An Ecological Assessment of My Cottage at Lynedoch EcoVillage – Stephen Forder

Existing Building

Location

Lynedoch EcoVillage is located at approximately 34ºS and 18 ºE and, despite it's proximity to Cape Town, experiences a microclimate with significantly colder minimum temperatures in winter and significantly warmer maximum temperatures in summer. This is due to the fact that it is located on the gentle slope of one side of a shallow valley containing the Eerste River as well as that it is 11 km from False Bay and thus escapes the moderating effect of the ocean.

The actual village, encompassing 42 plots, was initially laid out as a high density, low income residential development with little attention being paid to site orientation and solar access. It was later conceived as the Lynedoch EcoVillage, a mixed income residential development, closely coupled with the Sustainability Institute, an educational NGO in partnership with the University of Stellenbosch.

Materials Used[1]

The foundation consists of conventional concrete of about 600mm wide by 400mm deep. The slab is also made of conventional concrete poured atop compacted ground, a layer of coarse sand and a plastic waterproofing membrane.

The walls of the structure are built of a lower layer of conventional, furnace-fired clay bricks which are bonded with cement mortar. This layer is a cavity-wall, seven courses in height with a waterproof membrane tucked under the seventh course on the inner layer and under the sixth course on the outer layer such that any moisture in the cavity will run towards the exterior. The remainder of the walls are built from a single layer of sun-baked adobe blocks, 300mm wide, bonded with clay mortar and reinforced with galvanised steel mesh threaded between layers so as to form a z-shape between upper and lower layers, thus tying them together. Metal roof hoops are embedded into the clay walls four courses down and these are attached to the roof trusses.

Roof trusses are constructed from eucalyptus poles (eucalyptus is an alien species in South Africa) and are treated with boron. The trusses rest on a pine wall plate that is

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[1] Refer to Appendix 1 for photographs of the building materials

treated with *chromated copper arsenate* (CCA). A 150mm layer of thatch constitutes the roof covering.

Conventional, furnace-fired clay brick layers are plastered with normal cement plaster and the adobe brick layers are plastered with a layer of 1 part lime to 2 parts sand. The walls are painted internally with Breathecoat, a breathable and non-toxic paint which allows water vapour to escape but keeps water molecules out. The external walls are painted with a traditional mix of animal fat and unslaked lime.

Figure 1: A Scale Model of the Adobe Cottage

Ecological considerations of materials

When compared with the identical structure built entirely from conventional building materials, the greatest gains insofar as embodied energy is concerned are accrued from the *avoided* use of 2778 fired clay bricks and $2.2m^3$ of cement. An exact and rigorous quantification of the actual amount of this avoided embodied energy is an extremely complex exercise and is beyond the scope of this paper.

Fired clay bricks have major environmental impacts, not only in land use due to the expansive nature of brick yards and clay pits, but also in the large amounts of embodied energy that they contain due to the baking process and transportation. In contrast, the adobe bricks used in the cottage were made from clay sourced locally and were baked by the sun. Cement production also has extremely negative consequences for the environment and is energy intensive and resource depleting. There are also occupational hazards associated with its manufacture and use.

Toxicity

The most toxic substance that has been used in the construction process is the CCA used as a wood preserving agent on the pine wall plates. Fortunately, these strips of wood are concealed by clay and lime plastering and are thus not exposed to the internal environment of the cottage. The US Environmental Protection Agency has classified CCA as a restricted use product due to concerns around its carcinogenic properties. The use of this material will present a problem during the dismantling at the end of the cottage's lifecycle however and should either be appropriately re-purposed or properly disposed of.

The roof trusses were treated with boron compound which is non-toxic and is a suitable treatment for wood that is not exposed to the ground since the compound is water-soluble[2].

Thermal Properties of Floor, Walls and Roof

The floor slab, made from concrete, has no particular thermal enhancements. The floor screed consists of cement with an oxide colorant (for aesthetics) and is not carpeted or tiled. It provides good thermal mass for the small amount of sunlight that penetrates from the Northwest through the windows and the top portion of the stable door.

