10%	1	33%	0	0%	0	0%	0	0%	0	0%
	Is the connection between the roof (and wall and base in the case of Loh-Kat) members buildable?	1	10%	1	33%	0	0%	0	0%	0	0%	0	0%
	Is there some level of redundancy in the shelter? (Secondary load paths, ring beams)	7	70%	3	100%	1	100%	1	33%	1	50%	1	100%
DRR	Does the shelter have an elevated ground?	5	50%	2	67%	0	0%	1	33%	1	50%	1	100%
	Does the shelter have a raised floor?	5	50%	1	33%	0	0%	2	67%	1	50%	1	100%
	Does the shelters roof allow drainage?	8	80%	3	100%	1	100%	2	67%	1	50%	1	100%
	Does the shelters base allow drainage?	3	30%	1	33%	0	0%	0	0%	1	50%	1	100%
	Does the shelter have a roof overhang? (And is it dimensioned?)	6	60%	2	67%	1	100%	0	0%	1	50%	1	100%
	Is there reference to the previous flood level?	2	20%	1	33%	0	0%	0	0%	1	50%	0	0%
Total		67	34%	24	50%	5	25%	12	20%	10	25%	12	60%

International Organisation for Migration

Phase II – Research for Improved Shelter Responding to Floods in Pakistan

Thermal and Air Quality Analysis

REP/246089/TAQ001

Draft 1 | 3 February 2017

Job number 246089-00

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Contents

1 Introduction

The aim of this study is to interpret the thermal comfort and air quality survey data taken from shelters in Pakistan in 2016. This information should provide an understanding of the current performance of the shelters with respect to thermal comfort and air quality.

Through a combination of this survey data and analysis models this performance can be explored and design improvements can be tested and recommended. The following note outlines the inputs, methodology and intended outcomes for analysis of

- thermal comfort
- ventilation
- air quality

All three criteria can be considered within the same set of simple dynamic thermal analysis. Therefore the inputs and results are the same data set interpreted in different ways to align to the different criteria which are interlinked.

2 Methodology

- The following methodology was used in this study.
- Interpretation and investigation of survey data. This should be used to understand how well shelters are currently performing. Remove any outlying or erroneous data that might swing the result or alter conclusions.
- Understanding of weather file against external survey data
- Development of a typical shelter geometry (H x W x D), door size and ventilation opening size.
- Analyse typical shelter against survey results, tweak settings to achieve closer fit to data, this should create a baseline 'typical' shelter design.
- Consider design options to improve on baseline.

2.1 Definitions of variables

Dry bulb Temperature or "Air Temperature" is the ambient temperature of the air shielded from radiation and moisture and in this report will be given in degrees Celcuis (°C) however can be measured in Fahrenheit (°F) or the SI unit Kelvin (K).

Operative temperature (previously known as resultant temperature or dry resultant temperature) is a simple measure of thermal comfort derived from air temperature, mean radiant temperature and air speed. The equation for this is given below. This variable can be calculated within the analysis models undertaken in this study however due to the limited survey data this cannot be calculated for the survey data.

Relative humidity is a ratio (written as a percentage) of the amount of moisture contained within the air for a given temperature compared to the amount that would be present if the air was fully saturated at the same temperature (100% RH, also known as the dew point). Relative humidity is a function of both the moisture content and temperature, with the saturation point varying with temperature (warmer air can contain more moisture before saturation than cooler air).

3 Key Criteria

Acceptability	**Comfort**	**Thermal Comfort**	The shelter provides adequate protection from extremes of temperature.	Number of hours/ day the internal space is over a certain operative (average radiant and air) temperature difference from the external temperature.	The baseline operative temperature will need to be established - this may vary depending on location due to climate.
		Ventilation	Shelter has at least two windows / ventilators on different walls to allow air flow through the shelter		

The following data focuses on the temperature difference between the outside temperature and the internal temperature. These internal temperatures experienced by shelter occupants are a function of the external air temperature, the surface temperature, and therefore construction, and the ventilation rate.

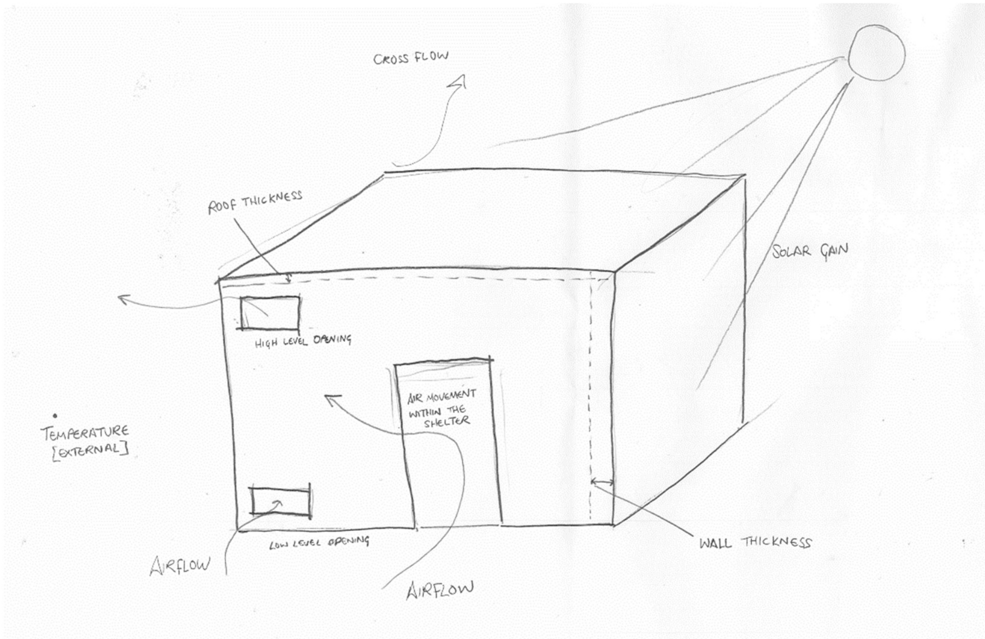


Figure 1 Sketch showing acting factors on comfort and ventilation of the shelters and their design.

3.1 Survey Data

- Air temperature inside and outside (shaded)
- Relative Humidity inside and outside
- Surface temperatures of walls
- Ventilator opening widths, height and location in wall
- Comfort opinions
- Wall thicknesses
- Roof construction

The primary data collected with regard to thermal comfort is the temperature and in particular the temperature difference between internal and external. This gives us a delta difference, the closer this is to zero the closer the internal temperature is to the external.

In the context of the survey data the external temperature was taken in the shade which provides a good target temperature as this often is deemed comfortable and the perceived or operative temperature will only be below this if the walls and roof temperatures are significantly below the air temperature or there is an increase in air movement.

Whilst the survey wasn't able to collect operative temperature (due to instrument limitations and the complex calculations of mean radiant temperature) the baseline model of the 'typical' shelter will be able to give us an approximation. The external operative temperature in the sun can also be approximated using a model and weather data.

Whilst the operative temperature (utilising air temperature and surface temperatures) will provide a comfort indicator, relative humidity can also have an impact on thermal comfort by effecting the body's ability to sweat and therefore reduce skin and body temperature.

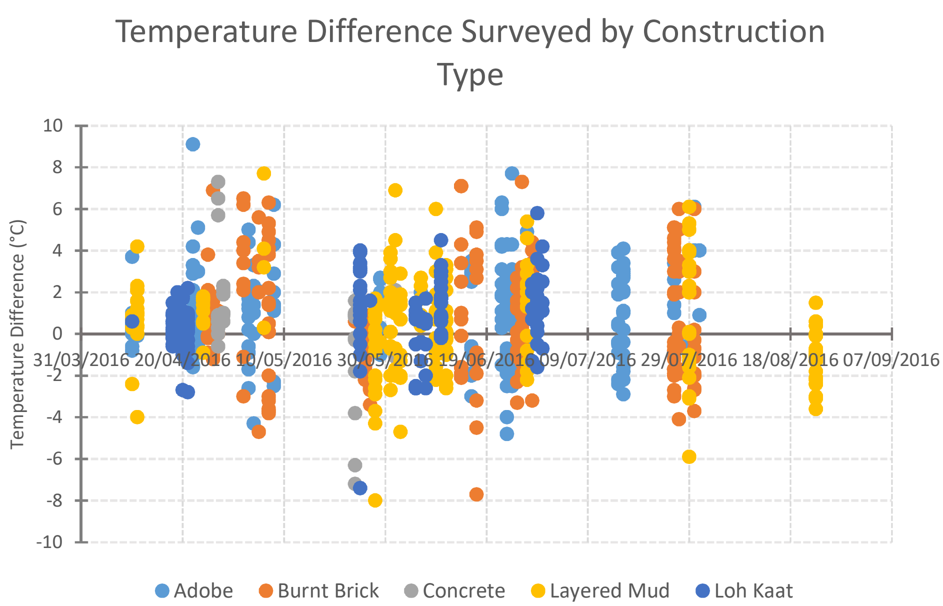
Relative humidity can have an impact on comfort, particularly when it is high. High relative humidity can be created if there is limited ventilation and there are some large moisture producing processes like cooking within the shelters. Normally however relative humidity would expect to be close to the external humidity.

Ventilation and opening sizes where surveyed in order to establish average shelter geometries and allow estimations of ventilation rates.

Finally occupants were surveyed to give an understanding of perception of comfort and understanding how conditions are felt within the shelters. This kind of data is often hard to draw conclusions from and establish trends as comfort is very subjective and respondents might be biased in the answers given if they think a particular outcome can be delivered. However it provides a useful baseline and understanding.

3.2 Survey data Results

The graph below plots the temperature difference between inside and outside for each construction type and the date at which the survey was taken. Two outlying points were removed from the data which had temperature differences of 18 and 35°C as these were considered unrealistic, this was for one layered mud and one concrete shelter.



The survey data shows no significant difference in the thermal performance of different construction types, summarised in the table below.

	Adobe	**Burnt Brick**	**Concrete***	**Layered Mud***	**Loh Kaat**
Average Temperature Difference	1.06	0.84	0.64	0.51	0.69
Standard deviation	2.2	2.7	2.8	2.3	1.5

*outliers were removed to derive these statistics.

The survey data overall is relatively close to the external temperature in the shade and therefore considered to be performing reasonably well already.

These statistics show that the temperature differences recorded for Layered Mud on average has the smallest difference between the internal and the external temperature, at 0.51°C. The distribution of the temperature difference for Loh kaat is closer to the mean with a standard deviation of 1.5, with Concrete construction having the greatest 'scatter' away from the external temperature (a standard deviation of 2.8).

The below graph shows the internal temperature recorded against the external shade temperatures recorded.

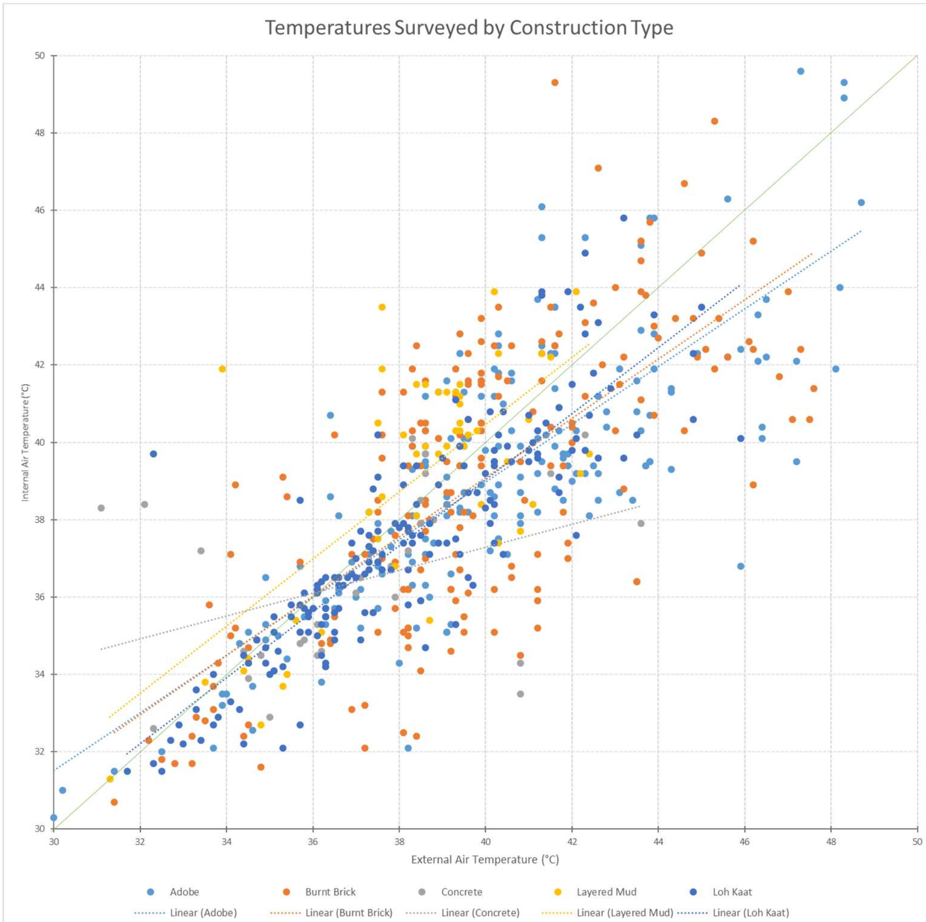


Figure 2 Comparison of recorded internal versus external air temperatures for each construction type

As can be seen from the figure above the trend of the temperatures measures is largely similar between most of the construction types. The line shows a zero temperature difference; the internal temperature is the same as the external shade temperature. This would represent a good result in the circumstances for air temperature, with any additional comfort / felt benefit being created by cooler surface temperatures. The results of this data is shown below.

The data average is fairly close to the external shade temperature and therefore performing quite well with the standard deviation for all shelters being within 3 degrees. Any design options should look to lower the mean and reduce the variation from this mean in terms of air temperature, hopefully creating an operative temperature below that of the external shade.

3.3 Surface temperatures

The internal surface temperatures of each survey was also surveyed, to give an indication of the temperature that might be ‘felt’ by occupants. Although a mean radiant temperature was not taken, the surface temperatures should provide an indication of whether the ‘felt’ temperature might be reduced or increased by the surface temperatures.

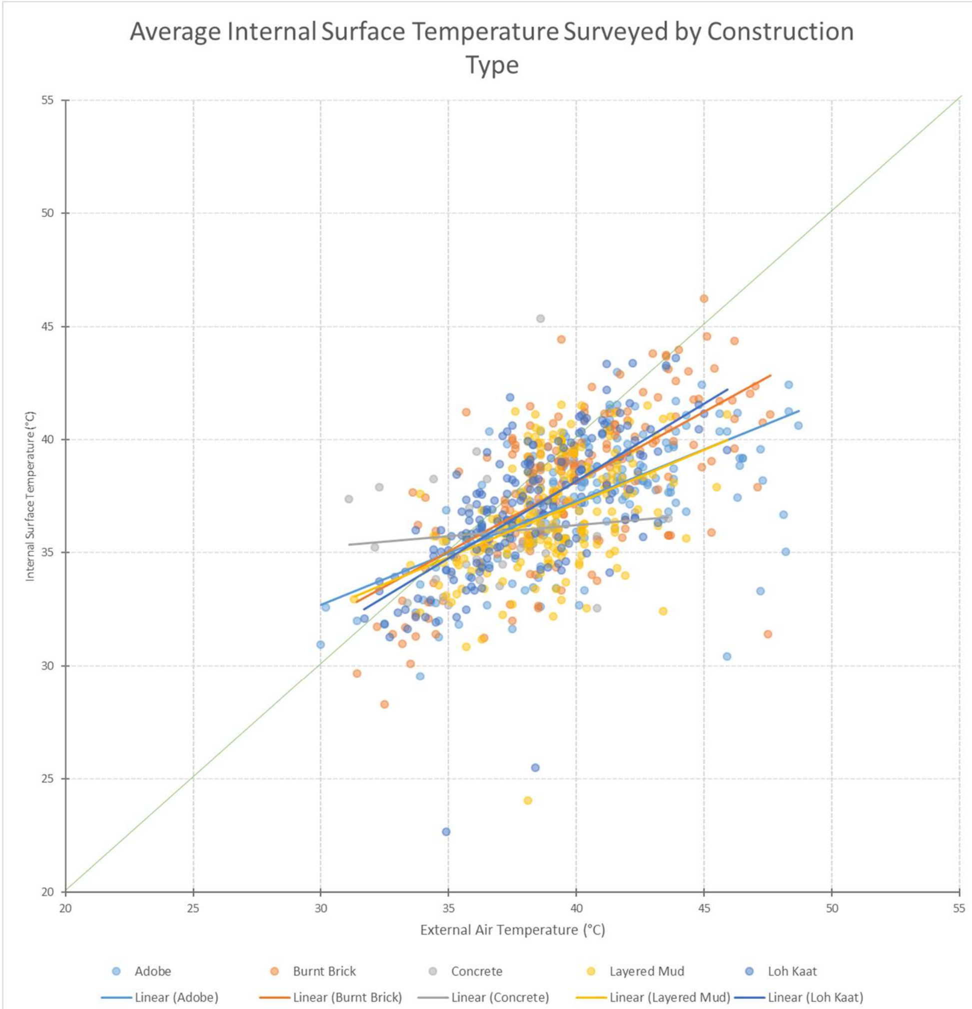


Figure 3 Average internal surface temperatures surveyed against the corresponding external shade temperature surveyed.

As shown above, in general the surface temperatures are cooler than the external shade temperatures. There are some differences in the trends shown between the construction types, namely concrete blocks where the surface temperatures are warmer at lower temperatures and cooler at higher temperatures. This is a characteristic of heavy weight thermal mass which would be expected from concrete, however the sample size was also too small for this construction type to draw any significant conclusions.

The following graphs breakdown the surface temperatures into the different surface types; floor, walls and roof.