Using U-values and Superficial Resistance values for materials, and taking a measurement of the indoor and outdoor temperatures at the time of writing (19º and 13 º C respectively), I was able to estimate how much energy was being lost through various elements of the cottage[3]. From Table 1 it is clear that the adobe walls afford better thermal resistance when compared with a conventional brick cavity wall i.e. they are offer better thermal insulation. The thick adobe walls also have good thermal mass and store heat (or coolth in the summer) with the result that they 'dampen' temperature swings.

Most of the heat is lost through the roof and a conventional tiled roof with ceiling and insulation would have afforded slightly better thermal performance than the current 150mm thatch layer. A large proportion of heat is lost through the closed doors and windows (289 Watts at the time of measurement which is more than that which is lost through the entire wall surface area).

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[2] http://www.toolbase.org/Technology-Inventory/Decks-Patios-Fences/low-toxicity-wood-preservative

[3] This methodology is far from rigorous and comprehensive is used for comparative purposes only.

Table 1: Heat losses through various elements of the cottage

Building Element	Heat loss in Watts
Walls	
Existing 300mm Adobe walls	200
Alternative fired clay brick cavity wall	404
Roof	
Existing Thatch	423
Alternative concrete tiles, ceiling & 50mm insulation	346
Windows	
Existing single glazed cottage panes	101
Alternative double glazed windows	57
Doors	
	188

Current Energy Consumption

Forty percent of world energy production is consumed in the construction and operation of buildings. The built environment thus presents a critical locus for intervention and the adoption of energy efficiency measures.

The cottage is powered by three energy sources;

1. The sun (5.3 kWh/m²/day)[4]
2. The electrical grid (5.12 kWh/day)
3. LPG gas (2.04 kWh/day)

The 100 litre solar water heating system with a 1.5m² flat-plate solar collector and electrical backup set at 55ºC is by far the most effective energy savings feature on the cottage. The electrical backup is switched off for the majority of summer, thus relying solely on solar energy for the provision of hot water. Whilst no baseline study has been conducted on this particular solar water heating system, similar systems in this region realise a savings of 40% of domestic energy consumption in middle income South African homes.

The amount of backup electricity that the solar water heater has consumed has been metered since it was installed and this averages out to 664.3 kWh per annum (1.82 kWh per day). Obviously, most of the backup electricity use takes place in the winter months where it functions primarily as a conventional, electric hot water cylinder with little input from the sun. The reverse is true during the summer.

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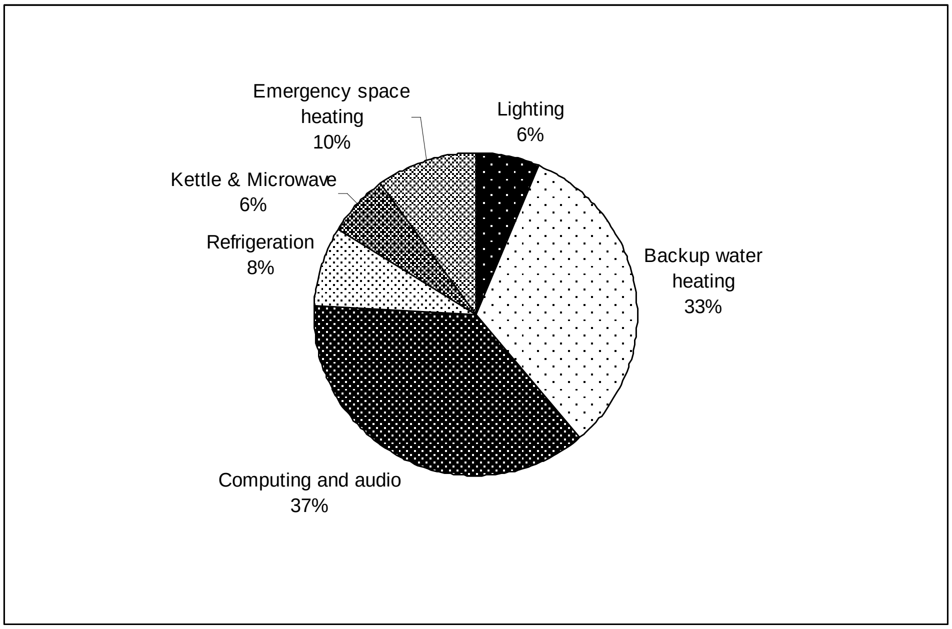
[4] Average annual solar radiation on a horizontal surface as given in AGAMA Energy’s report on Lynedoch Energy Services