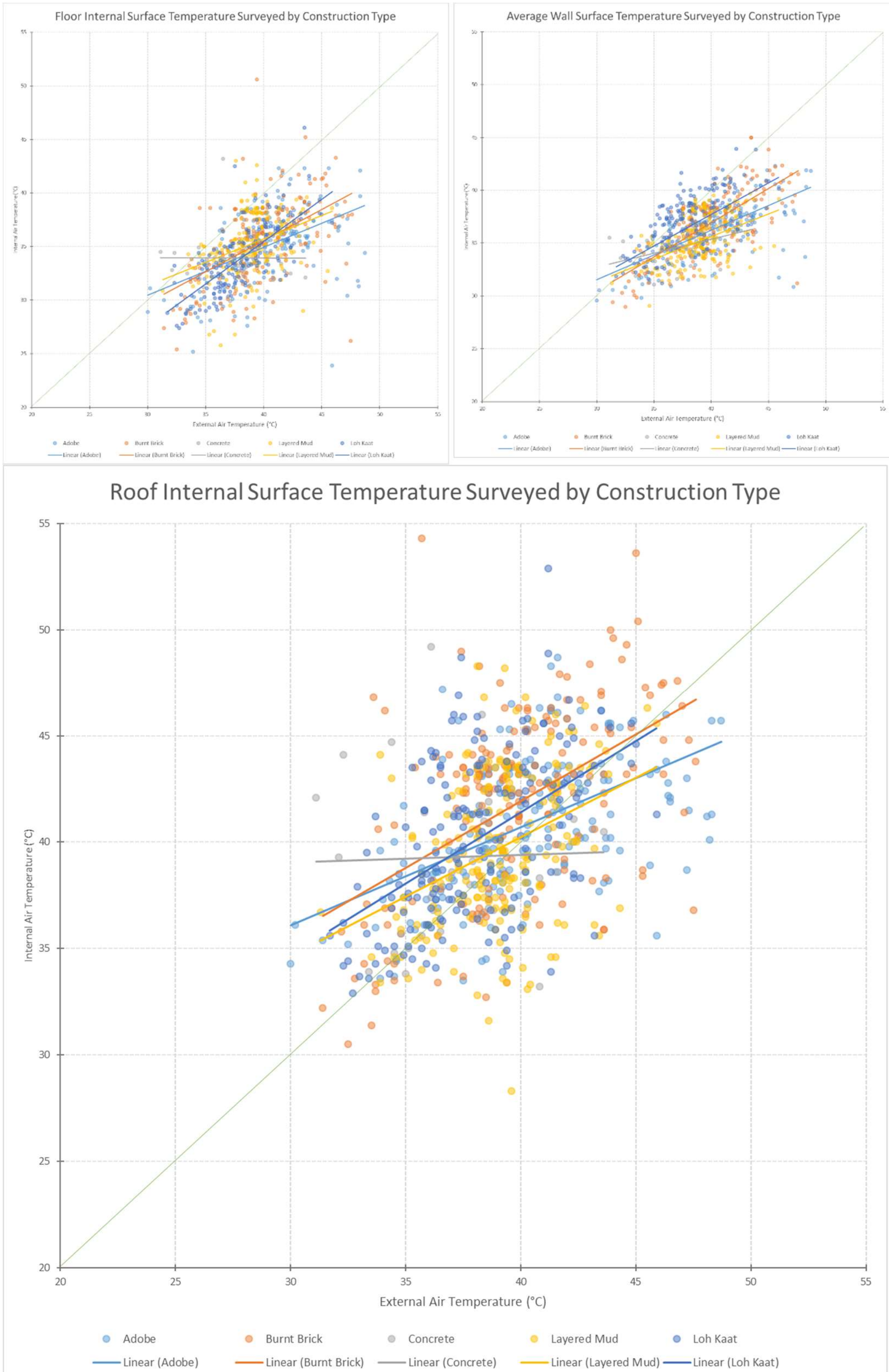


Figure 4 Internal surface temperatures surveyed by type against the corresponding external shade temperature surveyed.

The above data shows that the floor and wall surface temperatures are generally below the external shade air temperature and would therefore have the effect of reducing the ‘felt’ temperatures (operative temperatures) within the shelters. In contrast to this often the roof surface temperatures were higher than the external shade air temperatures, this would therefore most likely increase the ‘felt’ temperature within the shelters (depending on the air temperature within the shelter). This is therefore an area of investigation and design improvement to explore.

3.4 Wall Thickness

The wall surface temperatures are effected by the thickness of the construction or in other words its thermal mass or inertia. The higher the thermal mass the slower it is to respond to energy flows, this might result in cooler surfaces at peak periods and warmer surfaces at low temperatures.

The following graph shows the surveyed construction thicknesses.

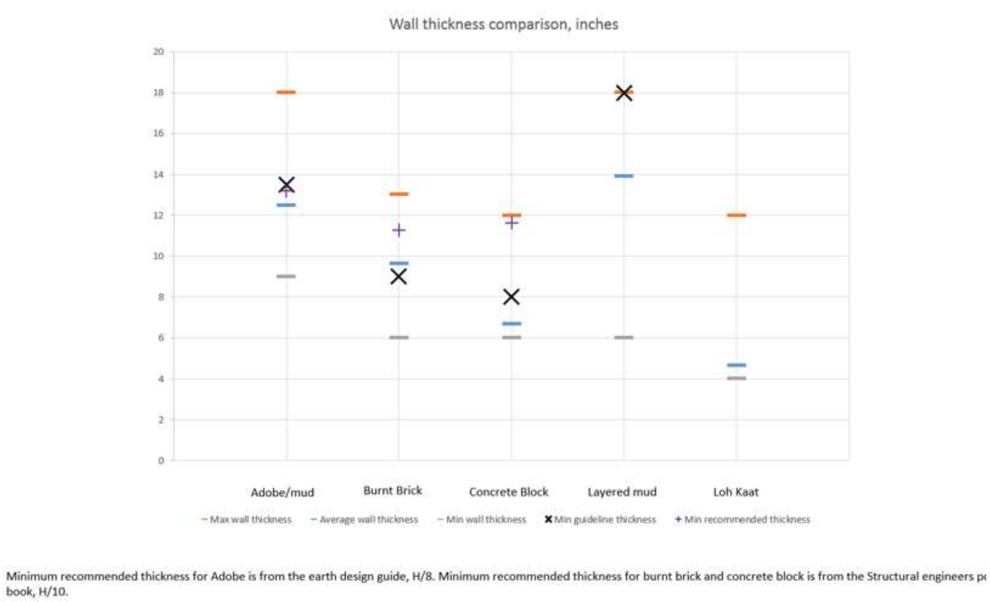


Figure 5 Wall thickness for each construction type

This shows that the Adobe and Layered Mud construction have the thickest walls. The thermal mass of these constructions will also depend on the density of the materials used.

3.5 Relative humidity

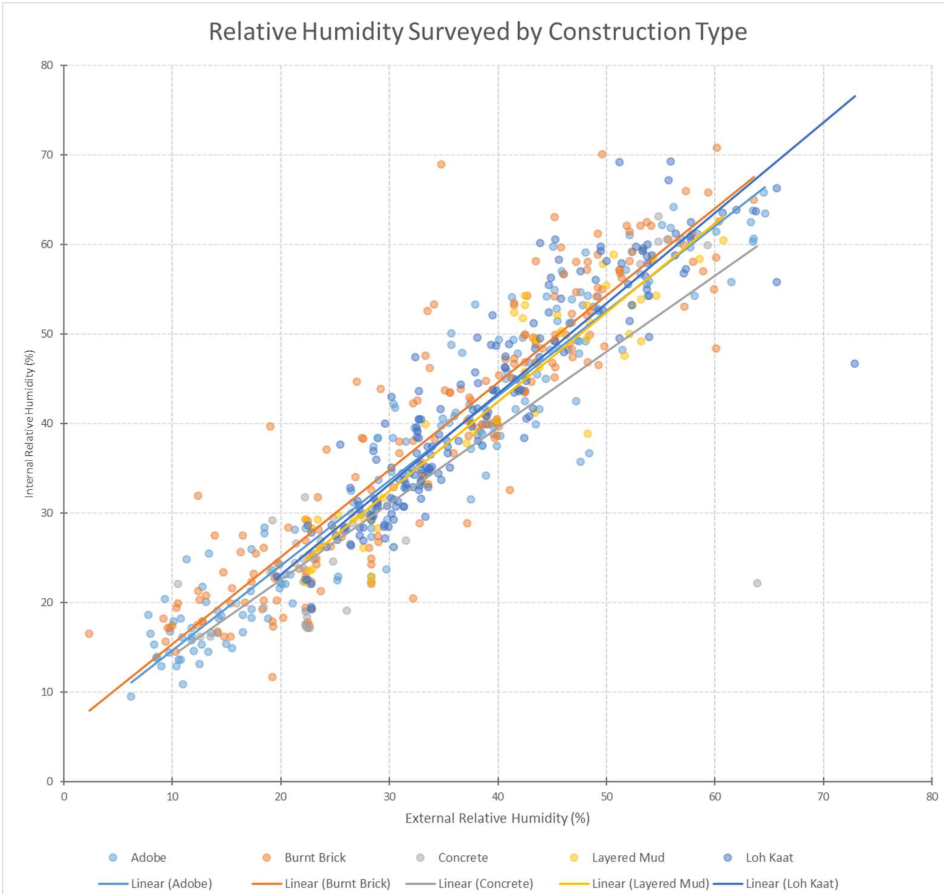


Figure 6 Relative Humidity measured, internal versus external

The graph above shows that there is no significant difference between construction types and the relative humidity within the shelters. The trend lines suggest the relative humidity is slightly higher inside the shelters compared to outside as would be expected due to moisture given off by people. This increase however is small.

3.6 Survey Response

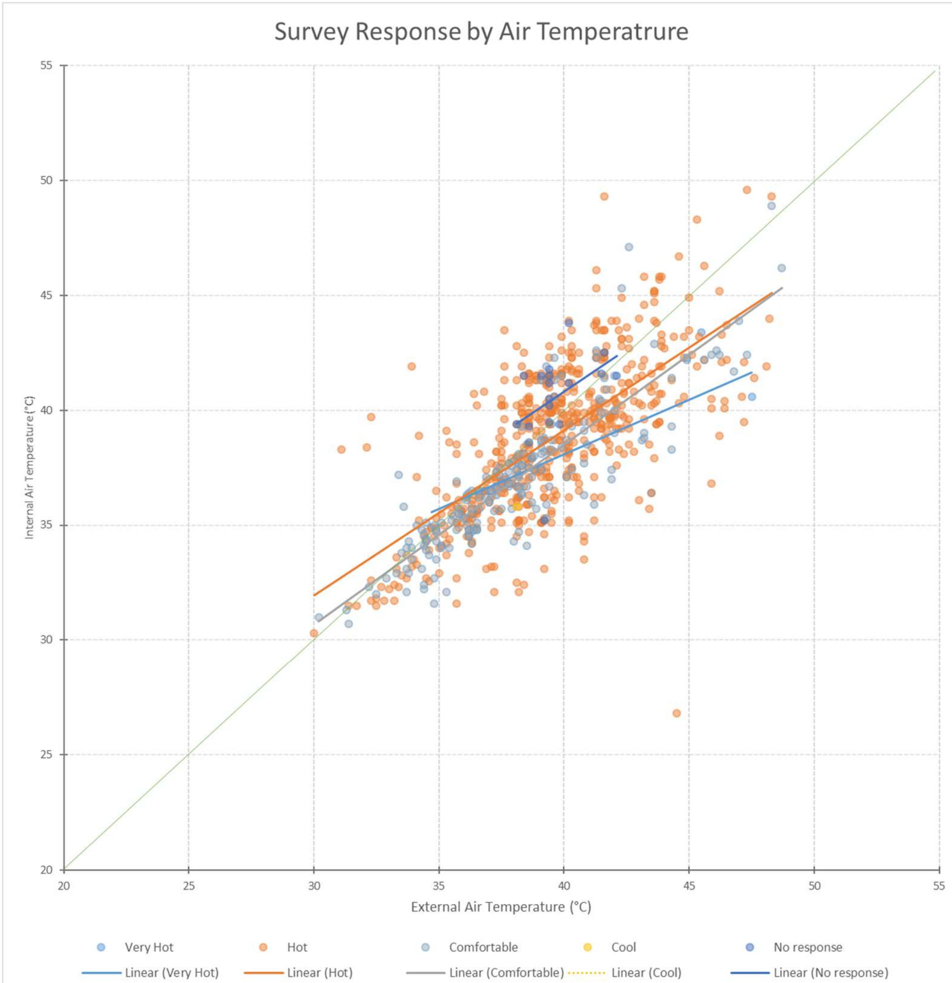


Figure 7 Survey responses against air temperature inside and outside

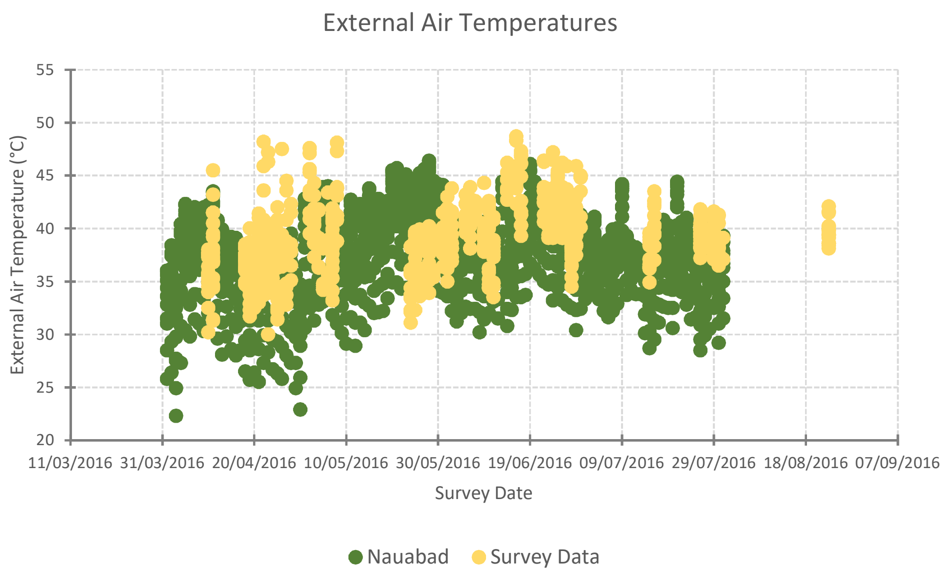
The responses above show little correlation between survey response and the temperature conditions, highlighting that different people have different opinions and perceptions of what is comfortable. Most of the respondents suggested conditions were hot inside the shelter.

4 Comparison of analysis against survey data

4.1.1 Climate

External air temperatures were measured as part of the survey. These temperatures will be subject to local microclimate variations and the calibration of the thermometer. For the subsequent analysis, a local historical weather file was used. Due to the availability and reliability of weather data and location of accurate weather stations this historical weather file is usually created to be typically representative year based on data over 15-20 years and may be a number of kilometres from the survey sites (typically at airports).

The closest reliable weather data source to the survey sites is Nawabshah, this typical year is based on data recorded in 2005. This data is shown against the survey data in the graph below.



This graphs shows that the data has some significant overlap and therefore a reasonable fit, compared to any others available. There are also some visible differences in the surveyed data and the weather file data, namely that the survey data seems to be a little bit hotter than those in the weather file. These differences could be for a number of reasons, listed below.

- Local microclimate variations between the survey data and Nawashah airport
- Different thermometer tolerances / calibrations
- Yearly variations in temperature, 2016 could have been a hotter year than 2005
- An increase in temperatures due to climate change

Local microclimate differences can be created by differences in surrounding contexts and surface materials such as large concrete aprons and built up areas.

Airport weather stations have standard calibration tolerances which might be different to the handheld equipment used in the survey.

The weather file is based on a long term average data (2005 selected as typical) it is expected that this would be a bit different to 2016. 2016 might not have been an average weather year.

There is 11 year difference in the weather years, there could conceivably be a climate change impact on the temperatures over this time period.

4.1.2 Climate Change

The expected climate change temperature increase in Pakistan as a whole is higher than the expected global average increase. Temperature increases of 1.4-3.7°C by 2060 with warming being more rapid in the southern and coastal zones.

Projected temperature increase in winter is more than that in summer. As yet, it is not possible to get a clear picture for precipitation change, due to large model uncertainties for the region. The yields of both wheat and rice will decrease everywhere except in the Northern Mountainous areas where wheat yields could potentially increase. The impact of climate change on Pakistan's water resources is unclear due to the uncertain behaviour of the Karakoram glaciers.

Within the wider South Asia region there is an expected trend of an increase in precipitation, with more variability (20-30%).

6 Analysis models

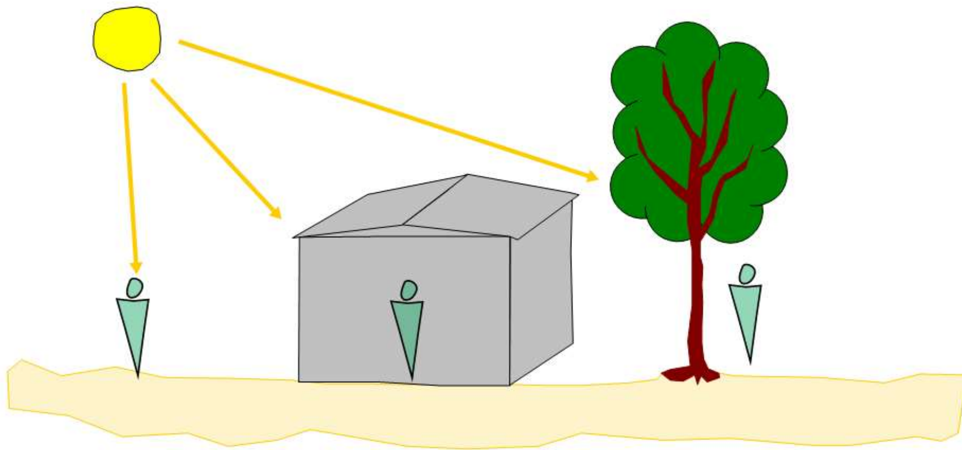


Figure 8 Diagram of thermal conditions; external under the sun, within the shelter and external shaded.

Shade from the sun has a significant effect on our comfort, the contrast between standing in the sun versus standing in the shade is great. The shelters primarily provide shade from the sun, however if there is a lack of air movement within these shelters they can be less comfortable or at least to be perceived as such. Within the shelters there are also additional heat sources which can heat up the internal spaces, these include people, lighting and other appliances (cooking etc.). Surface temperatures can help to reduce the comfort temperature if they are cooler than the air temperature.

These effect of being exposed to the sun is illustrated in the following graph where the external operative temperature is estimated for an external unshaded area.

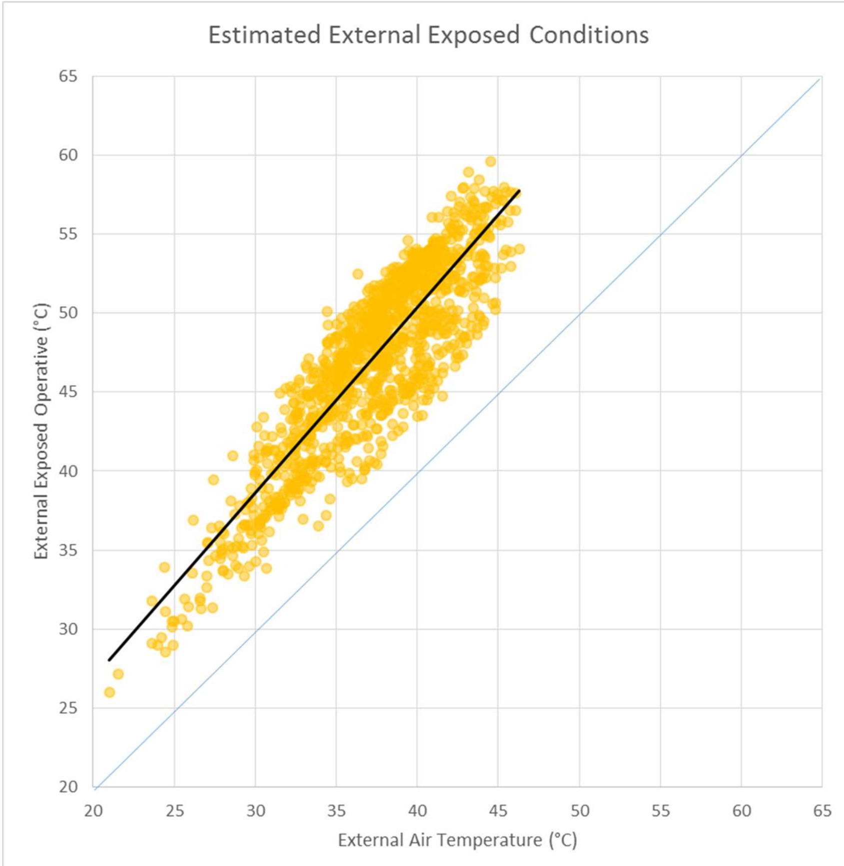


Figure 9 Estimated External Exposed Operative Temperature against external air temperature

This show the significant impact of the exposure to the sun on comfort resulting in a 10°C increase in operative over the air temperature.