Electricity is also used for refrigeration, computing, lighting and audio applications. Figure 2 shows electrical consumption across all applications.

Figure 2: Electricity consumption per application



Propane gas, bought in 9kg bottles, is used for cooking and heating in the following quantities – 9kg per annum for cooking and 45kg for heating. An additional 265 kWh (measured using a kWh meter) was used over 36 days in June and July 2007 to power a 500/1000W electric heater that had to be used due to a local shortage of LPG gas and a spell of extremely cold weather.

Carbon Footprint Attributable to Household Energy Consumption

The total CO_2 footprint attributable to energy consumption in the cottage is 2.15 tonnes. This noteworthy for two reasons:

1. There is only one occupant
2. Taking projected population levels in 2030 and the capacity of the global carbon sink, this is almost 1.8 times the sustainable emissions level per capita (Monbiot, 2006) and this is *without* taking my transportation and consumer patterns into account.

Table 2 presents the annual CO_2 emissions attributable to each energy-consuming application in the cottage[5]. Again, it is noteworthy that the annual emissions attributable to my computing and audio entertainment activities alone are greater than those of the average Ethiopian's total emissions over the same timeframe (Monbiot, 2006). This raises uncomfortable ethical questions about my lifestyle.

Table 2: Carbon footprint (in kg of CO_2) per application

Application	Annual CO2 emissions in kg
Lighting	127
Backup water heating	648
Computing and audio	728
Refrigeration	161
Kettle & Microwave	121
Emergency space heating	201
LPG Gas Heating	133
LPG Gas Cooking	27
	2145

Water

Water-consuming activities inside the cottage result in a direct daily consumption of 125.4 litres whilst electricity generation accounts for a further 7 litres per day (this is turned into steam at the power stations and is used to drive the steam turbines that generate electricity[6]). This is in line with the World Health Organisation's recommendation of 135 litres per capita per day for healthy living. Apart from water from the washing machine, waste water from all direct uses is recycled for use in toilet flushing (see Sanitation section below).

Washing machine grey water is discharged after each weekly cycle into the garden for irrigation purposes. It must be noted that there are no natural bodies of water or natural water channels in the immediate vicinity and thus contamination with the high levels of phosphates characteristic of grey water discharge is not an issue.

The shower is fitted with a low flow shower head which is an energy-saving device as much as a water saving device.

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[5] Figures for electricity are based on Eskom's 2006 annual report and for propane gas on the carbon calculator hosted at "Resurgence": http://www.resurgence.org/carboncalculator/

[6] Calculated by using the figure of 1.4 l for every kWh produced as given in Eskom's annual report of 2006

Table 3: Direct and indirect water use

Direct and Indirect Water Consumption			
Direct Use - Daily			
	Shower	64.8	l
	Toilet flushing	30	l
	Basin	8	l
	Kitchen	8	l
	Washing machine	15	l
	Total direct	**125.4**	l
Indirect Use - Electricity	Consumption:	7.2	l
	Total	**132.6**	l

Currently, no water harvesting techniques are employed. This is largely due to the majority of the roof surface area consisting of thatch and the associated difficulties in attaching guttering. The flat roofed portion of the cottage does present a small degree of opportunity for rainwater harvesting, but this is currently not taking place.

Sanitation

Being part of Lynedoch EcoVillage, the cottage is connected to the village sanitation system. This consists of a shared septic tank per every 2 or 3 houses where most of the solids entering the sanitation system are retained. Septic tanks throughout the village are joined in series and the liquid effluent, along with suspended solids, proceeds under the force of gravity through the system to a large communal sump at the bottom of the village.

When the liquid effluent in the sump reaches a certain level, it is automatically pumped into a vertically constructed wetland where water slowly percolates downwards through various stone and sand layers planted with wetland plants. In this process, contaminants are released through various physical, chemical and biological means.

The bed of the wetland is such that it channels the water into a second large sump. A Trunz filtration plant powered by a bank of batteries charged by photovoltaic panels and a 600 Watt wind turbine is the final step in the purification process and pumps water from the sump, through the filters and into a holding tank. This water is then meant to be pumped to the top of the village into a tank that feeds the toilet inlets of every house (at the time of writing, this step was about to be commissioned). Thus, it is intended that all toilet flushing be done with recycled water rather than municipal water.

The village sanitation system is a good example of design that eliminates externalities since it is a closed loop with nothing leaving the boundaries of the development.

Solid Waste

All plastic, glass and paper waste is recycled. Organic kitchen waste is processed in a worm bin located outside. Organic garden waste is composted in a compost heap and I apply liquid from the worm bin to the compost heap from time to time to assist with the composting process.

The cottage's compost heap and worm bin

***Eisenia fetida* processing organic kitchen waste into vermicompost**

Drainage

There are no impermeable surfaces around the home. Through the time that I have been living in the cottage, in true *Permaculture* tradition, I have paid careful attention to water flow and used a simple swale, reinforced with natural rock, to deflect runoff away from the exterior walls. This is depicted below at a time of heavy runoff.

Drainage through simple swales

Summary of Measures Mitigating Ecological Impact

The table presented in the previous section on measures employed in a number of ecological developments in European developments provides a useful checklist against which to assess the ecological effectiveness of the cottage at Lynedoch.

A Summary of Ecological Design Measures Employed in the Cottage at Lynedoch	
Materials	
Recycled building materials	Yes
Sustainable materials (no tropical woods, zinc, pvc, paint)	Yes
Connection with natural systems	
Preservation of nature	Yes
Gardens	Yes
Natural green fences (hedges)	Yes
Allotments	No
No chemicals permitted	Yes, but not applied too strictly
Water and Sanitation	
Permeable surfaces to reduce runoff	Yes
Constructed wetlands	Yes
Rainwater collection	No
Water recycling	Yes
Low flow shower heads	Yes
Low/Dual flush toilets	Yes
Energy Systems	
Solar water heating	Yes
Orientation	No, very poor initial layout
Solar glass rooms	No
Solar panels (photovoltaic)	No
Insulation (materials, double glazing)	No
Low flow shower heads	Yes
Solar access	Not enough
Ventilation chimneys	No
Low energy appliances	Yes
Energy efficient lighting	Yes
Waste Management	
Facilitation of waste recycling	Yes, albeit poorly implemented
Composting	Yes
Layout	
30% of floor space devoted to occupant’s primary economic livelihood	Yes
Dense, compact design	Yes

A Critical Review of the Current Design

Around 16% of total carbon emissions attributable to energy consumption in my home are as a result of space-heating in the winter. During cold winter weeks, when sun shine is minimal due to cloud cover, indoor temperatures drop to 14ºC without space-heating being applied. In these instances, the thermal mass of the thick adobe walls acts as a cold store and it is very difficult to heat the home internally.

Larger windows allowing more solar gain from the north western aspect would have alleviated this to a large degree, with the sun's rays falling on the concrete slab which would serve as thermal mass, storing the heat and re-radiating it into the internal space of the home during times of little or no sun. This would have fundamentally altered the design of the cottage however.