Part 1: establishing a baseline

For the following analysis models the survey data was used to derive a ‘typical’ shelter geometry, based on the average shelter dimensions. The following image summarises the survey variations.

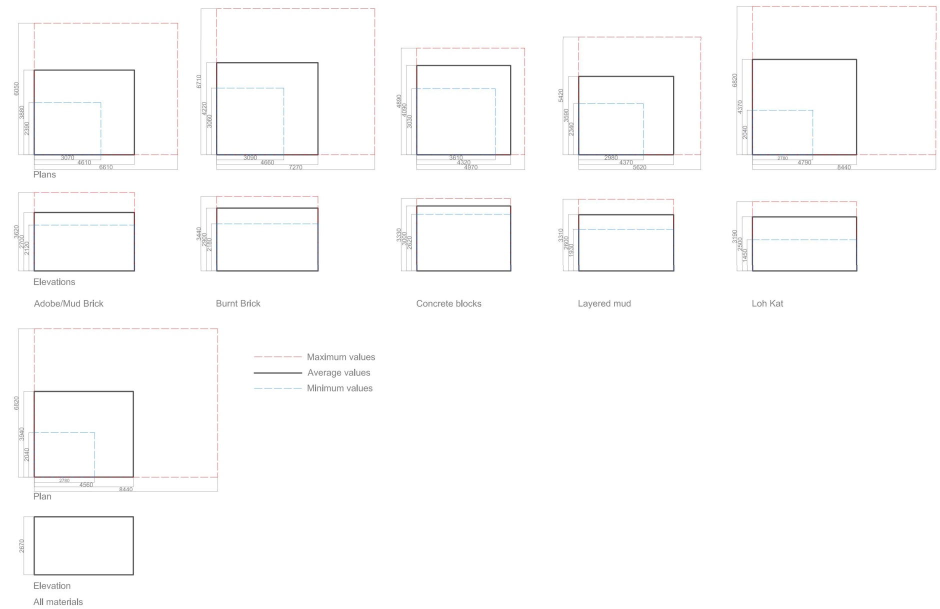


Figure 10 Shelter geometry variations and averages with construction type and overall average.

Based on this information the typical shelter was built to represent the average shelter typology. This has a plan area of 17m2 being 4.56m wide and 3.94m deep and the shelter being 2.67m high.

An average door opening and ventilation opening was also derived from the average of the survey data. These are as follows:

Ventilation opening: 0.13m^2 (0.37 H by 0.37 W)

Door opening: 1.76m^2 (1.71m H by 1.03m W)

The shelter geometry is shown below.

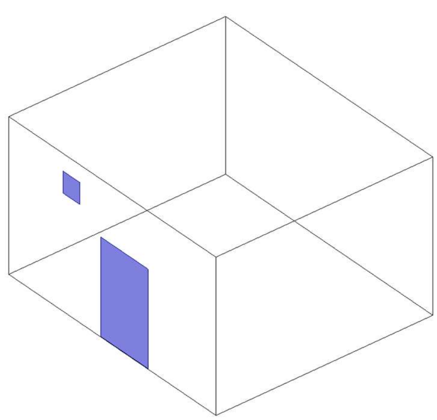


Figure 11 Model shelter geometry

Aim of the initial models is to replicate the survey data to provide a base line.

6.1.1 Average ventilation openings

Based on the average ventilation openings recorded in the survey data, a typical single ventilation opening of $0.13m^2$ was used. For the initial model the doors were modelled as shut.

The wall construction thicknesses were taken as the average surveyed for each construction type.

	Survey data	**Analysis with Average opening surveyed**
	Air Temperature	Air Temperature
Average Temperature Difference	0.77	-1.5
Standard Deviation	1.85	2.85

The average temperature difference of the combined modelled shelters (all constructions) is -1.5°C below that of the external compared to the 0.77 of the surveyed data. The models variability in temperature difference is also greater than the survey.

The fit to the survey data can be seen in the graph below.

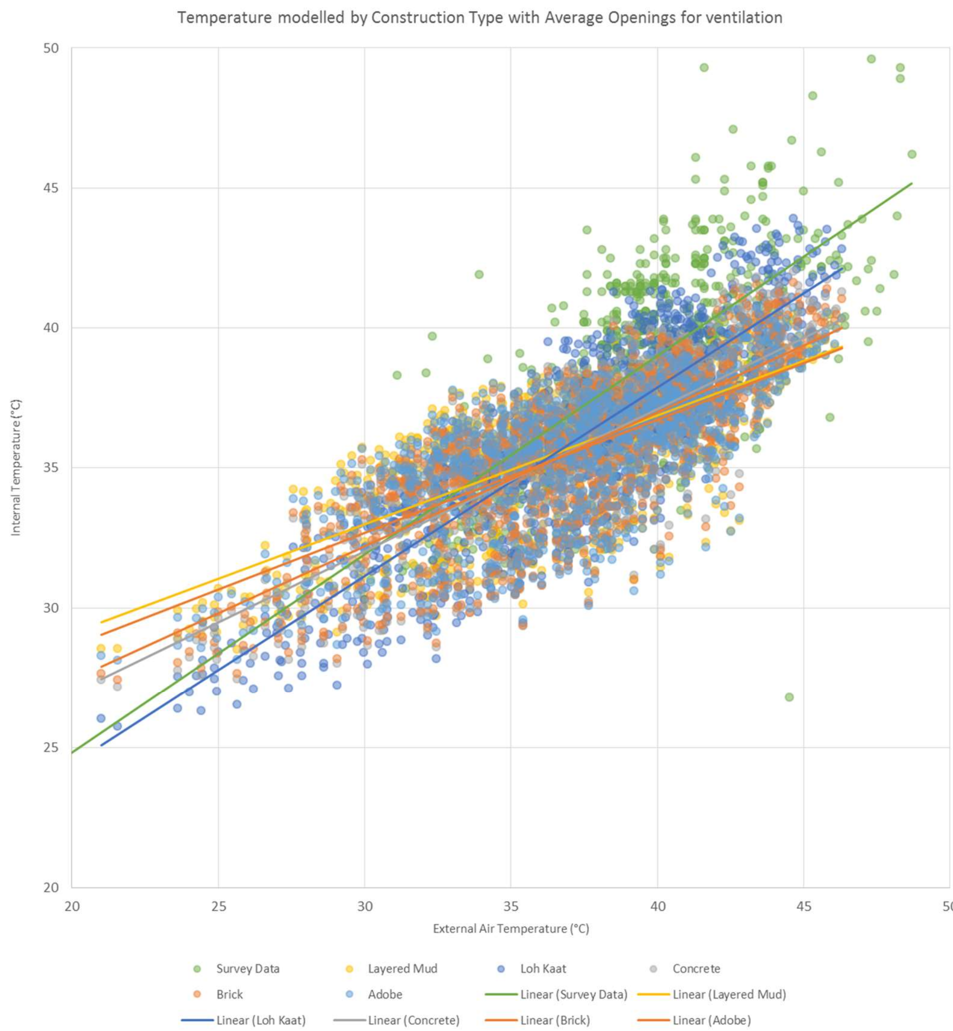


Figure 12 Comparison of modelled internal operative versus external air temperatures for each construction type with ventilation provided by average surveyed opening sizes.

As can be seen the fit to the surveyed data has the right trend, with Loh Kaat model showing the same trend as the survey data as a whole. As can be seen by the trend lines the other construction type models are showing warmer temperatures than the survey data at lower temperatures and cooler temperatures than the survey data at higher temperatures.

		Modelled shelters				
	Survey data	**Adobe**	**Burnt Brick**	**Concrete**	**Layered Mud**	**Loh Kaat**
Average Temperature Difference	0.77	-1.68	-1.61	-1.58	-1.47	-1.23

Standard deviation	1.85	3.13	2.84	2.73	3.17	2.23

In order to achieve a better fit to the survey data, the models where re-run with the door being left open, as this was fairly likely to be the case during the survey measurement.

6.1.2 Doors Open

Door open: lower 1/3 (0.587m^2) acts as an inlet, upper 1/3 (0.587m^2) acts as an outlet

Ventilation opening closed.

As it was likely that during the survey itself the doors might have been left open and some of the surveys noted that there was no door within the opening, in this scenario this opening would provide ventilation and alter the internal temperature. This was modelled to determine a closer fit to the survey data.

Due to the size of the door opening, the typical ventilation opening was ignored as this would add very little in terms of ventilation opening.

		Modelled shelters				
	Survey data	**Adobe**	**Burnt Brick**	**Concrete**	**Layered Mud**	**Loh Kaat**
Average Temperature Difference	0.77	-0.66	-0.71	-0.67	-0.8	-0.28
Standard deviation	1.85	2.44	1.52	1.44	1.77	1.6

Figure 13 Comparison of modelled internal operative versus external air temperatures for each construction type with ventilation provided by open doors

This performance provides a good approximation to the survey data. The data is generally lower than those surveyed, this could be for a number of reasons. One of these could be that in the model, the doors were permanently left open which might provide some pre-cooling at the start of the surveyed time periods, this might not have been the case for the actual surveys.

The benefits of precooling created by the permanently open doors in the model might be difficult to create in reality due the security issues of open doors at night or some times of day, however larger secure openings could be investigated.

Although the model has been adjusted to fit the survey data an important characteristic is identified through this investigation; the benefits of opening the doors on the air temperature. It is therefore recommended that the doors are opened when the shelter is occupied.

6.2 Design options

After establishing a reasonable fit to the survey data the following section explores different design options or improvements that can be made to the typical shelter design. The fit to the survey data provides confidence that the model is performing reasonably and the difference from the baseline model to the survey data is known.

The aim is through the design process is to get the average closer to 0 or below the baseline level and reduce the instances of extreme conditions, improving the variability from this average.

For the purposes of this design exploration Adobe construction was used to limit the number of variables.

6.2.1 Ventilation Openings

Using high and low level openings allows ventilation via stratification, hot air rising and escaping through the top vent while cooler air enters through the low level opening. 2.5% of floor area of the typical shelter is equal to 0.37m^2

	Doors Open		**Low level opening = 2.5% of Floor area** **High Level Opening = 2.5% of Floor area**		**Low level opening = 5% of Floor area** **High Level Opening = 2.5% of Floor area**	
	Air Temperature	Operative Temperature	Air Temperature	Operative Temperature	Air Temperature	Operative Temperature
Average Temperature Difference	-0.66	-0.87	-1.19	-1.74	-1.10	-1.73
Standard Deviation	1.07	1.93	1.43	2.10	1.29	2.01

*statistics include data for April-July from the hours 9-18

The above analysis assumed the ventilation openings were open constantly, however if there was some control to shut off the openings when either the external temperature is hotter than the internal in summer or if the temperature outside is too cold then the results can be improved.

	Doors Open	**Low level opening = 2.5% of Floor area**	**Low level opening = 2.5% of Floor area**

			High Level Opening = 2.5% of Floor area		**High Level Opening = 2.5% of Floor area With Opening Control**	
	Air Temperature	Operative Temperature	Air Temperature	Operative Temperature	Air Temperature	Operative Temperature
Average Temperature Difference	-0.66	-0.87	-1.19	-1.74	-1.79	-2.19
Standard Deviation	1.07	1.93	1.43	2.10	1.67	2.21

*statistics include data for April-July from the hours 9-18

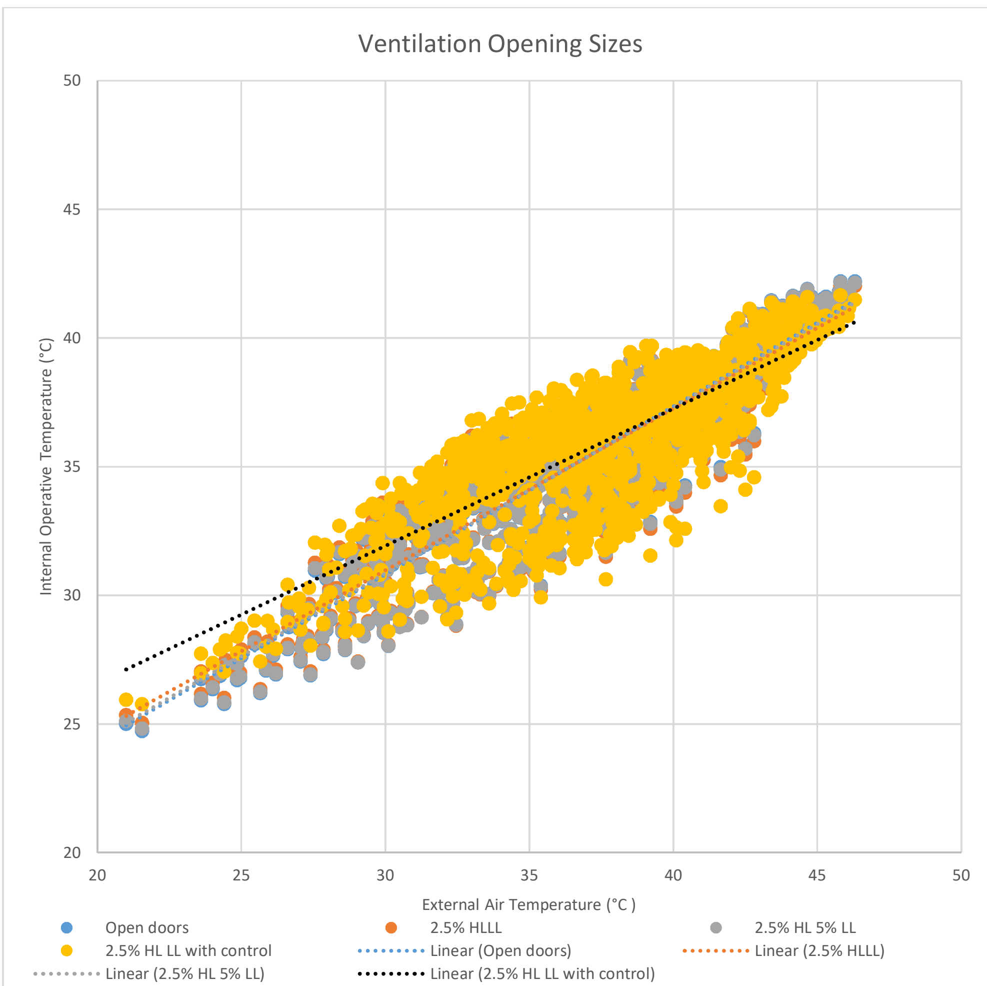


Figure 14 Internal Operative Temperature versus External Air Temperature for several ventilation opening sizes.

This shows the benefits that can be made if occupants have some control over the opening sizes, i.e. a sliding cover. This means that in winter if temperatures are too cold outside, ventilation can be restricted but also allows ventilation to be restricted when external temperatures are too hot, above the operative (comfort) temperature created by the cooler internal surface temperatures. This is shown in slightly higher operative temperatures in the last case due to the fact that the surfaces are being used in order to absorb more heat and coolth as ventilation is restricted and the surface temperatures become more dominant under these conditions.

6.2.2 Cross Ventilation

If the shelter is orientated to make use of the wind the opening sizes can be rationalised and can make use of greater ventilation potential.

The orientation of the shelter relates to the direction of the wall with the door opening within it. As shown in the image below, this shelter is ‘facing’ south.

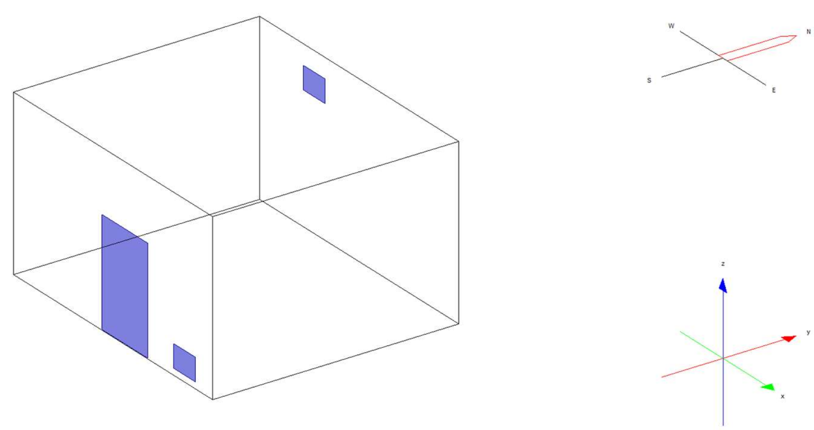


Figure 15 Cross ventilation geometry

The cross flow ventilation openings are positioned at high and low level in order to make use of the stack ventilation on still days as previously shown. They are also positioned on opposite wall to generate the most effective ventilation and airflow distribution. Locations on opposite walls should also maximise the pressure differential created by the wind and therefore increase ventilation rates.

	North	East	South	West
Average Temperature Difference	-1.43	-1.13	-1.32	-1.04

Standard Deviaton	1.47	1.41	1.40	1.40

*statistics include data for April-July 24hours a day

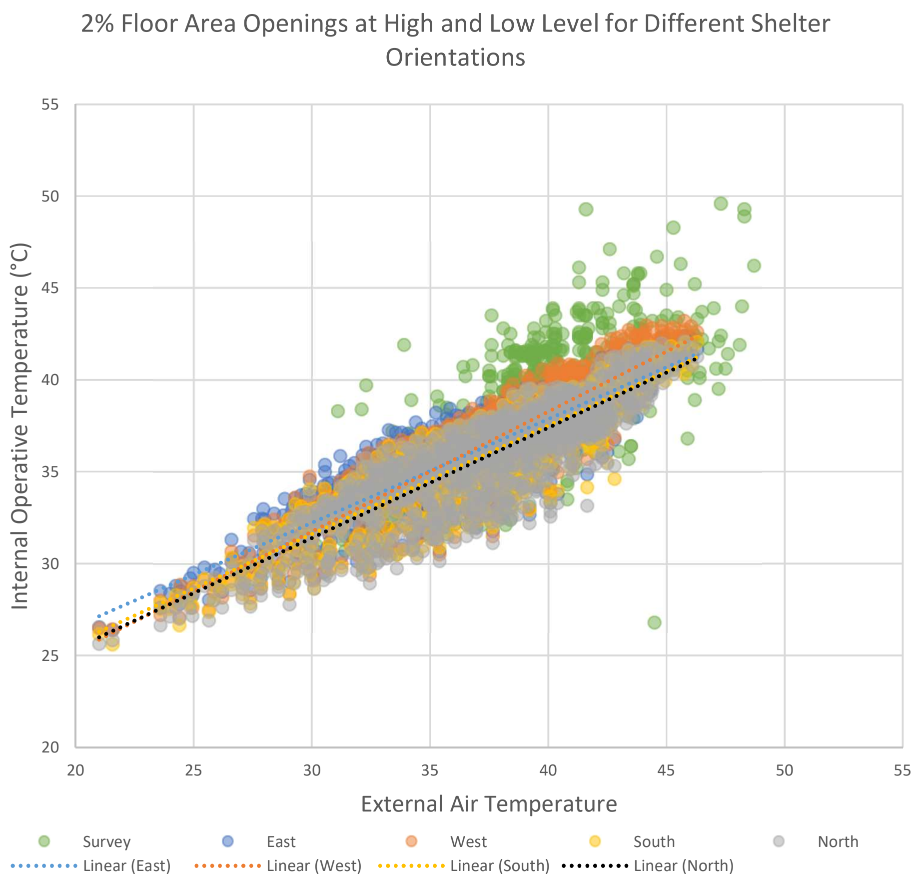


Figure 16 2% Floor Area Ventilation Openings at High and Low Level for Different Shelter Orientations

Openings of 2% of the floor area were chosen (although see below for exploration of the impact of smaller or larger openings).