Another low cost possibility would be to fit a trombe wall on the north-western side of the cottage. This is a simple solar collector that convects warmed air into the internal space of a building that is then replaced by cooler air from the floor level. This air is in turn is heated such that the internal environment becomes incrementally warmer when the sun is shining on the collector. The air flow would be arrested by some mechanism in the summer to prevent this heating effect.

Unfortunately, orientation options for the home were very limited due to the small plot size (17m X 8m). One would have to be careful of employing measures (such as the trombe wall) that may be rendered redundant were a neighbour to build directly on the north western boundary (zoning for the adjacent plot does allow for this). These difficulties highlight the importance of proper town planning to allow good solar access for all properties in an ecologically planned development.

Potential for Immediate Improvements

There are two improvements that should be made in the immediate to short term:

1. Place a timer on the solar water heater

   Setting the solar water heater's electrical backup to switch on 30 minutes before I woke up every morning would ensure that water is not kept at 55ºC needlessly during the night. I estimate that such a measure would shave off 0.5 kWh per day (which equates to 178 kg of CO_2 per annum). The payback period for this intervention would equate to approximately a year at the estimated energy saving.

2. Move the solar water heater to the flat-roofed portion of the cottage and place it on a stand so that it is oriented true north.

   This would increase its efficiency and save even more on the electrical backup.

> Also, the tank would then be directly above the main hot water draw off points (the shower, sink and basin). This would save significant volumes of water and energy as I would not have to wait too long for the hot tap to supply hot water. Currently the tank is approximately 7 metres away from these points which means that I waste 7 litres of cold water before the hot water starts coming out of the tap.

A Conceptual Design for Phase 2

To conclude, Appendix E and F show a conceptual design for a possible phase 2 extension of the home. Main design constraints include small plot size and the possibility of a neighbour building right up onto the border of the adjacent plot, thus limiting my solar access. In the design, much more emphasis has been placed on solar gain than was done so in the phase one design, despite the aforementioned limitation.

I would consider the “Building by Bag” system of construction using sandbags and ecobeams. These materials would have good embodied energy benefits and perform well thermally and acoustically. The simplicity of the system would mean that much of phase 2 could be owner built.

I could, at substantial capital outlay, consider installing a photovoltaic cells and battery storage for the 5.12kWh of electrical energy I use per day. If I then changed the electrical backup on the solar water heating system to gas backup, the house would effectively become “off grid”. Unfortunately, at the time of writing, the payback period on such an implementation would be lengthy and thus the main driver would be the ecological imperative rather than the financial one.

Appendix A: Building Materials

Figure 1: Freshly made adobe bricks drying in the sun

Figure 2: The conventional concrete foundations

Figure 3: Interface between conventional clay brick and adobe

Figure 4: View showing conventional brick and adobe layers

Appendix B: Surface areas

SURFACE AREAS

Wall surface areas:

External			
NW		10.28	m²
SE		10.28	m²
NE gable		16.60	m²
SW gable		16.60	m²
Afdak'		25.14	m²
Total:		**78.90**	**m²**
Internal			
Bathroom		3.45	m²
Total		**3.45**	**m²**

Window Surface area:

	No.		
NW (solar gain)	2	0.37	m²
Stable door panes	1	0.51	m²
NE (solar gain)	3	0.36	m²
SW	1	0.36	m²
Total window area		**2.69**	**m²**

Portal space

Stable door with panes	1.24	m²
Stable door	1.75	m²
Walkthrough	1.22	m²
Internal door	1.58	m²
Total portal area	**5.80**	**m²**

Roof

Total thatch area	**17.28**	**m²**

MATERIALS

Brick conversion factor (m² to conventional bricks)	55	
Fired Clay brick & mortar area	21.00	m²
Total clay area	49.41	m²
Number of fired clay bricks avoided:	5435	bricks
Amount of cement avoided:	2.2	m³
Total floor surface area:	39.60	m²