This shows that shelters orientated to the North (openings on the north and south walls) have improved predicted comfort levels.

Due to the added benefits of wind flow the openings can be rationalised, as shown below for a North facing shelter.

	1% Floor Area openings at high and low level	**2% Floor Area openings at high and low level**	**2.5% Floor Area openings at high and low level**	**5% Floor Area openings at high and low level**

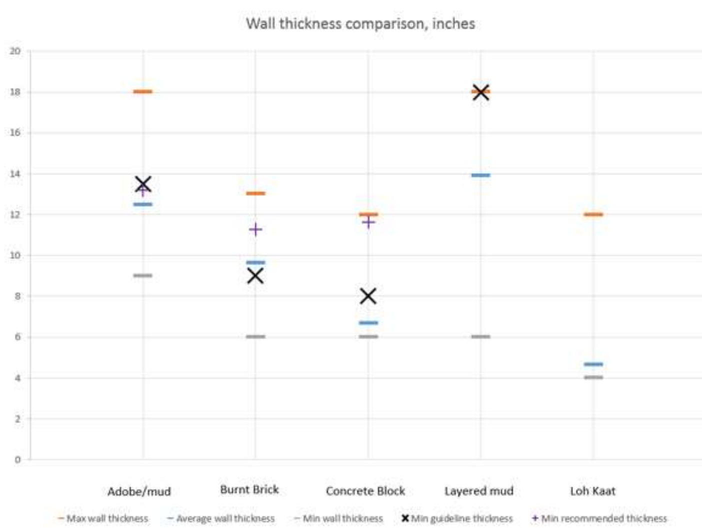
	(opposite walls)	(opposite walls)	(opposite walls)	(opposite walls)
Average Temperature Difference	-1.70	-1.43	-1.32	-0.93
Standard Deviation	1.85	1.47	1.35	0.99

*statistics include data for April-July 24hours a day

This shows that for the smaller openings the average is lower but the deviation is greater. During hot periods of the day, limiting the hot outside air from entering is a benefit, therefore reducing the average temperature difference. When there is a benefit from introducing the outside air (during still warm or during cool temperatures) the limited opening size limits the ability for ventilation and therefore greater variability is seen. With openings of 2-2.5% to provide background ventilation whilst during beneficial periods opening the door would give the option to adapt the opening size to the external conditions or occupant desires for more or less airflow.

6.2.3 Wall thickness

The survey data shows a range in wall thicknesses. Adobe and Layered Mud have the greatest thickness measured, and the highest average.



Minimum recommended thickness for Adobe is from the earth design guide, H/8. Minimum recommended thickness for burnt brick and concrete block is from the Structural engineers pc book, H/10.

Figure 17 Wall thicknesses surveyed against recommended thicknesses

In both of the following cases the ventilation was assumed through open doors, the construction type was for an Adobe construction. Average thickness correlates to the average Adobe wall thickness surveyed, increased correlates to the maximum wall thickness.

	Average Wall Thickness		**Increased Wall thickness**	
	Air Temperature	Operative Temperature	Air Temperature	Operative Temperature
Average Temperature Difference	-0.66	-0.87	-0.90	-1.54
Standard Deviation	1.07	1.93	1.16	1.97

*statistics include data for April-July 24hours a day.

This shows the advantage of applying a thicker wall material. As expected this difference is greater on the operative temperature as this includes the comfort created by surface temperatures. There is a small increase in variability but this considered insignificant.

6.2.4 Roof thickness

In both of the following cases the ventilation was assumed through open doors, the construction type was for an average Adobe construction.

	Average Roof Thickness		**Increased roof thickness**	
	Air Temperature	Operative Temperature	Air Temperature	Operative Temperature
Average Temperature Difference	-0.66	-0.87	-1.17	-2.09
Standard Deviation	1.07	1.93	1.24	2.16

*statistics include data for April-July 24hours a day.

This shows the advantage of applying a thicker roofing material. As expected this difference is greater on the operative temperature as this includes the comfort created by surface temperatures.

The variability of the internal conditions has increased probably due to the slower thermal response of the thicker roof material. Meaning it takes longer to heat up and cool down, this provides a benefit to the mean however the variation increases.

6.2.5 Roof overhang

Roof overhangs could provide some small benefit of shading the walls from solar gain. This would have a greater impact where there are large openings or windows as these will allow the solar gain directly into the shelters.

A roof overhang would also allow the creation of a shaded outside space which the survey showed to be a feature added by occupants since construction. This kind of space can be useful for those times when external conditions are acceptable when shaded from the strong sun.

7 Design Recommendations

It is recommended where possible the following elements are included in the shelter construction.

Two ventilation openings of a combined area of least 2% of the floor area of the shelter, these should be located one at high level, one at low level, one on a north facing wall the other on a south facing wall.

That doors are used to ventilate the shelter when possible.

The orientation of the shelter (determined by the door) should where possible face North.

Walls should have a mud plaster coat on them to provide thermal mass and the wall should be thickened (16-18in).

The roof plaster covering should be thickened to 5in.

Whilst roof overhangs didn't show a significant benefit in the analysis, a veranda provides some shaded space outside which will most likely provide a comfortable space on a still day condition.

8 Air Quality

If cooking or a fire is required in the shelter then we would recommend a dedicated flue be installed to remove particulates.

For a fire or stove of approx. 500mm by 550mm a flue of 200mm diameter would be acceptable (British Building Regulations Part J), this system would also require a permanently open vent with a total equivalent of at least 50% of the cross sectional area of the flue.

Material	Used for	Production											Production Carbon Factor (kg CO2 per kg of material)
		ICE		Winnipeg		UKGov		INBAR	IPCC-NGGIP	SEI	Highways England	Factor	
Cement (OPC)	*walls (secondary component) / concrete component*	0.74		0.89								0.1	0.89
Sand	*walls (secondary component) / concrete component*	0.0051		0.01								0.3	0.01
Stone Aggregate	*concrete component / foundations*	0.0052				0.011	0.002					0.6	0.011
Concrete	*roof structure / foundations / ring beams*												0.099
Burnt Brick	*walls (primary component) / foundations*	0.239				0.245							0.245
Mud Brick	*walls (primary component) / foundations*												0
Mud	*walls (primary component) / roof covering / foundations*												0
Poplar	*walls (secondary component)*	0.2	0.59			0.44	0.046						0.59
Bamboo	*roof structure / ring beams*							0.4					0.4
Polythene Sheet	*roof covering*	2.08		2.06	1.01	2.62							2.62
Chicks (bamboo)	*roof covering*							0.4					0.4
Concrete Blocks	*walls (primary component) / foundations*												0.099
Lime	*walls (secondary component) / foundations*	0.78		0.74					0.75				0.78
Sawn Timber	*roof structure*	0.2	0.59			0.44	0.046						0.59
Structural Steel	*roof structure / ring beams*	2.89	0.47	3.29	0.88							0.4063	2.31
Reinforcing Steel	*walls (secondary component) / roof structure*	2.89	0.47	3.29	0.88							0.4063	2.31
Straw	*walls (secondary component) / roof covering*											0.361	0.10
Nails (iron)	*other*	2.03		1.91									2.03
Screws (steel)	*other*	2.89	0.47	3.29	0.88							0.4063	2.31
Cotton Rope	*other*									0.0038			0.0038
Nylon Rope	*other*			7.9									7.9
PVC Pipe	*other*	3.23		2.22	0.48	3.43							3.43
Reed Mat	*walls (secondary component) / roof covering / other*												0
Palm Mat	*walls (secondary component) / roof covering / other*												0
Galvanised Wire	*other*										1.54		1.54

Notes on material carbon factors

Row heading - column heading - comment

Cement (OPC) - ICE - based on UK weighted average
Burnt Brick - ICE - based on 0.55 for a 2.3kg brick
Poplar - ICE - sawn softwood, from a sustainably managed forest
Lime - ICE - based on UK weighted average
Sawn Timber - ICE - sawn softwood, from a sustainably managed forest
Structural Steel - ICE - virgin
Reinforcing Steel - ICE - virgin
Screws (steel) - ICE - virgin
Poplar - ICE - sawn softwood, NOT from a sustainably managed forest
Sawn Timber - ICE - recycled
Structural Steel - ICE - recycled
Reinforcing Steel - ICE - recycled
Screws (steel) - ICE - recycled
Polythene Sheet- Winnipeg- virgin
Structural Steel-Winnipeg-virgin
Reinforcing-Winnipeg-virgin
Screws(Steel)-Winnipeg-recycled
PVC Pipe-Winnipeg- recycled
Polythene Sheet- Winnipeg- recycled
Structural Steel-Winnipeg-recycled
Reinforcing-Winnipeg-recycled
Screws(Steel)-Winnipeg-recycled
PVC Pipe-Winnipeg- recycled
Stone Aggregate-UKGov-word, primary production
Burnt Brick-UKGov-primary production
Poplur-UKGov- wood, primary production,
Sawn Timber-UKGov- wood, primary production
Stone Aggregate-UKGov-reused
Poplur-UKGov- wood,reused
Sawn Timber-UKGov- wood, reused
Bamboo-INBAR-page 24; steps 1, 2, 6, 11 + 0.20 added for treatment
Chicks (bamboo)-INBAR-page 24; steps 1, 2, 6, 11 + 0.20 added for treatment
Cotton Rope-SEI-figure for organic cotton in India
Galvanised wire-Highways England-case study: galvanised steel handrail
Cement(OPC)-Factor-proportion of cement in M10 concrete
Sand-Factor-proportion of sand in M10 concrete
Stone-Factor-proportion of stone in M10 concrete
Structural Steel-Factor-1,600 million tonnes of steel650 million tonnes recycled
Reinforcing-Factor-1,600 million tonnes of steel650 million tonnes recycled
Straw-Factor-wheat carbon factor
Screws(steel)-Factor-1,600 million tonnes of steel650 million tonnes recycled
Concrete-Production Carbon Factor (kg CO2 per kg of material)-using factors and values f
Structural steel-Production Carbon Factor (kg CO2 per kg of material-virgin/recycled weig
Reinforcing-Production Carbon Factor (kg CO2 per kg of material-virgin/recycled weighte
Straw-Production Carbon Factor (kg CO2 per kg of material-based on…value of straw = £
Screws(Steel)-Production Carbon Factor (kg CO2 per kg of material-virgin/recycled weigh
Sand-Factor-proportion of sand from quarry
Concrete-Transport Carbon Factor (kg CO2)-using factors and values from constituent par

Transport																
Source	Source to market (km)	Mode	kg CO2 per km			Factor	Market to shelter (km)	Mode	kg CO2 per km				Transport Carbon Factor (kg CO2)		
Karachi	400	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0212	per kg material +	70.4
Rohri	40	Truck	0.00005	per kg material +	0.17	0.5	20	Tractor trolley	0.00006	per kg material +	0.12		0.0016	per kg material +	9.2
Rohri	40	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0032	per kg material +	9.2
													0.0045	per kg material +	88.8
Khānpur	11	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0018	per kg material +	4.27
							1	Animal drawn cart	0	per kg material			0	per kg material	
							1	Animal drawn cart	0	per kg material			0	per kg material	
KPK	900	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0462	per kg material +	155.4
Punjab	650	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0337	per kg material +	112.9
Lahore	700	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0362	per kg material +	121.4
Punjab	650	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0337	per kg material +	112.9
													0.0045	per kg material +	88.8
KPK	900	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0462	per kg material +	155.4
Punjab province	250	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0137	per kg material +	44.9
Karachi	400	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0212	per kg material +	70.4
Karachi	400	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0212	per kg material +	70.4
Punjab province	40	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0032	per kg material +	9.2
Karachi	400	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0212	per kg material +	70.4
Karachi	400	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0212	per kg material +	70.4
Punjab province	40	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0032	per kg material +	9.2
Lahore	700	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0362	per kg material +	121.4
KPK	900	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0462	per kg material +	155.4
							20	Tractor trolley	0.00006	per kg material +	0.12		0.0012	per kg material +	2.4
							20	Tractor trolley	0.00006	per kg material +	0.12		0.0012	per kg material +	2.4
Karachi	400	Truck	0.00005	per kg material +	0.17		20	Tractor trolley	0.00006	per kg material +	0.12		0.0212	per kg material +	70.4

	A		B
Transport options (kg CO2 per km)			
Truck	0.00005	per kg material +	0.17
Tractor trolley	0.00006	per kg material +	0.12
Bus	0.00005	per kg material +	0.085
Motorcycle	0.00017	per kg material +	0.034
Rail	0.00003	per kg material +	2.07
Animal drawn cart	0	per kg material	
Handcart	0	per kg material	
On foot	0	per kg material	

Notes of transport carbon factors

Transport carbon factors are made of two parts, A and B:

A) carbon factor ultiplied by material weight

B) carbon factor for transport mode if vehicle were running with no cargo

IOM Pakistan Shelter Assessment - Sustainability Analysis

Quantitative and qualitative findings
Recommendations for the design guide

Compiled by David McLennan, AT&R, February 2017

ARUP

Sustainability Analysis - contents

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Sustainability Analysis – key criteria

- Original criteria for sustainability, drawn up during 2014/2015

Criteria	Indicator	Variable	Qualitative Metric	Quantitative Metric
Sustainability	Cost	Building Element		Material Cost of each building element ($ or $/m^2)
		Construction		Labour Cost (Cost/day over X number of days)
	Life Cycle Cost	Affordability of maintenance		Quantify Life Cycle cost
		Non – Monetary cost of Maintenance		
	Local Supply chain	Availability of materials		Average distance for people to travel to source building materials (km)
		Labour standards	Human rights are respected, harm to people is avoided and efforts are made to maximise the positive contribution of the project ensuring that human rights are met throughout the supply chain	
	Natural resources	Recycled/ Reused	The materials used in the shelter can be reused/ recycled	
		Embodied Energy		Carbon footprint for each building type with specific key features (measured in units of carbon dioxide/m^2)

Part of the Cost Analysis Study

These indicators feature in this study, although have been modified and developed from this original outline. Please see next slide

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Areas of the Sustainability Analysis

The following broad areas were defined to aid in the assessment of sustainability for each shelter:

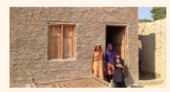
1. Embodied Carbon ★
2. Material Availability
3. Labour Standards
4. Recyclability / Reusability
5. Homeowner Satisfaction

★ Arguably most significant to stakeholders

4 ARUP

Shelter typologies

- Five basic typologies are shown in the adjacent table
- This is a simplified subset of the huge variety of shelters seen in Pakistan
- Layered Mud, Adobe, Loh Kaat, Burnt Brick and Concrete Block are the most common wall types
- These can be combined with a variety of different roof structure designs, including ring beams, vertical columns, door/window lintels and other structural design features which are sometimes present and sometimes not
- Note that the data set for concrete block constructions was too small to have complete confidence in the trends seen for this subset of the shelters (approx. 30 concrete block shelters, compared with approx. 200 for each of the other typologies)

Shelter Typology	Description		
Mud	Layered mud construction		IOM
Adobe	Sun-dried mud brick construction		Concern
Loh kaat	Timber/bamboo frame, bamboo/ grass matted walls with mud rendering		ACTED
Burnt Brick	Masonry using charcoal fired bricks		TFK
Concrete Block	Masonry using cement bricks/ block		UN-Habitat

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List of agencies

- The following nine agencies were responsible for the various shelter designs covered in this study, and also contributed to our research by way of participating in the stakeholder meetings:
  - *ACTED*
  - *CESVI*
  - *CRS*
  - *HANDS*
  - *IOM*
  - *Prepared*
  - *Sangtani*
  - *SEAD*
  - *UN Habitat*

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Input data received

- Homeowner survey
  - 800 shelter homeowners surveyed
- Shelter assessment
  - 800 shelters assessed
- Stakeholder meeting minutes
  - CESVI (4 April 2016)
  - CRS (4 April 2016)
  - KII Data (summary of all stakeholder meetings)
- Flood/Rain Testing Workshop meeting minutes (20 October 2016)
- Various materials-related documentation

Material usage in shelters

800 shelters surveyed in total

Foundations Material	
Mud	332
Burnt brick	236
Concrete,Burnt brick	45
Lime,Mud	41
Adobe/ mud bricks	37
Adobe/ mud bricks,Lime	16
Concrete	16
Burnt brick,Mud	15
Compacted earth	13
Compacted earth,Lime,Mud	9
Dung,Mud	8
Adobe/ mud bricks,Mud	5
Compacted earth,Mud	4
Lime,Dung,Mud	4
Burnt brick,Compacted earth	3
Stone rubble,Lime,Mud	3
Adobe/ mud bricks,Compacted earth	2
Burnt brick,Compacted earth,Mud	2
Burnt brick,Lime,Mud	2
Adobe/ mud bricks,Lime,Mud	1
Burnt brick,Adobe/ mud bricks	1
Burnt brick,Lime	1
Concrete,Lime,Mud	1
Stone rubble,Burnt brick	1
Stone rubble,Mud	1
Unknown	1

Wall Primary Material	
Layered Mud	200
Burnt Brick	193
Loh Kaat	177
Adobe/ Mud brick	176
Concrete blocks	33
Adobe/ Mud brick with lime	19
Layered Mud with Lime	2

Wall Mortar Material	
None	379
Cement,Sand	203
Mud	157
Mud,Lime	40
Cement	6
Mud,Straw	6
Mud,Lime,Dung	3
Mud,Dung	2
Mud,Lime,Cement,Sand	1
Mud,Lime,Straw	1
Mud,Lime,Straw,Dung	1
Mud,Straw,Dung	1

Wall Plaster Material	
Mud,Straw,Dung	350
Mud,Straw	106
Cement,Sand	99
None	67
Mud,Lime,Straw	62
Mud,Lime,Straw,Dung	46
Mud,Dung	23
Mud	20
Mud,Lime,Dung	12
Mud,Cement,Sand	4
Mud,Lime	3
Mud,Straw,Cement,Sand	2
Cement	1
Lime,Cement,Sand	1
Lime,Straw,Dung	1
Mud,Lime,Cement,Sand	1
Mud,Lime,Straw,Cement	1
Unknown	1

Roof Structure Primary Material	
Iron girder/ Steel	433
Bamboo	209
Timber/wood	136
Concrete	22

Roof Structure Secondary Material	
Bamboo	652
Timber/wood	73
Iron Girder/ Steel	45
Concrete	11
None	10
Chicks	4
roof tiles	2
Bamboos&Chicks	1
bushes	1
Tear Steel	1