Appendix C: Heat Loss Calculations

Thermal Calculations

Inside temp.	19	ºC
Outside temp.	13	ºC
Difference:	6	K

Walls			
	300mm Adobe	**Brick cavity**	**units**
U-values	0.67	1.36	W/(K.m2)
Heat loss @ specified gradient	4.05	8.18	W/m²
Total loss through walls	**200**	**404**	**W**

Adobe Wall				Brick Cavity			
	Thick	Factor	Resistence		Thick	Factor	Resistence
Indoor Resist			0.13	**Indoor Resist**			0.13
Plaster	0.025	0.8	0.03	Cement plaster	0.025	1.16	0.02
Adobe Wall	0.3	0.24	1.25	Brick Cavity			0.52
Plaster	0.025	0.8	0.03	Cement plaster	0.025	1.16	0.02
Outdoor Resist			0.04	**Outdoor Resist**			0.04
Total Resist			**1.48**	Total Resist			**0.73**
Total U-Value			**0.67**	Total U-Value			**1.36**

Doors		
		units
U-values	5.41	W/(K.m2)
Heat loss @ specified gradient	32.46	W/m²
Total loss through doors	**188.23**	W

Doors			
	Thick	Factor	Resistence
Indoor Resist			0.13
Wooden Doors	0.045	3.03	0.01
Outdoor Resist			0.04
Total Resist			**0.18**
Total U-Value			**5.41**

Roof			
	Thatch	**Tiled roof and Ceiling***	
U-values	4.08	3.33	W/(K.m2)
Heat loss @ specified gradient	24.49	20.00	W/m²
Total loss through roof	**423**	**346**	**W**

Thatch				Tiled			
	Thick	Factor	Resistence		Thick		Resistence
Indoor Resist			0.13	**Indoor Resist**		Factor	0.13
Roofs	0.15	2	0.08	Tiled	0.15	1.154	0.13
Outdoor Resist			0.04	**Outdoor Resist**			0.04
Total Resist			**0.25**	Total Resist			**0.30**
Total U-Value			**4.08**	Total U-Value			**3.33**

Sources:

Ward, 2002

http://www.e-star.com/ecalcs/table_rvalues.html

Conversion factor to convert Imperial R-values to S 0.1761

U-value used in above calculations is inverse of R-values

Appendix D: Energy Calculations

ELECTRICITY

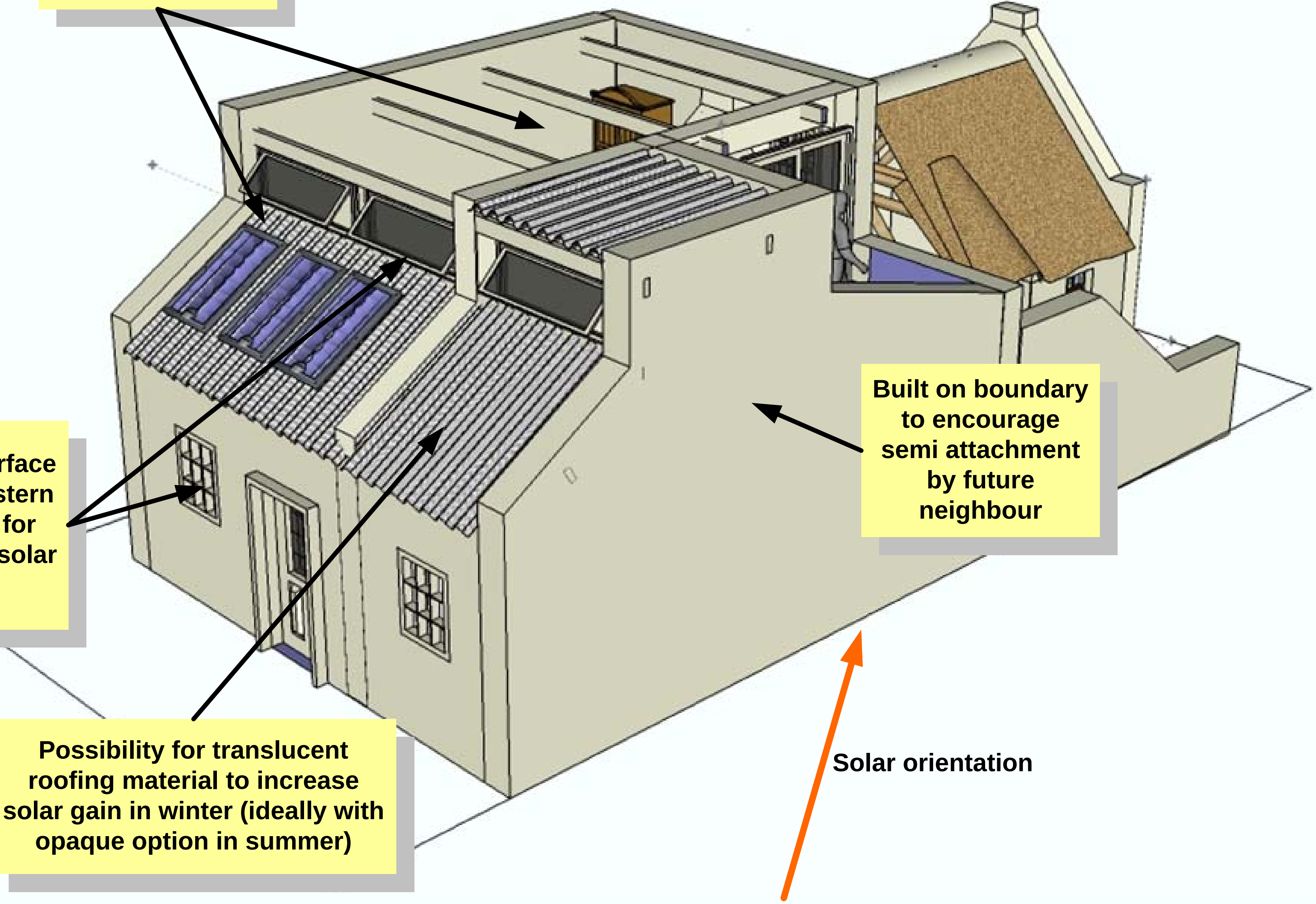
Measuring start date:	19-Apr-06				
Current date:	11-Aug-07				
Number of Days:	472				
Factor to convert ESKOM kWh to CO2:	0.978				
Metered amounts:					
Total	2416.00	kWh			
Water heating	857.00	kWh			
Emergency electrical heating	265.40	kWh			
Proportion of consumption for SWH backup	35.47	%			
Daily average - water heating	1.82	kWh			
Daily Estimates:					
Lighting					
Desk	20	W	15	hrs	
Kitchen	11	W	2	hrs	
Bathroom	11	W	1	hrs	
Utility	11	W	1	hrs	
Bed	11	W	1	hrs	
Average daily lighting total:	0.355	kWh			
Computing and audio	170	W	12	hrs	
Total:	2.04	kWh			
Fridge	0.45	kWh			
Kettle	0.32	kWh			
Microwave	0.02	kWh			
Emergency heating	0.56	kWh			5.56
Average daily electricty consumption:	**5.12**	kWh			
Annual CO2 emissions from elec consumption:	**1827.20**	kg			

LPG GAS

Factors:		
x litres per kg	1.95	*
Conversion factor (litres to kWh)	7.0859	**
Conversion factor (litres to kg CO2)	1.51	*

	Cooking	**Heating**	
9 kg bottles per annum	1	5	
Litres of LPG	17.55	87.75	l
Equivalent kWh	124.36	621.79	
CO2	**26.50**	**132.50**	kg

Appendix E: Conceptual Design – North Western aspect



Good roof surface area for rainwater harvesting and solar panels

Good window surface area on north eastern aspect to allow for natural light and solar gain

Built on boundary to encourage semi attachment by future neighbour

Possibility for translucent roofing material to increase solar gain in winter (ideally with opaque option in summer)

Solar orientation

Appendix F: Conceptual Design – Western aspect