Door Material	
Wood	408
No door	275
Steel	104
cloth	4
chicks	2
Plastic	2
Unknown	2
Bamboo	1
Iron Door	1
Sindhi Rillii (rug)	1

Roof Covering Material	
Plastic,Chicks,Mud	658
Roof tiles	47
Plastic,Chicks,Mud,Lime	30
Chicks,Mud	15
Plastic,Chicks	15
Plastic,Mud	10
Plastic	6
Thatch / Grass	4
Chicks	3
Mud,Thatch / Grass	2
Plastic,Chicks,Mud,Thatch / Grass	2
Chicks,Mud,Lime	1
Chicks,Mud,Metal sheets	1
Chicks,Mud,Roof tiles	1
Chicks,Mud,Thatch / Grass	1
Mud	1
None	1
Plastic,Chicks,Thatch / Grass	1
Plastic,Mud,Roof tiles	1

Ring Beam Material	
No ring beam	588
Bamboo	175
Concrete	23
Iron girder/ Steel	14

1. Embodied Carbon

ARUP

Embodied Carbon – list of materials

- *Most abundant/significant:*
  - Cement (OPC)
  - Stone Aggregate
  - Sand
  - Concrete
  - Burnt Brick
  - Mud Brick
  - Mud
  - Poplar
  - Bamboo
  - Polythene Sheet
  - Chicks
- *Somewhat abundant/significant:*
  - Concrete Blocks
  - Lime
  - Sawn Timber
  - Structural Steel
- *Least abundant/significant:*
  - Reinforcing Steel
  - Nails
  - Screws
  - Straw
  - Cotton Rope
  - Nylon Rope
  - PVC Pipe
  - Reed Mat
  - Palm Mat
  - Galvanized Wire

- Values in the following slides will be given as "kg CO2 per kg of material", subject to information from the Bill of Quantities (BoQ), which will vary from shelter to shelter
- The following additional materials are *not* listed on the BoQ but *do* feature in the survey data set:
  Roof Tiles, Iron Girder, Dung, Thatch, Grass, Metal Sheets, Sindhi Rillii, Cloth, Metal Mesh, Plastic Mesh

References
- *Lottie McCarthy emails (2016-12-14_145603, 2017-01-10_114252)*
- *20161102 Assessments Combined V5.xlsx*

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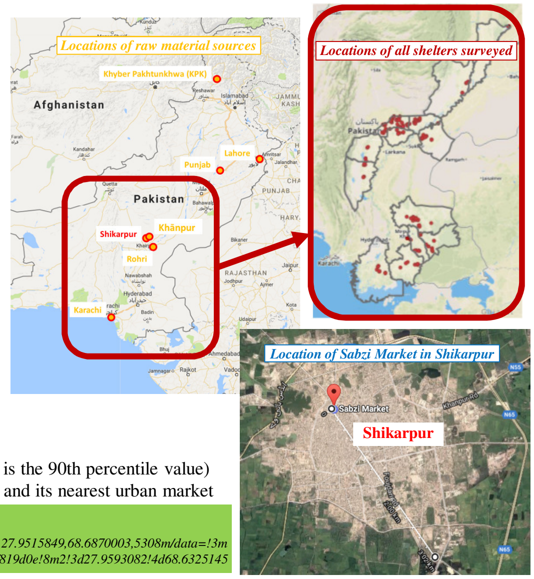
Embodied Carbon – transport map assumptions

- Assumed shelter location:
  - **Shikarpur**
  - This is an example location chosen based on where the largest number of surveyed shelters are clustered
- Assumed locations of raw materials/processing plants:
  - **Khyber Pakhtunkhwa (KPK)**
  - **Lahore**
  - **Punjab**
  - **Karachi**
  - **Rohri**
  - **Khānpur**
  - These are assumed based on locations of nearest suitable sources, or from information in stakeholder interviews, as referenced for each material
- Assumed distance to market:
  - 20 km from shelter
  - This is a reasonable worst case (20 km is the 90th percentile value) for the distance between a rural shelter and its nearest urban market



References

- *https://www.google.co.uk/maps/place/Sabzi+Market/@27.9515849,68.6870003,5308m/data=!3m1!1e3!4m5!3m4!1s0x39343bef847412a9:0x51443ed2ff819d0e!8m2!3d27.9593082!4d68.6325145*

Embodied Carbon – transport modes assumptions

- CO_2 emissions of the different transport modes (mentioned in the survey data), using closest-match vehicle types from the references given, with mass and emission values calculated accordingly:
  - Truck — "Heavy diesel rigid" (3.5 tonne mass, max 17 tonne load) — 0.17 kg CO_2 per km + 0.00005 kg CO_2 per km per kg of material
  - Tractor trolley — "Light diesel rigid" (1.8 tonne mass, max 7.5 tonne load) — 0.12 kg CO_2 per km + 0.00006 kg CO_2 per km per kg of material
  - Bus — "Diesel minibus" (1.8 tonne mass, max 3.5 tonne load) — 0.085 kg CO_2 per km + 0.00005 kg CO_2 per km per kg of material
  - Motorcycle — "Petrol motorbike" (0.2 tonne mass, max 0.5 tonne load) — 0.034 kg CO_2 per km + 0.00017 kg CO_2 per km per kg of material
  - Rail — "Rail freight" (74 tonne locomotive mass) — 2.07 kg CO_2 per km + 0.00003 kg CO_2 per km per kg of material
  - Animal drawn cart — 0 kg CO_2 per km per kg of material
  - Handcart — 0 kg CO_2 per km per kg of material
  - On foot — 0 kg CO_2 per km per kg of material

Typical examples:
- Truck
- Tractor trolley
- Animal drawn cart

References

- *Tractor http://www.faizantraders.com/wp-content/uploads/2015/10/mf240.pdf*
- *Bus http://driver.pk/cars/toyota/toyota-hiace-2016-model-price-in-pakistan/*
- *Rail http://pakistanrail.com/locotech/pages/ALU95.htm*
- *CO_2 https://ig-tools.com/files/2014_Conversion_Factors.pdf*
- *CO_2 http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
- *General https://en.wikipedia.org/wiki/Transport_in_Pakistan*

Embodied Carbon – Cement (ordinary Portland cement, OPC)

Used for — *walls (secondary component) / concrete component*

Description of production process

- Raw material extraction, controlled mixing

Production (raw material extraction and manufacturing)

- According to *IOM*, in the Kacha area of Punjab, it was more challenging to procure cement than to produce lime. Cement is less carbon friendly than lime – one aspect of this is transportation because there are only one or two cement factories in Sindh, versus lime kilns which are widely scattered all over the region, and typically burn twigs instead of fossil fuels

kg CO_2 per kg of material	0.74 [ICE, based on UK weighted average]	0.89 [Winnipeg]

Transport (from production location to site)

- Assume originates from Karachi
- Distance from Karachi to market — 400 km
- Mode from Karachi to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 400) + (0.00006 * 20) + (0.17 * 400)+ (0.12 * 20)
= (0.021 per kg material + 70.4) kg CO2

References

DESC ▪ *http://www.cement.org/cement-concrete-basics/how-cement-is-made*
PROD ▪ *Email from Hasballah to Tim White (19 February 2017)*
PROD ▪ *ice_v2.0_-_jan_2011.xls*
PROD ▪ *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
TRAN ▪ *http://www.apcma.com/members.html*

 ARUP

Embodied Carbon – Sand

Used for — *walls (secondary component) / concrete component*

Description of production process

- Excavating from riverbed (i.e. 50% river sand) and from quarry (50% hill sand, via market)

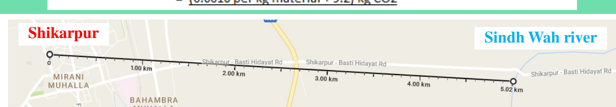
Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	0.0051 [ICE]	0.01 [Winnipeg]

Transport (from production location to site)

- Distance from nearest river (Sindh Wah) to shelter — worst case 15 km
- Mode from nearest river (Sindh Wah) to shelter — Animal drawn cart: 0 kgCO2/km/kg material
- Distance from Rohri (quarry, for hill sand) to market — 40 km
- Mode from Rohri (quarry, for hill sand) to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market (for hill sand) to shelter — 20 km
- Mode from market (for hill sand) to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = 0 + (0.00005 * 0.5 * 40) + (0.00006 * 0.5 * 20) + (0.17 * 40)+ (0.12 * 20)
= (0.0016 per kg material + 9.2) kg CO2



Hill sand – quarry locations
Rohri
Bulhari (District Noori abad)
Choondko (District Khairpur)
Johi
KN Shah & Mehar (District Dadu)
Ghari Khero (Jacobabad)
Sui (Balochistan, near Jacobabad)
Dera Bughti (near District Kashmore)
Hyderabad to Karchi Mountain belt
Makli/Thatta

References

PROD ▪ *ice_v2.0_-_jan_2011.xls*
PROD ▪ *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
TRAN ▪ *Email from Abdul Samad to Lottie McCarthy (27Jan2017)*

 ARUP

Embodied Carbon – Stone Aggregate

Used for *concrete component / foundations*

Description of production process

- Quarrying, rock extraction, crushing

Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	**0.011** [UK Gov, primary production]	**0.002** [UK Gov, reused]	**0.0052** [ICE]

Transport (from production location to site)

- Typically bought from the market as "crushed aggregate" rather than obtaining loose rocks local to the shelter
- Distance from Rohri (quarry) to market: 40 km
- Mode from Rohri (quarry) to market: Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter: 20 km
- Mode from market to shelter: Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 40) + (0.00006 * 20) + (0.17 * 40)+ (0.12 * 20)
= (0.0032 per kg material + 9.2) kg CO2

Crushed aggregate – quarry/crush plant locations
Rohri
Bulhari (District Noori abad)
Choondko (District Khairpur)
Johi
KN Shah & Mehar (District Dadu)
Ghari Khero (Jacobabad)
Sui (Balochistan, near Jacobabad)
Dera Bughti (near District Kashmore)
Hyderabad to Karchi Mountain belt
Makli/Thatta

References

- DESC *http://www.lafarge.ua/wps/portal/ua/3_2_1-Manufacturing_process*
- PROD *ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls*
- PROD *ice_v2.0_-_jan_2011.xls*
- TRAN *Email from Abdul Samad to Lottie McCarthy (27Jan2017)*

Embodied Carbon – Concrete

Used for *roof structure / foundations / ring beams*

Description of production process

- Cement production, aggregate production, mixing, compacting, curing

Production (raw material extraction and manufacturing)

- The raw materials (Cement, Sand, Stone Aggregate) are discussed on other slides
- Assume M10 concrete (cement:sand:aggregate, 1:3:6)

M10 Carbon Factor = (1/10 * 0.89) + (3/10 * 0.01) + (6/10 * 0.011)
= 0.099 kg CO2 per kg

Transport (from production location to site)

- Assume concrete mixed locally with the raw materials transported in
- The raw materials (Cement, Sand, Stone Aggregate) are discussed on other slides

Total CO2 (one trip) = (1/10 * 0.021) + (3/10 * 0.0016) + (6/10 * 0.0032) + 70.4 + 9.2 + 9.2
= (0.0045 per kg material + 88.8) kg CO2

References

- DESC *http://www.madehow.com/Volume-1/Concrete.html*
- PROD *http://theconstructor.org/concrete/methods-of-proportioning-concrete/5283/*

Embodied Carbon – Burnt Brick

Used for *walls (primary component) / foundations*

Description of production process

- Raw material extraction, crushing, mixing, forming, firing in a kiln, coating, drying

Production (raw material extraction and manufacturing)

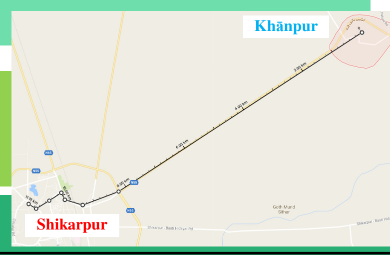
- *IOM* discouraged the use of burnt bricks due to environmental reasons – specifically because of the increasing scarcity of timber due to trees being cut down to burn in the brick kilns

kg CO_2 per kg of material	**0.245** [UK Gov, primary production]	**0.239** [ICE, based on 0.55 for a 2.3kg brick]

Transport (from production location to site)

- Assume originates from the local Mughal Bricks Kiln facility in Khānpur
- Distance from Khānpur to market — 11 km
- Mode from Khānpur to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 11) + (0.00006 * 20) + (0.17 * 11)+ (0.12 * 20)
= (0.018 per kg material + 4.3) kg CO2



References

- DESC — *http://www.madehow.com/Volume-1/Brick.html*
- PROD — *ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls*
- PROD — *ice_v2.0_-_jan_2011.xls*
- PROD — *KII Data.xlsx*
- TRAN — *http://www.directoryforest.com/mughal-bricks-kiln-khanpur(shikarpur)/*

Embodied Carbon – Burnt Brick – Kilns

- A lot of the environmental reservations for using burnt bricks originate from:
  - The uncertainty over the efficiency of the brick kilns
  - The choice of fuelled which is used inside the kilns to fire the bricks
- According to a study carried out in India in 2012, there are five commonly used varieties of brick kiln, each with different inherent carbon factors:

Kiln technology		Carbon Factor (kg CO_2 per kg of fired brick)
DDK	Down Draught Kiln	0.282
Tunnel	Tunnel Kiln	0.166
FCBTK	Fixed Chimney Bull's Trench Kiln	0.115
Zig-Zag	Zig-Zag Kiln	0.103
VSBK	Vertical Shaft Brick Kiln	0.070

Table 5: Emission Factors for the Monitored Kilns

Technology	Emission Factors (g/kg of fired brick)				
	SPM	PM2.5	SO_2	CO	CO_2
FCBTK	0.86	0.18	0.66	2.25	115
Zig-zag	0.26	0.13	0.32	1.47	103
VSBK	0.11	0.09	0.54	1.84	70
DDK	1.56	0.97	n.d	5.78	282
Tunnel	0.31	0.18	0.72	2.45	166

Notes:

The emission factors for FCBTK, zig-zag and VSBK are a simple average of the three FCBTKs, two zig-zag kilns and two VSBK kilns respectively; for all the other kiln types, the data is for a single kiln.

n.d. = not detectable (measurement below detection limit)

- *DDK* are the least friendly of these kiln types, with a higher carbon factor than even the assumed "Production" value on the previous slide. *DDK* also ranks worst according to its particulate matter count (both SPM and PM2.5), and also for its carbon monoxide (CO) emissions. However did it emit very little sulphur dioxide (SO_2) according to the study
- It can be seen that other designs have a far better carbon factor performance. *Zig-Zag* and *VSBK* in particular have low values for CO_2, CO, SO_2 and particulates
- A further study could be done on selecting the most appropriate brick kiln for Pakistan

References

- *Brick_Kilns_Performance_Assessment.pdf*

ARUP

Embodied Carbon – Mud Brick

Used for — *walls (primary component) / foundations*

Description of production process
- Digging, shaping, sun-drying

Production (raw material extraction and manufacturing)
- Mud brick lifespan is typically more than 10 years
- Assume mud is excavated by hand and the bricks are dried naturally in the sun

kg CO_2 per kg of material	**0.0**

Transport (from production location to site)
- Assume that the mud is dug locally and carried or carted to the site of the shelter
- Distance from mud source to shelter — 1 km
- Mode from mud source to shelter — Animal drawn cart: 0 kgCO2/km/kg material

References
- PROD — *Stakeholder_Minutes_CESVI.docx* – CESVI meeting (4 April 2016)
- TRAN — *20161102 Assessments Combined V5.xlsx*

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Embodied Carbon – Mud

Used for — *walls (primary component) / foundations*

Description of production process
- Digging, sun-drying

Production (raw material extraction and manufacturing)
- Assume mud is excavated by hand and dried naturally in the sun
- Dung is also sometimes used as a component in the mud

kg CO_2 per kg of material	**0.0**

Transport (from production location to site)
- Assume that the mud is dug locally and carried or carted to the site of the shelter
- Distance from mud source to shelter — 1 km
- Mode from mud source to shelter — Animal drawn cart: 0 kgCO2/km/kg material

References
- PROD — *Stakeholder_Minutes_CESVI.docx* – CESVI meeting (4 April 2016)
- TRAN — *20161102 Assessments Combined V5.xlsx*

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Embodied Carbon – Poplar

Used for *walls (secondary component)*

Description of production process

- Logging, sizing, (treatment unlikely)

Production (raw material extraction and manufacturing)

- Alignment issues due to variety in the shapes and sizes of poplar trunks available
- Although fast growing, it is susceptible to termite attack whilst growing and once chopped
- According to *CESVI*, poor quality poplar (e.g. not seasoned properly, not straight) often had to be returned to the supplier

kg CO_2 per kg of material	**0.44** [UK Gov, wood, primary production]	**0.046** [UK Gov, wood, reused]	**0.20** [ICE, sawn softwood, from sustainably managed forest]	**0.59** [ICE, sawn softwood, *not* from sustainably managed forest]

Transport (from production location to site)

- Assume originates from KPK, as stated by the *CRS* agency – there are also various regional irrigated poplar plantations
- Distance from KPK to market: 900 km
- Mode from KPK to market: Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter: 20 km
- Mode from market to shelter: Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 900) + (0.00006 * 20) + (0.17 * 900)+ (0.12 * 20)
= (0.046 per kg material + 155.4) kg CO2

ICE calculation for sawn softwood: $0.20_{fos} + 0.39_{bio}$

- fos = fossil fuel value for chopping wood etc.
- bio = biomass value for amount of CO_2 no longer absorbed now that tree has been chopped down – only include if forest is *not* sustainably managed
- Beneficial effects of sequestration (i.e. carbon held molecularly within wood) not considered here

References

- DESC *http://www.wood-database.com/poplar/*
- PROD *http://www.fao.org/docrep/005/AC778E/AC778E15.htm*
- PROD *https://en.wikipedia.org/wiki/Forestry_in_Pakistan*
- PROD *ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls*
- PROD *ice_v2.0_-_jan_2011.xls*
- TRAN *Stakeholder_Minutes_CESVI.docx* – CESVI meeting (4 April 2016)
- TRAN *KII Data.xlsx*

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Embodied Carbon – Bamboo

Used for *roof structure / ring beams*

Description of production process

- Chopping, baked at low heat, termite-resistant (car oil) coating, possible oxide paint coating

Production (raw material extraction and manufacturing)

- Alignment issues due to variety in the shapes and sizes of bamboo available
- According to *CESVI*, poor quality bamboo often had to be returned to the supplier
- Bamboo is expected to last 15 years, provided treatment is carried out regularly (oil/Diesel/paint/grease/lime coatings)

kg CO_2 per kg of material	**0.40** [INBAR, page 24; steps 1, 2, 6, 11 + 0.20 added for treatment]

Transport (from production location to site)

- Assume originates from Punjab, as stated by the *CRS* agency
- Distance from Punjab to market: 650 km
- Mode from Punjab to market: Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter: 20 km
- Mode from market to shelter: Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 650) + (0.00006 * 20) + (0.17 * 650)+ (0.12 * 20)
= (0.034 per kg material + 112.9) kg CO2

References

- DESC *http://www.inbar.int/wp-content/uploads/downloads/2014/08/Technical-Report-No.35.pdf*
- PROD *http://www.bellobamboo.com/bamboo-facts-news/best-bamboo-treatment-for-long-lasting-results/*
- PROD *Stakeholder_Minutes_CESVI.docx* – CESVI meeting (4 April 2016)
- PROD *Bamboo Information Sheet.xlsx*
- TRAN *KII Data.xlsx*
- TRAN *Punjab suppliers contact details (ACTED).xlsx*

22 ARUP

Embodied Carbon – Polythene Sheet

Used for *roof covering*

Description of production process

- Cracking of crude oil, refining, heating, extruding

Production (raw material extraction and manufacturing)

- Assume LDPE (low density polyethylene)

kg CO_2 per kg of material	2.62 [UK Gov]	2.08 [ICE]	2.06 [Winnipeg, virgin]	1.01 [Winnipeg, recycled]

Transport (from production location to site)

- Assume originates from Lahore, in one of Pakistan's largest manufacturers of plastic products
- Distance from Lahore to market: 700 km
- Mode from Lahore to market: Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter: 20 km
- Mode from market to shelter: Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 700) + (0.00006 * 20) + (0.17 * 700)+ (0.12 * 20)
= (0.036 per kg material + 121.4) kg CO2

References

- DESC *http://nzic.org.nz/ChemProcesses/polymers/10J.pdf*
- PROD *ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls*
- PROD *ice_v2.0_-_jan_2011.xls*
- PROD *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
- TRAN *http://www.arcoplastics.com/contact-us.html*

Embodied Carbon – Chicks (bamboo)

Used for *roof covering*

Description of production process

- Chopping, heating, coating

Production (raw material extraction and manufacturing)

- Assume bamboo chicks
- *Prepared* claim that an increased harvesting of chicks material around rivers adversely affects the natural ecology

kg CO_2 per kg of material	0.40 [INBAR, page 24; steps 1, 2, 6, 11 + 0.20 added for treatment]

Transport (from production location to site)

- Assume originates from Punjab, as stated by the *CRS* agency
- Distance from Punjab to market: 650 km
- Mode from Punjab to market: Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter: 20 km
- Mode from market to shelter: Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 650) + (0.00006 * 20) + (0.17 * 650)+ (0.12 * 20)
= (0.034 per kg material + 112.9) kg CO2

References

- DESC *http://www.bellobamboo.com/bamboo-facts-news/best-bamboo-treatment-for-long-lasting-results/*
- PROD *http://www.inbar.int/wp-content/uploads/downloads/2014/08/Technical-Report-No.35.pdf*
- PROD *Bamboo Information Sheet.xlsx*
- PROD *KII Data.xlsx*
- TRAN *Punjab suppliers contact details (ACTED).xlsx*

Embodied Carbon – Concrete Blocks

Used for *walls (primary component) / foundations*

Description of production process

- Cement production, aggregate production, mixing, molding, curing

Production (raw material extraction and manufacturing)

- Assume blocks made locally with the raw materials transported in
- The raw materials (Cement, Sand, Stone Aggregate) are discussed on other slides
- Assume M10 concrete (cement:sand:aggregate, 1:3:6)

M10 Carbon Factor = (1/10 * 0.89) + (3/10 * 0.01) + (6/10 * 0.011)
= 0.099 kg CO2 per kg

Transport (from production location to site)

- Assume concrete mixed locally with the raw materials transported in
- The raw materials (Cement, Sand, Stone Aggregate) are discussed on other slides

Total CO2 (one trip) = (1/10 * 0.021) + (3/10 * 0.0016) + (6/10 * 0.0032) + 70.4 + 9.2 + 9.2
= (0.0045 per kg material + 88.8) kg CO2

References

DESC ▪ *http://www.madehow.com/Volume-3/Concrete-Block.html*
PROD ▪ *http://theconstructor.org/concrete/methods-of-proportioning-concrete/5283/*
TRAN ▪ *Email from Abdul Samad to Lottie McCarthy (27Jan2017)*

ARUP

Embodied Carbon – Lime

Used for *walls (secondary component) / foundations*

Description of production process

- Raw material extraction, crushing, preheating, calcining, forced cooling

Production (raw material extraction and manufacturing)

- Lime typically used in shelters built from 2014 onwards, and heated locally from limestone in small-scale kilns
- Improves waterproofing qualities of the wall structure and so improves durability
- According to *IOM*, in the Kacha area of Punjab, it was less challenging to produce lime than to procure cement. Lime is more carbon friendly than cement – one aspect of this is transportation because there are only one or two cement factories in Sindh, versus lime kilns which are widely scattered all over the region, and which typically burn twigs/branches/grass/straw husks (mostly due to cost) instead of fossil fuels

kg CO_2 per kg of material	**0.78** [ICE, based on UK weighted average]	**0.74** [Winnipeg]	**0.75** [IPCC-NGGIP]

Transport (from production location to site)

- Assume originates from KPK, at the Gray Limestone Quarry
- Distance from KPK to market — 900 km
- Mode from KPK to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 900) + (0.00006 * 20) + (0.17 * 900)+ (0.12 * 20)
= (0.046 per kg material + 155.4) kg CO2

References

DESC ▪ *http://lime.org/lime-basics/how-lime-is-made/*
PROD ▪ *Stakeholder_Minutes_CESVI.docx* – CESVI meeting (4 April 2016)
PROD ▪ *Email from Hasballah to Tim White (19 February 2017)*
PROD ▪ *ice_v2.0_-_jan_2011.xls*
PROD ▪ *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
TRAN ▪ *http://www.stonecontact.com/pakistan-grey-limestone-quarries*

ARUP

Embodied Carbon – Sawn Timber

Used for *roof structure*

ICE calculation for sawn softwood: $0.20_{fos} + 0.39_{bio}$
- fos = fossil fuel value for chopping wood etc.
- bio = biomass value for amount of CO_2 no longer absorbed now that tree has been chopped down – only include if forest is *not* sustainably managed
- Beneficial effects of sequestration (i.e. carbon held molecularly within wood) not considered here

Description of production process

- Logging, sawing, treating

Production (raw material extraction and manufacturing)

- Species of timber not specified

kg CO_2 per kg of material	0.44 [UK Gov, wood, primary production]	0.046 [UK Gov, wood, reused]	0.20 [ICE, sawn softwood, from sustainably managed forest]	0.59 [ICE, sawn softwood, *not* from sustainably managed forest]

Transport (from production location to site)

- Assume originates from nearest significant patch of forest
- Distance from nearest forest to market — 250 km
- Mode from nearest forest to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 250) + (0.00006 * 20) + (0.17 * 250)+ (0.12 * 20)
= (0.014 per kg material + 44.9) kg CO2

References

- PROD — *http://www.fao.org/docrep/005/AC778E/AC778E15.htm*
- PROD — *https://en.wikipedia.org/wiki/Forestry_in_Pakistan*
- PROD — *ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls*
- TRAN — *ice_v2.0_-_jan_2011.xls*

Embodied Carbon – Structural Steel

Used for *roof structure / ring beams*

Description of production process

- Ore extraction, iron-making, furnace, possible cold forming, coating

Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	2.89 [ICE, virgin]	0.47 [ICE, recycled]	3.29 [Winnipeg, virgin]	0.88 [Winnipeg, recyc]

- Assume a mixture of virgin steel (from China) and recycled steel from a market in Pakistan
- 1,600 million tonnes of steel were produced in 2015 according to World Steel Association, and 650 million tonnes of steel are recycled each year

Steel Carbon Factor = (650/1600 * 0.47) + (950/1600 * 2.89)
(based on ICE) = 1.91 kg CO2 per kg

Steel Carbon Factor = (650/1600 * 0.88) + (950/1600 * 3.29)
(based on Winnipeg) = 2.31 kg CO2 per kg

Transport (from production location to site)

- Assume originates from Karachi
- Distance from Karachi to market — 400 km
- Mode from Karachi to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 400) + (0.00006 * 20) + (0.17 * 400)+ (0.12 * 20)
= (0.021 per kg material + 70.4) kg CO2

References

- DESC — *http://www.eef.org.uk/uksteel/About-the-industry/How-steel-is-made/*
- DESC — *161020.NED Meeting notes.docx*
- PROD — *ice_v2.0_-_jan_2011.xls*
- PROD — *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
- PROD — *World Steel in Figures 2016.pdf*
- TRAN — *http://www.paksteel.com.pk/contact.html*

ARUP

Embodied Carbon – Reinforcing Steel

Used for *walls (secondary component) / roof structure*

Description of production process

- Ore extraction, iron-making, furnace, possible cold forming, coating

Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	2.89 [ICE, virgin]	0.47 [ICE, recycled]	3.29 [Winnipeg, virgin]	0.88 [Winnipeg, recyc]

- Assume a mixture of virgin steel (from China) and recycled steel from a market in Pakistan
- 1,600 million tonnes of steel were produced in 2015 according to World Steel Association, and 650 million tonnes of steel are recycled each year

Steel Carbon Factor = (650/1600 * 0.47) + (950/1600 * 2.89)
(based on ICE) = 1.91 kg CO2 per kg

Steel Carbon Factor = (650/1600 * 0.88) + (950/1600 * 3.29)
(based on Winnipeg) = 2.31 kg CO2 per kg

Transport (from production location to site)

- Assume originates from Karachi
- Distance from Karachi to market — 400 km
- Mode from Karachi to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 400) + (0.00006 * 20) + (0.17 * 400)+ (0.12 * 20)
= (0.021 per kg material + 70.4) kg CO2

References

DESC ▪ *http://www.eef.org.uk/uksteel/About-the-industry/How-steel-is-made/*
DESC ▪ *161020.NED Meeting notes.docx*
PROD ▪ *ice_v2.0_-_jan_2011.xls*
PROD ▪ *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
PROD ▪ *World Steel in Figures 2016.pdf*
TRAN ▪ *http://www.paksteel.com.pk/contact.html*

ARUP

Embodied Carbon – Straw

Used for *walls (secondary component) / roof covering*

Description of production process

- Harvesting, separation from grain (wheat), bailing

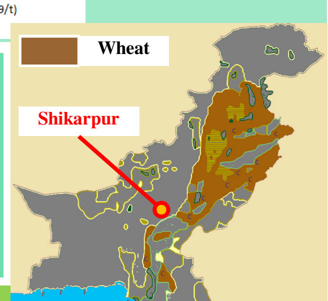
Production (raw material extraction and manufacturing)

Straw Carbon Factor = Wheat Carbon Factor * (Value of Straw) / ((Value of Straw) + (Value of Wheat))
= 0.361 * £0.038/t / (£0.038/t + £0.099/t)
= 0.100 kg CO2 per kg

Transport (from production location to site)

- Using wheat map of Pakistan, can assume the nearest likely source
- Distance from wheat fields to market — 40 km
- Mode from wheat fields to market
  Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter
  Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 40) + (0.00006 * 20) + (0.17 * 40)+ (0.12 * 20)
= (0.0032 per kg material + 9.2) kg CO2



References

DESC ▪ *https://cereals.ahdb.org.uk/media/176733/g57_understanding_carbon_footprinting_for_cereals_and_oilseeds.pdf*
PROD ▪ *http://www.indexmundi.com/commodities/?commodity=wheat&months=12&currency=gbp*
PROD ▪ *https://dairy.ahdb.org.uk/market-information/farm-expenses/hay-straw-prices/#.WIc8tE1VrvU*
TRAN ▪ *https://upload.wikimedia.org/wikipedia/commons/e/e1/Pakistan_Agriculture.png*

ARUP

Embodied Carbon – Nails (iron)

Used for *other*

Description of production process

- Raw metal extraction, wire forming, shaping in nail-making machine, cleaning, finishing

Production (raw material extraction and manufacturing)

- Assume iron nails

kg CO_2 per kg of material	**2.03** [ICE]	**1.91** [Winnipeg]

Transport (from production location to site)

- Assume originates from Karachi, at one of Pakistan's largest fastener manufacturers
- Distance from Karachi to market — 400 km
- Mode from Karachi to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 400) + (0.00006 * 20) + (0.17 * 400)+ (0.12 * 20)
= (0.021 per kg material + 70.4) kg CO2

References

- DESC *http://www.madehow.com/Volume-2/Nail.html*
- PROD *ice_v2.0_-_jan_2011.xls*
- PROD *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
- TRAN *http://www.adamjee-engg.com/fastener/contact.html*

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Embodied Carbon – Screws (steel)

Used for *other*

Description of production process

- Raw metal extraction, forming into wire, thread rolling, cleaning, finishing

Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	**2.89** [ICE, virgin]	**0.47** [ICE, recycled]	**3.29** [Winnipeg, virgin]	**0.88** [Winnipeg, recyc]

- Assume steel screws

Steel Carbon Factor = (650/1600 * 0.47) + (950/1600 * 2.89)
(based on ICE) = 1.91 kg CO2 per kg

Steel Carbon Factor = (650/1600 * 0.88) + (950/1600 * 3.29)
(based on Winnipeg) = 2.31 kg CO2 per kg

Transport (from production location to site)

- Assume originates from Karachi, at one of Pakistan's largest fastener manufacturers
- Distance from Karachi to market — 400 km
- Mode from Karachi to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 400) + (0.00006 * 20) + (0.17 * 400)+ (0.12 * 20)
= (0.021 per kg material + 70.4) kg CO2

References

- DESC *http://www.madehow.com/Volume-3/Screw.html*
- PROD *ice_v2.0_-_jan_2011.xls*
- PROD *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
- TRAN *http://www.adamjee-engg.com/fastener/contact.html*

32 ARUP

Embodied Carbon – Cotton Rope

Used for *other*

Description of production process

- Extraction of natural materials, spinning, twisting

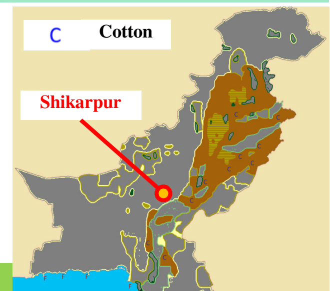
Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	**0.0038** [Stockholm Environment Institute, figure for organic cotton in India]

Transport (from production location to site)

- Using wheat map of Pakistan, can assume the nearest likely source
- Distance from cotton fields to market 40 km
- Mode from cotton fields to market
  Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter 20 km
- Mode from market to shelter
  Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 40) + (0.00006 * 20) + (0.17 * 40)+ (0.12 * 20)
= (0.0032 per kg material + 9.2) kg CO2



References

- DESC *http://www.madehow.com/Volume-2/Rope.html*
- PROD *https://oecotextiles.wordpress.com/2011/01/19/estimating-the-carbon-footprint-of-a-fabric/*
- TRAN *https://upload.wikimedia.org/wikipedia/commons/e/e1/Pakistan_Agriculture.png*

33 ARUP

Embodied Carbon – Nylon Rope

Used for *other*

Description of production process

- Cracking of crude oil, refining, spinning, twisting

Production (raw material extraction and manufacturing)

kg CO_2 per kg of material	**7.90** [Winnipeg]

Transport (from production location to site)

- Assume originates from Lahore, at Haid Enterprises, the nearest known nylon rope manufacturer
- Distance from Lahore to market 700 km
- Mode from Lahore to market Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter 20 km
- Mode from market to shelter Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 700) + (0.00006 * 20) + (0.17 * 700)+ (0.12 * 20)
= (0.036 per kg material + 121.4) kg CO2

References

- DESC *http://www.madehow.com/Volume-2/Rope.html*
- PROD *http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf*
- TRAN *http://wk101536103.company.weiku.com/*

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Embodied Carbon – PVC Pipe

Used for *other*

Description of production process

- Cracking of crude oil, refining, shaping, heating

Production (raw material extraction and manufacturing)

- Assume manufactured pipe sections of PVC (polyvinyl chloride)

kg CO_2 per kg of material	**3.43** [UK Gov]	**3.23** [ICE]	**2.22** [Winnipeg, virgin]	**0.48** [Winnipeg, recycled]

Transport (from production location to site)

- Assume originates from KPK, at Pakistan's largest PVC products manufacturer
- Distance from KPK to market 900 km
- Mode from KPK to market Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter 20 km
- Mode from market to shelter Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 900) + (0.00006 * 20) + (0.17 * 900)+ (0.12 * 20)
= (0.046 per kg material + 155.4) kg CO2

References

- DESC http://www.pvc.org/en/p/how-is-pvc-made
- PROD ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls
- PROD ice_v2.0_-_jan_2011.xls
- PROD http://www.winnipeg.ca/finance/findata/matmgt/documents/2012/682-2012/682-2012_Appendix_H-WSTP_South_End_Plant_Process_Selection_Report/Appendix%207.pdf
- TRAN http://www.royalpvc.com.pk/contact-royalpvc

Embodied Carbon – Reed Mat

Used for *walls (secondary component) / roof covering / other*

Description of production process

- Reed plant harvesting, weaving (by hand?) into mats

Production (raw material extraction and manufacturing)

- Assume reeds collected by hand, and from an environment where replenishment is assured
- Assume small volumes, obtained from local market, and weaved by hand

kg CO_2 per kg of material	**0**

Transport (from production location to site)

- Point of origin unknown, assume within walking/carting distance of the market
- Distance from market to shelter 20 km
- Mode from market to shelter Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00006 * 20) + (0.12 * 20)
= (0.0012 per kg material + 2.4) kg CO2

References

- DESC https://www.lime.org.uk/reed-matt.html
- PROD https://en.wikipedia.org/wiki/Forestry_in_Pakistan
- PROD ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls

Embodied Carbon – Palm Mat

Used for — *walls (secondary component) / roof covering / other*

Description of production process

- Palm plant harvesting, weaving (by hand?) into mats

Production (raw material extraction and manufacturing)

- Assume palm leaves stripped by hand, and that the trees themselves are not cut down
- Assume small volumes, obtained from local market, and weaved by hand

kg CO_2 per kg of material	**0**

Transport (from production location to site)

- Point of origin unknown, assume within walking/carting distance of the market
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00006 * 20) + (0.12 * 20)
= (0.0012 per kg material + 2.4) kg CO2

References

DESC ▪ *http://www.palmwood.com.my/the-wood.html*
PROD ▪ *https://en.wikipedia.org/wiki/Forestry_in_Pakistan*
PROD ▪ *ghg-conversion-factors-2016update_MASTER__links_removed__v2.xls*

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Embodied Carbon – Galvanised Wire

Used for — *other*

Description of production process

- Raw metal extraction, formed into wire, coating

Production (raw material extraction and manufacturing)

- Assume steel wire with zinc coating

kg CO_2 per kg of material	**1.54** [Highways England case study: galvanised steel handrail]

Transport (from production location to site)

- Assume originates from Karachi, at Pakistan Wire Industries, one of Pakistan's only manufacturers of this kind
- Distance from Karachi to market — 400 km
- Mode from Karachi to market — Truck: 0.17 kgCO2/km + 0.00005 kgCO2/km/kg material
- Distance from market to shelter — 20 km
- Mode from market to shelter — Tractor trolley: 0.12 kgCO2/km + 0.00006 kgCO2/km/kg material

Total CO2 (one trip) = (0.00005 * 400) + (0.00006 * 20) + (0.17 * 400) + (0.12 * 20)
= (0.021 per kg material + 70.4) kg CO2

References

DESC ▪ *http://www.tecnofil.net/produzione-prodotto-tecnofil.asp/lang_2/category_1/product_1/galvanized-wire.html*
PROD ▪ *Task_446_Carbon_Tool_v1.03.xlsm*
TRAN ▪ *http://www.pwi.com.pk/Location.htm*

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Embodied Carbon – Summary table *for shelters in Shikarpur region*

Material	Used for	Production Carbon Factor (kg CO_2 per kg of material)	Transport Carbon Factor (kg CO_2)
Cement (OPC)	*walls (secondary component) / concrete component*	0.89	0.021 per kg material + 70.4
Sand	*walls (secondary component) / concrete component*	0.010	0.0016 per kg material + 9.2
Stone Aggregate	*concrete component / foundations*	0.011	0.0032 per kg material + 9.2
Concrete	*roof structure / foundations / ring beams*	0.099	0.0045 per kg material + 88.8
Burnt Brick	*walls (primary component) / foundations*	0.245	0.018 per kg material + 4.3
Mud Brick	*walls (primary component) / foundations*	0	0 per kg material
Mud	*walls (primary component) / roof covering / foundations*	0	0 per kg material
Poplar	*walls (secondary component)*	0.20 / 0.59 *	0.046 per kg material + 155.4
Bamboo	*roof structure / ring beams*	0.40	0.034 per kg material + 112.9
Polythene Sheet	*roof covering*	2.62	0.036 per kg material + 121.4
Chicks (bamboo)	*roof covering*	0.40	0.034 per kg material + 112.9
Concrete Blocks	*walls (primary component) / foundations*	0.099	0.0045 per kg material + 88.8
Lime	*walls (secondary component) / foundations*	0.78	0.046 per kg material + 155.4
Sawn Timber	*roof structure*	0.20 / 0.59 *	0.014 per kg material + 44.9
Structural Steel	*roof structure / ring beams*	2.31 virgin/recycled weighted average	0.021 per kg material + 70.4
Reinforcing Steel	*walls (secondary component) / roof structure*	2.31 virgin/recycled weighted average	0.021 per kg material + 70.4
Straw	*walls (secondary component) / roof covering*	0.10	0.0032 per kg material + 9.2
Nails (iron)	*other*	2.03	0.021 per kg material + 70.4
Screws (steel)	*other*	2.31 virgin/recycled weighted average	0.021 per kg material + 70.4
Cotton Rope	*other*	0.0038	0.0032 per kg material + 9.2
Nylon Rope	*other*	7.90	0.036 per kg material + 121.4
PVC Pipe	*other*	3.43	0.046 per kg material + 155.4
Reed Mat	*walls (secondary component) / roof covering / other*	0	0.0012 per kg material + 2.4
Palm Mat	*walls (secondary component) / roof covering / other*	0	0.0012 per kg material + 2.4
Galvanised Wire	*other*	1.54	0.021 per kg material + 70.4

* from a sustainably managed forest / *not* from a sustainably managed forest

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2. Material Availability

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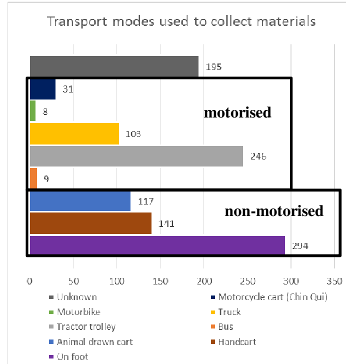
Material Availability – Transportation Options

- Considerations:
  - *Availability of each mode* e.g. most people have access to some form of cart but there may be only a small number of trucks throughout a village, which would need to be hired/shared
  - *Number of journeys needed* to transport full amount of material from the market to the shelter location i.e. different modes have different capacities – a truck or large cart can carry large volumes whereas a motorcycle/handcart/on foot cannot
  - *Human effort required* for each transport mode e.g. a bus may take a lot of trips but it is a relatively low energy option in comparison with using a motorcycle or carrying on foot
- The survey question relating to transportation options was asked independently of the material types obtained. So there is a gap in the information given for this



- Only 48% of homeowners (383 out of 800) stated having used some form of motorised transportation in order to collect materials. There may be additional homeowners who do have access to motorised transportation but who didn't need to use it. And others without transportation may have borrowed it, however the data does not allow any insight into this
- There were 9 instances of homeowners using only an animal drawn cart to collect wall materials from distances of between 10km and 19km
- The furthest reported distance to collect materials on foot was 5km

References
- *20161102 Assessments Combined V5.xlsx*

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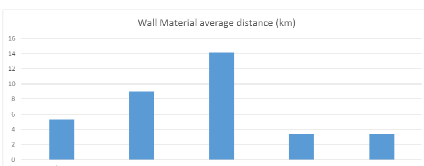
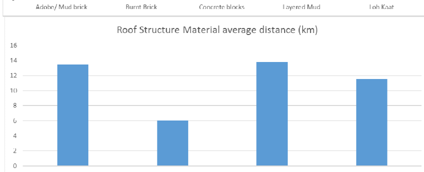
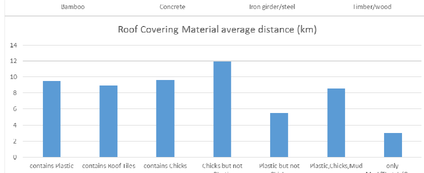
Material Availability – Distances to obtain material







- Average distances (5-15 km) are manageable when tractors/carts are available – gives a round trip time of approx. 30 minutes at an average speed of 50km/hour
- Those distances would be likely be too great to expect a person travel on foot whilst carrying a load – would represent a 6 hour roundtrip at an average walking speed of 5km/hour

	distance (km)					
wall material	AVERAGE	MAX	MIN	sample size	did not answer	total shelters
Adobe/ Mud brick	5.3	50	0.5	141	54	195
Burnt Brick	9.0	40	0.25	113	80	193
Concrete blocks	14.2	45	4	6	27	33
Layered Mud	3.4	38	0.5	119	83	202
Loh Kaat	3.4	30	0.5	98	79	177
				477	323	800

	distance (km)					
roof structure material	AVERAGE	MAX	MIN	sample size	did not answer	total shelters
Bamboo	13.5	180	0.5	129	80	209
Concrete	6.0	6	6	6	16	22
Iron girder/steel	13.8	300	0.5	227	206	433
Timber/wood	11.6	50	0.5	83	53	136
				445	355	800

	distance (km)					
roof covering material	AVERAGE	MAX	MIN	sample size	did not answer	total shelters
contains Plastic	9.5	180	0.5	502	221	723
contains Roof Tiles	9.0	80	0.5	33	16	49
contains Chicks	9.7	180	0.5	507	206	713
Chicks but not Plastic	11.9	30	1	14	8	22
Plastic but not Chicks	5.6	19	1	9	8	17
Plastic,Chicks,Mud	8.6	80	0.5	458	200	658
only Mud/Thatch/Grass	3.0	8	1	4	3	7

References
- *20161102 Assessments Combined V5.xlsx*

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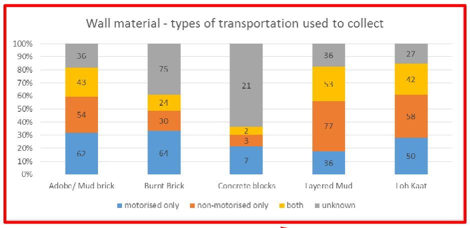
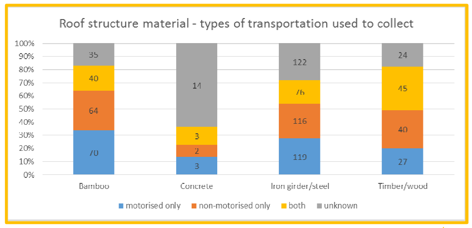
Material Availability – Materials vs transport modes





wall material	TOTAL SHELTERS	Truck	Tractor trolley	Bus	Motorcycle	Animal drawn cart	Handcart	On foot	Unknown	Motorised only	Non-motorised only	Both
										Type of transporation available		
Adobe/ Mud brick	195	19	86	0	4	29	37	69	36	62	54	43
Burnt Brick	193	15	63	2	11	23	4	34	75	64	30	24
Concrete blocks	33	4	5	0	0	2	1	3	21	7	3	2
Layered Mud	202	47	25	2	18	34	54	108	36	36	77	53
Loh Kaat	177	18	67	6	6	29	45	80	27	50	58	42
	800	103	246	10	39	117	141	294	195	219	222	164
									800			

roof structure material	TOTAL SHELTERS	Truck	Tractor trolley	Bus	Motorcycle	Animal drawn cart	Handcart	On foot	Unknown	Motorised only	Non-motorised only	Both
										Type of transporation available		
Bamboo	209	30	72	7	7	22	48	83	35	70	64	40
Concrete	22	3	1	2	2	0	2	5	14	3	2	3
Iron girder/steel	433	53	129	1	17	65	64	137	122	119	116	76
Timber/wood	136	17	44	0	13	30	27	69	24	27	40	45
	800	103	246	10	39	117	141	294	195	219	222	164
									800			

- Adobe, layered mud and loh kaat shelters typically had a greater percentage of homeowners using *only* non-motorised modes of transport to collect material, possibly due to motorised vehicles being unnecessary rather than them being unavailable
- It was common for a mix of motorised and non-motorised transportation to be used by a single homeowner
- For shelters containing concrete, greater than 60% of homeowners did not know how the material arrived to them, and similarly for those using burnt brick/iron/steel – presumably heavy materials were often delivered by agencies

References
- *20161102 Assessments Combined V5.xlsx*

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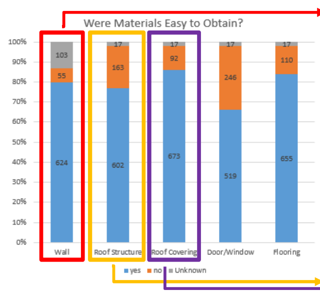
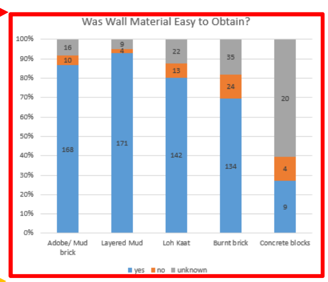
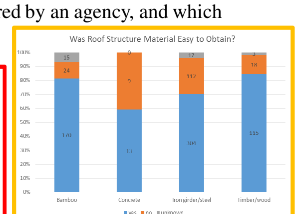
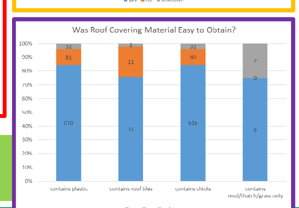
Material Availability – Ease of obtaining materials

- Overall, 70-80% of all materials were reported as "easy to obtain" in the surveys – this is positive, and suggests that both the surroundings and the local markets are well-stocked with materials appropriate for constructing some form of liveable shelter
- Doors/windows are harder to obtain than wall/roof material because they are relatively complex, engineered products rather than basic raw materials. Second-hand doors/windows were often donated by members of the local community – *HANDS* state that >80% of beneficiaries installed used doors/windows
- The survey data does not specify which materials may have been delivered by an agency, and which materials were collected (e.g. from a market) by the homeowners









References
- *20161102 Assessments Combined V5.xlsx*
- *KII Data.xlsx*

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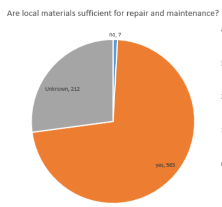
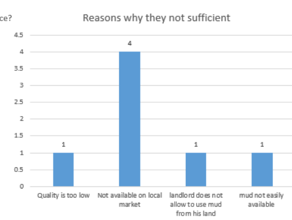
Material Availability – Repairs and Modifications

- Approximately 70% of homeowners said that local materials were sufficient to cover the repair and maintenances needs of their shelter. With a lot of "No comment" answers, only 7 examples of why local materials were insufficient were given, usually down to lack of availability in the local market
- In general, homeowners believed repairing/maintaining their shelter with local materials was a challenge – of the 570 homeowners who commented, 78% of them described it as "Difficult", with one additional homeowner describing their loh kaat and bamboo shelter as being "Impossible" to repair/maintain
- Proportionally, burnt brick was the easiest to repair/maintain, with 27% of commenting homeowners stating that their burnt brick shelters were "Manageable" or "Easy" to repair/maintain
- Worth noting that the wording of the question with "local" materials could be ambiguous to the homeowner. Do they consider the market to be local? Or did they take "local" to mean within a short walking distance of their shelter?





How easy is it for you to repair/maintain the shelter?

wall material	Impossible or Difficult	Manageable or Easy	No Comment	Sample Size
Adobe/ Mud brick	126	24	45	195
Burnt Brick	69	25	99	193
Concrete blocks	10	2	21	33
Layered Mud	126	40	36	202
Loh Kaat	118	30	29	177
	449	121	230	800

roof structure material	Impossible or Difficult	Manageable or Easy	No Comment	Sample Size
Bamboo	136	37	36	209
Concrete	6	2	14	22
Iron girder/steel	214	66	153	433
Timber/wood	93	16	27	136
	449	121	230	800

References

- *20161102 Assessments Combined V5.xlsx*

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Material Availability – Other comments

- Design life for the shelters is typically quoted as being between 5 and 15 years for most agencies depending on whether they want the shelter to be transitional or "permanent"
- *IOM* encouraged project communities to jointly procure materials
- According to *CESVI*, getting good quality material such as poplar and bamboo was a problem and materials often had to be returned to the supplier
- *Sangtani* had a "Complaint Response Mechanism" in place to ensure material quality – complaints made by the beneficiaries about poor quality burnt bricks/cement/wet bamboo
- *UN Habitat* say that the quality of construction material in the local markets was identified as a major concern. *CRS* and *SEAD* also reported complaints from the beneficiaries
- Maintenance activities (as part of structured agency programs) include mud plastering and anti-termite treatment
- Trees are generally hard to come by in the hot and dry Sindh region. According to *IOM*, the limited tree population and the number of shelters that had to be built during the same period may have contributed to the low availability of branches to be used in shelter construction – homeowners did not wish to cut down "productive" trees (e.g. mango) for the purposes of construction
- Materials were transported to warehouses near project sites. Beneficiaries transported them individually from there by tractor, according to *ACTED*
- *CESVI* say much of the material was not local – from North Punjab, Sheikhupura, Lahore and KPK
- *IOM* brought up a particular issue with soil salinity in relation to quality of mud for layered mud shelters. Loh kaat became an attractive option for those homeowners who struggled with the mud due to a high salt content
- Local partners stated a concern with the use of chicks, due to risk of it becoming an un-replenished resource
- There were also anecdotal stories of landlords barring access to earth which homeowners would have used for mud-based shelter construction

References

- *KII Data.xlsx*
- *Email from Abdul Samad to Lottie McCarthy (1 February 2017)*
- *Email from Hasballah to Tim White (11 January 2017)*

ARUP

Material Availability – Summary of key findings

- In general, materials had good availability from local markets and suppliers – 70-80% of all materials were reported as “easy to obtain” in the surveys
- Only 48% of homeowners used some form of motorised transportation in order to collect materials. For the other 52% (i.e. exclusively non-motorised means of collecting materials), typically small distances were involved – this ties in with mud-based shelters (i.e. adobe, layered mud and loh kaat) having a greater percentage of homeowners using *only* non-motorised modes of transport to collect material
- There were 9 instances of homeowners using only an animal drawn cart to collect wall materials from distances of between 10km and 19km, and the furthest reported distance to collect materials on foot was 5km (i.e. a 2 hour roundtrip)
- It was common for a mix of motorised and non-motorised transportation to be used by a single homeowner
- It is presumed that heavy materials were often delivered by agencies, because >50% of concrete/burnt brick/iron/steel homeowners did not know how the material arrived to them
- Second-hand doors/windows were often donated by members of the local community – *HANDS* state that >80% of beneficiaries installed used doors/windows
- Approximately 70% of homeowners said that local materials were sufficient to cover the repair and maintenances needs of their shelter, and the few comments given against this opinion usually mentioned a lack of availability in the local market
- 78% of homeowners who commented described repairing/maintaining their shelter as “Difficult”
- Burnt brick was the easiest to repair/maintain, with 27% of commenting homeowners describing it as “Manageable” or “Easy”
- Getting good quality poplar/bamboo was a problem – materials often had to be returned to the supplier

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3. Labour Standards

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Labour Standards – Overview

- "Labour Standards" is all about ensuring that:
  - human rights are respected and assured throughout the supply chain
  - reasonable precautions and standards are in place to actively mitigate against harm being done
    - to any individuals involved in construction of the shelters
    - to any individuals during the habitation phase of the shelters
  - efforts are made to maximise the positive contribution of the project on the homeowners and the wider community
- Labour Standards encourages the benefits of homeowner involvement, and tries to minimise any detriments due to his/her involvement
- Supplementary aspects include the quality of training provided to workers, and any reported cases of using child labour at the suppliers' end
- *IOM* claimed that there were a lack of experts and technical staff observed from the implementing partner organisations

References
- *20161102 Assessments Combined V5.xlsx*

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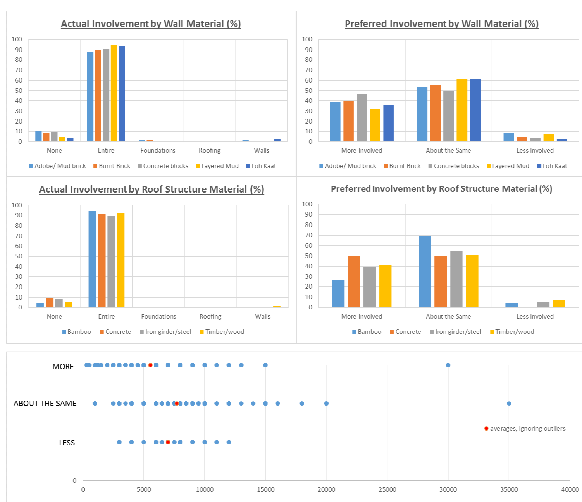
Labour Standards – Involvement

- 91% of homeowners were involved in the entire construction process
- The combination least likely to have homeowner involvement was mud brick walls with iron girder roofs
- Only 6% of those who were involved would have liked less involvement, whereas 37% would have liked to have been even more involved in construction
- The trends for preferred involvement do not depend on material types used
- Those homeowners on the smallest monthly incomes were most likely to desire more involvement in their shelters, either to earn more money or perhaps due to having more free time



References
- *20161102 Assessments Combined V5.xlsx*

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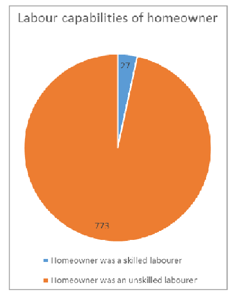
Labour Standards – Training

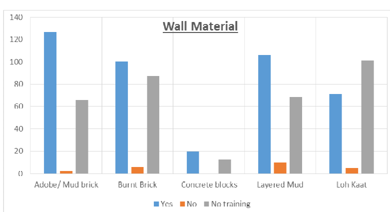
- All of the agencies organised some kind of training workshops for local workers to improve the construction quality of the shelters. Most were aimed at skilled labourers but some involved the community in general. Training sometimes extended to DRR (Disaster Risk Reduction) techniques, repair and maintenance
- Only 27 of the 800 homeowners were already skilled labourers, prior to this period of training

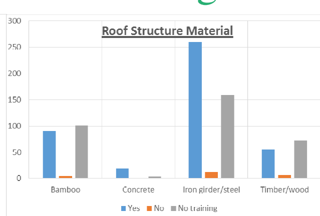
Agency	Training Arrangements
ACTED	organized 2 day training workshops for workers on use of lime with mud bricks and its preparation
CESVI	training for community - DRR measures, foundation construction, maintenance
CRS	general training given to the community
IOM	levels of training were good but needed further training related to maintenance and material treatments
Prepared	1 day training workshops for identified skilled workers where demo shelters were constructed
Sangtani	organised training workshops for identified skilled labour about shelter design as well as workshops on maintenance for the community
SEAD	training sessions organised for various stages of the project - especially for mud with lime use



References
- *20161102 Assessments Combined V5.xlsx*
- *KII Data.xlsx*

Labour Standards – Was Training Sufficient?

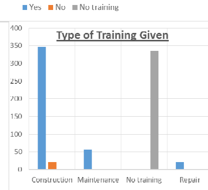


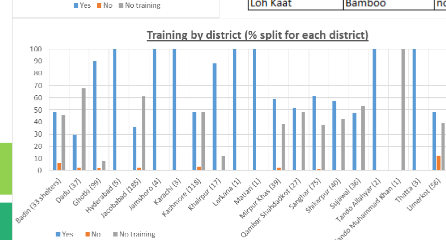


Shelters (wall/roof structure combinations) where training was described as "not sufficient":

Adobe/ Mud brick	Iron girder/ Steel	no
Adobe/ Mud brick	Timber/wood	no
Burnt Brick	Iron girder/ Steel	no
Burnt Brick	Iron girder/ Steel	no
Burnt Brick	Iron girder/ Steel	no
Burnt Brick	Timber/wood	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Iron girder/ Steel	no
Layered Mud	Timber/wood	no
Layered Mud	Timber/wood	no
Layered Mud	Timber/wood	no
Loh Kaat	Bamboo	no
Loh Kaat	Bamboo	no
Loh Kaat	Bamboo	no
Loh Kaat	Bamboo	no
Loh Kaat	Bamboo	no

- Approximately 43% of all homeowners received no training whatsoever – of the more significant districts, particularly poor ones were Dadu (68% untrained) and Jacobabad (61% untrained), whereas Ghotki was particularly good (90% received sufficient training)
- Only 3% of homeowners were taught repair skills, and only 7% were taught about maintenance for their shelter
- Of those who received some form of training, 95% believed it to be sufficient, and the 5% who did not were all being taught construction skills, rather than the simpler repair/maintenance
- The data states that training for layered mud shelters was often insufficient, however this could perhaps be due to the large correlation with having iron/steel on layered mud shelter, and hence the iron/steel being the aspect which required better training

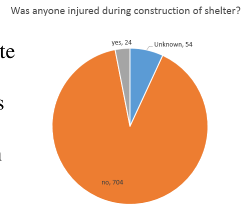


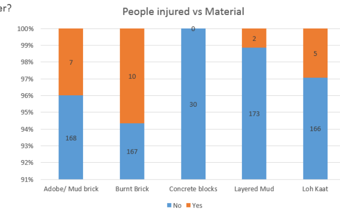


References
- *20161102 Assessments Combined V5.xlsx*

Labour Standards – Injuries

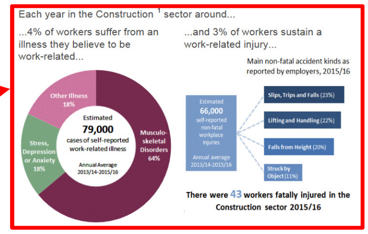
- The survey contains 24 shelters where injuries were reported on site – equal to 3% of all shelters built
- The worst offending wall type was burnt brick, with nearly 6% of all of these shelters bringing about an injury of some kind during construction
- There is no known record of what these injuries were, or their severity, or what caused them to occur – it is recommended to track this information in future
- The table opposite shows a comparison with number of injuries seen in the UK construction sector for 2015-16





In summary, injury rates appear to be comparable:

Pakistan (this study) – 3%
UK (annual rate) – 3%



References
- *20161102 Assessments Combined V5.xlsx*
- *http://www.hse.gov.uk/statistics/industry/construction/*

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Labour Standards – Child Labour

- It is important that agencies employ a policy strictly against using child labour on their projects, and to extend this policy back to all suppliers in the chain of obtaining materials (e.g. in brick factories and other manufacturing settings)
- Agencies insist that they follow a strict anti-child labour policy
  - *ACTED* say that worked hired were 18-60 years old
  - *HANDS* regularly monitored construction, and both they, *Sangtani* and *CRS* say that there was no case of child labour on their projects
  - *IOM* say there was an effective monitoring system in place for child labour violation, which also discouraged the use of burnt bricks due to the tradition of child labour being used in brick kilns. *UN Habitat* had a similar monitoring system
  - *Prepared* signed agreements with supplies not to tolerate child labour. No children were hired by *Prepared*
- Children of beneficiary families did regularly help out in building and collecting material for their own family's shelter

References
- *20161102 Assessments Combined V5.xlsx*
- *KII Data.xlsx*

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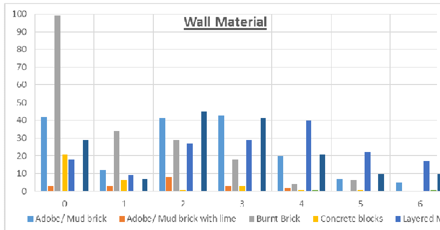
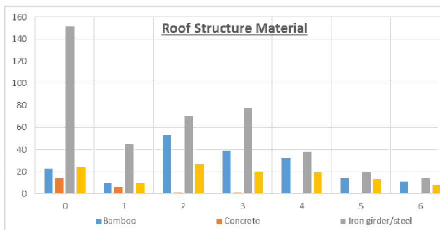
Labour Standards – Repairs Required



wall material	0	1	2	3	4	5	6	7	8	9+	No Comment	Sample Size
Adobe/ Mud brick	42	12	41	43	20	7	5	0	0	6	0	176
Adobe/ Mud brick with lime	3	3	8	3	2	0	0	0	0	0	0	19
Burnt Brick	99	34	29	18	4	6	0	2	0	1	0	193
Concrete blocks	21	6	1	3	1	1	0	0	0	0	0	33
Layered Mud	18	9	27	29	40	22	17	4	5	11	18	200
Layered Mud with Lime	0	0	0	0	1	0	1	0	0	0	0	2
Loh Kaat	29	7	45	41	21	10	10	3	5	6	0	177
	212	71	151	137	89	46	33	9	10	24	18	800

In summary:
- Shelters with burnt brick or concrete block walls typically required lower number of repairs than others
- Large number of repairs needed on most mud shelters



roof structure material	0	1	2	3	4	5	6	7	8	9+	No Comment	Sample Size
Bamboo	23	10	53	39	32	14	11	2	4	8	13	209
Concrete	14	6	1	1	0	0	0	0	0	0	0	22
Iron girder/steel	151	45	70	77	38	19	14	3	4	10	2	433
Timber/wood	24	10	27	20	19	13	8	4	2	6	3	136
	212	71	151	137	89	46	33	9	10	24	18	800

In summary:
- Shelters with iron girder/steel roofs typically required lower number of repairs than others

References
- *20161102 Assessments Combined V5.xlsx*

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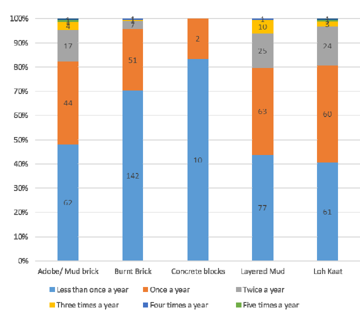
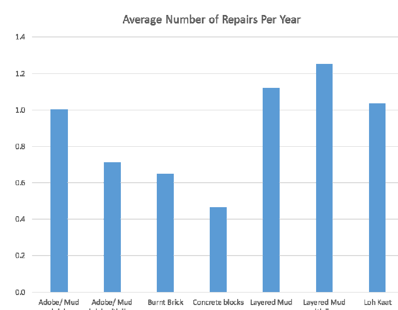
Labour Standards – Material vs Frequency of Repair

- Aside from concrete blocks, burnt brick had the largest proportion of shelters (70%) with fewer than one repair occurring per year
- Mud-based shelters had the highest average number of repairs per year. Although more frequent, it should be noted that a repair to a mud house is typically less onerous than one to a house built from a less abundant form of building material





References
- *20161101 Graphs - part 2.pptx*

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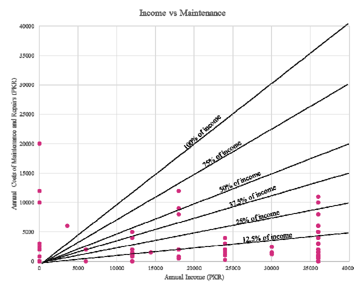
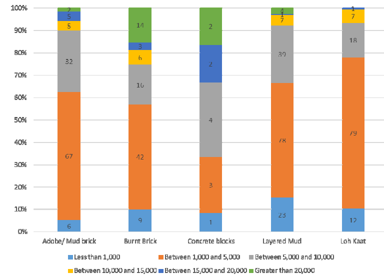
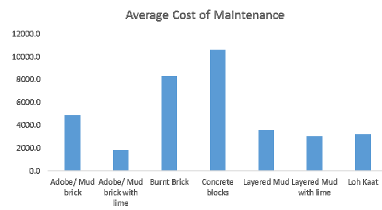
Labour Standards – Material vs Cost of Maintenance

- Average cost of maintenance for burnt brick is approximately twice that for adobe/mud brick
- Based on the typical low incomes of homeowners, it is most sustainable to maintain shelters with a low value for the product of "annual cost of maintenance" * "annual number of repairs" * "annual cost of repairs"







References
- *20161101 Graphs - part 2.pptx*

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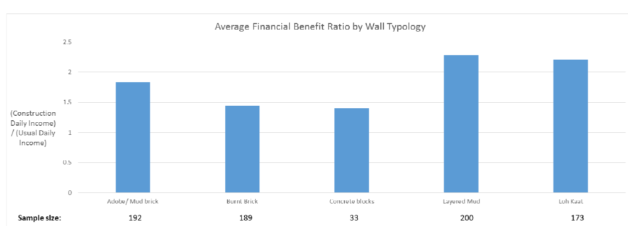
Labour Standards – Financial benefit to homeowner

- **Benefit = (Construction Daily Income) / (Usual Daily Income)**
- Assume:
  - Construction Daily Income = 350 rupees for unskilled labour
  - Based on the "Cash for Work Strategy" described by CESVI
  - (compared to 700 rupees for skilled labour)
- *N.B. See Cost Analysis Study for further information*



Need to multiply by number of days to construct each shelter for this to be meaningful

References
- *20161102 Assessments Combined V5.xlsx*
- *Stakeholder_Minutes_CESVI.docx* – CESVI meeting (4 April 2016)

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Labour Standards – Summary of key findings

- 91% of homeowners were involved in the entire construction process of their shelter
- Only 6% of those who were involved would have liked less involvement, whereas 37% would have liked to be more involved (especially those on the smallest monthly incomes). The trends for preferred involvement do not depend on material types used
- Approximately 43% of all homeowners received no training whatsoever, and the presence and standard of training varied considerably from region to region. Of those who received some form of training, 95% believed it to be sufficient. Only 3% of homeowners were taught repair skills, and only 7% were taught about maintenance for their shelter
- The survey contains 24 shelters where injuries were reported on site – equal to 3% of all shelters built. This injury rate is equal to the annual injury rate on construction sites in the UK. The worst offending wall type was burnt brick, with nearly 6% of all of these shelters resulting in injury
- The agencies insist that they and their suppliers follow a strict anti-child labour policy
- Shelters with burnt brick/concrete walls, or iron girder/steel roofs, typically required lower number of repairs than others. Mud-based shelters require the largest number of repairs
- Financial benefit to homeowner is an aspect of Labour Standards better covered by the Cost Analysis Study

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4. Recyclability / Reusability

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Recyclability / Reusability

- Homeowners are resourceful and reuse/repurpose as much material as they can, mostly due to their low level of wealth
- *ACTED* say c
- Homeowners typically buy only what they need from the market, and are not wasteful. Only five instances were reported (out of the 800 shelters featured in the homeowner surveys) of materials being left unused following construction. On one occasion, this unused material (bamboo) was reused on a different shelter. And in one of the other instances, this material was mud, so it going "unused" was completely insignificant
- Homeowners typically had limited knowledge about which materials they could reuse. 571 of 800 homeowners either said "none" (287) or did not answer (284). 142 homeowners thought they would be able to reuse steel at some point in the future, and 103 homeowners said the same about bamboo. A surprisingly low number (35) said that they would be able to reuse mud, however perhaps they just did not consider it. *CRS* say that materials in the shelter can be reused easily
- Also relevant to note that the nature of the waste from these shelters does not usually pose a significant environmental risk/hazard of any kind. For example, materials such as mud/bamboo/timber will naturally decompose. Also, no chemicals are used which could pollute water supplies or emit gaseous pollutants into the atmosphere, with the exception of bamboo which uses various toxic chemicals (e.g. Diesel) for treatment
- As mentioned under Material Availability, second-hand doors/windows are often donated by members of the local community – *HANDS* state that >80% of beneficiaries installed used doors/windows
- Insecure land tenure is linked to the desire to be able to de-mount the roof of a homeowner's shelter
- According to *Sangtani* and *UN Habitat*, there was no availability for recycling technologies in the local area
- Recyclability / Reusability should not be considered as an important factor when determining preferred shelter designs, for the reasons outlined above

References
- *20161102 Assessments Combined V5.xlsx*
- *KII Data.xlsx*

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5. Homeowner Satisfaction

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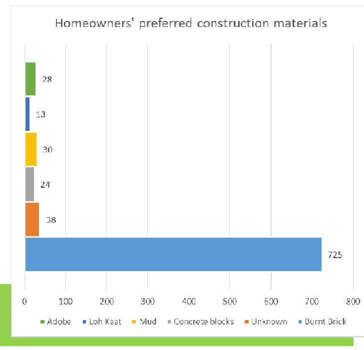
- Sustainable designs are also ones which homeowners are happy to be constructing and happy to live in for a number of years
- From the chart, it can be seen that homeowners overwhelmingly would have chosen a burnt brick house, given the choice. It is unclear as to whether each homeowner would know of somebody who owned a shelter of each typology, or whether the efficacy of burnt brick was simply passed on via word of mouth. Burnt brick is also seen as a status symbol, regardless of its structural performance level
- In the survey, homeowners were able to choose more than one "preferred construction material" but 674 selected exclusively "burnt brick"
- 11% of homeowners lived in bush huts before the floods, of which 97% considered their new shelters to be an upgrade (see next slide for more)
- Despite encouraging local construction materials, *HANDS* report that ~50% of beneficiaries preferred to use fired bricks



References
- *20161102 Assessments Combined V5.xlsx*

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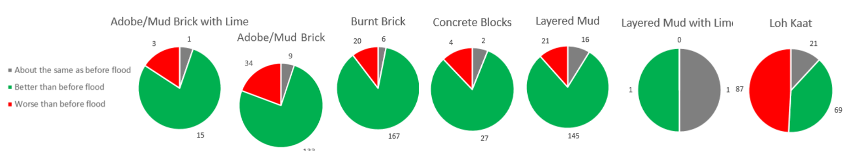
Homeowner Satisfaction – old vs new shelters

- Homeowners were asked how they rated their post-flood shelter in comparison with their pre-flood shelter. The charts below are broken up into the 7 post-flood shelter types



- At the time of the survey, 70% of homeowners believed that they preferred their post-flood shelter to the one in which they lived prior to the flood
- However, this clearly wasn't the case for those given a loh kaat shelter – greater than 50% of loh kaat homeowners declared it worse than what they were living in before the flood – note that many were living in huts made from either mud or bushes, so considered loh kaat worse than these
- Burnt brick shelters received particularly positive responses
- There was very little correlation between the typology of house lived in pre-flood and the better/worse response from the homeowner post-flood
- As explained by PEDA (a local partner), the majority of the beneficiaries live below the poverty line but are now very happy as at least they have a roof to protect them from sun and rain. As an old lady said; "we were living with buffalos and cows but thanks to you we have a roof now"

References
- *20161102 Assessments Combined V5.xlsx*

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Final thoughts

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Summary of Sustainability findings

- *Embodied Carbon* indicates that plastics and steel have particularly large production carbon footprints – most significant due to the abundance of steel used in roof structures and polythene used as covering. Lime has a reasonably high carbon factor but this must be weighed against the benefit it brings to the durability of the mud structures it is used with – and the main alternative, cement, has an even higher carbon factor. Bamboo and burnt bricks also have quite high carbon factor values based on the production assumptions made here. Obviously, mud has a low (nominally zero) carbon factor value, assuming it can be obtained locally, dug by hand and transported without motorised transportation. Transport carbon factors will vary significantly based on the location of any particular shelter, and the mode of transport chosen. Further conclusions can be drawn once factors are applied to these values based on the information in each shelter's bill of quantities (BoQs), taking into account the mass of each material used in a shelter.
- *Material Availability* broadly suggests that the availability of construction materials at the local markets is high - 70-80% of materials reported as "easy to obtain". However only 48% of homeowners used motorised transport to collect what they need. Short distance, especially mud-based shelters, had the greatest percentage of homeowners using *only* non-motorised modes of transport. Mud was most easy to obtain for homeowners, whereas bricks, concrete blocks, iron/steel and other engineered components were the least easy to obtain. 70% of homeowners said that local materials were sufficient to cover the repair and maintenances needs of their shelter, however 78% of homeowners who commented described repairing/maintaining their shelter as a "Difficult" process.
- *Labour Standards* tells us that homeowner involvement and quality of the workforce are both encouragingly good, and are essentially independent of the shelter typologies and materials used. Only 57% of homeowners were trained on how to construct their shelter, 3% how to repair, and 7% how to maintain – so dissemination of knowledge is something which will have to be improved. Of those who received some form of training, 95% believed it to be sufficient. Shelters which contain burnt brick/concrete/iron/steel are more sustainable from the standpoint of needing fewer repairs, whereas mud houses in particular require a lot more ongoing maintenance. Eliminating child labour in the supply chain and maximising financial benefit to the homeowners are also encouraged
- *Recyclability / Reusability* should not be considered as an important factor when determining preferred shelter designs, for the reasons outlined above. The concepts of recyclability and reusability are not well understood, however people minimise waste out of necessity.
- *Homeowner Satisfaction* reveals that 91% of homeowners would prefer to live in a burnt brick shelter, when asked during the survey. There was a lot of dissatisfaction with loh kaat design shelters, with 50% of homeowners saying it was worse than the place in which they resided before the flooding.
- According to *Prepared*, sustainability or environmental factors are not usually considered in emergency shelter programs in Pakistan.

References
- *20161102 Assessments Combined V5.xlsx*
- *KII Data.xlsx*

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Overall Recommendations based on Sustainability

- Overall, this study swings slightly more towards ***favouring burnt brick shelters***, possibly ***with a bamboo-dominated roof construction***.
- Construction results are only sustainable if they obtain the support of the homeowners who will live in them and who will be willing to maintain them in a sustainable manner.
- Burnt brick can be made locally in small-scale kilns, which could potentially provide a stronger local economy, and have minimal negative environmental impacts if efficient kiln designs are adopted.
- *IOM* had concerns about trees being cut down to burn in the brick kilns – but this would not be a sustainability issue if the forests were managed sustainably.

References
- *KII Data.xlsx*

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