# Sustainable construction in South Africa –

## Theoretical and practical analysis of sustainable infrastructures in the case study of the Hawequas Straw Bale Accommodation

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# Comments

OpenOffice was used for texts and calculation with spreadsheets, using OpenOffice file formats .odt and .ods. To make it accessible for everyone, the files in the accompanying CD are additionally stored as .doc and .xls, although the layout was made in OpenOffice. Text, spreadsheets and charts may not be represented properly. The author recommends downloading a free version of OpenOffice on www.openoffice.org.

Pictures are courtesy of Rebekka Eiholzer, Andy Horn, Ansgar von Oertzen, Deon Prinsloo and Marcel Bruelisauer.

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# Abstract

The concept of sustainable development has to be understood in the context of the local situation and environment. This study examines the concept of sustainable construction before the South African background and compares it to the European understanding. The theoretical analysis is completed by the practical implementation of sustainable construction, in the actual construction of load-bearing Straw Bale houses in South Africa by the author as the construction manager.

The building sector has a major influence on resource use and energy consumption; so has transport and mobility, but in what mutual relation? A Life Cycle Assessment is carried out for the mentioned building project, examining the environmental performance of said Straw Bale construction in terms of embodied energy, using Inventory Tables mostly from Switzerland, corrected with the energy intensity of the national economies. All life cycles from material extraction to building demolition are considered, with a detailing on the construction process and the utilisation stage. The Straw Bale construction is compared to a conventional brick design to assess the influence of this natural building technique. The impact of the building is then compared to the different transport processes to find an order of magnitude for that relation.

### Keywords

Sustainable construction, South Africa, Straw Bale, Life Cycle Assessment, Inventory table, Embodied energy, Transport

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# 1 Introduction

## 1.1 Introduction

Ever since “Limits to Growth”, the report to the Club of Rome in 1972, environmental issues have been given growing attention. More and more people acknowledge that our world's resources are limited. But we still continue to exploit the natural environment and limit its capacity to achieve economic growth and social welfare without regard. The concept of sustainability has been introduced to integrate these three dimensions. Sustainable development (SD) is built on two core principles:

1. Satisfaction of the essential, worldwide needs of today.
2. Following development patterns which preserve the limited natural resources for future generations

An overarching principle for SD does not exist. SD respects the specific background, the geographical, political, cultural, climatic and ecological context. This study enquires the concept of SD in the South African context and compares it to the European understanding. This examination is performed both on a theoretical and a practical level, in a case study of a Straw Bale construction project in South Africa.

The building sector has got a heavy influence on nature. Half of all natural resources and 40% of greenhouse gas emissions are connected to the built environment. Mobility and transport have a similar influence. Most of today's transport systems are based on fossil fuels, 32 % of all energy in Switzerland is used for transport. It is though not clear in what relation building and transport stand. Which part has got a heavier impact on the environment and must be addressed with greater care?

This question is examined in the case study of the Hawequas Straw Bale Accommodation where the author served as the construction manager for half a year. Applying an alternative construction method makes it interesting to know its impact on the environment in comparison to a conventional building. Both these questions are analysed in a Life Cycle Assessment.

## 1.2 Objectives and tasks

The general, central question addressed in the scope of this diploma thesis is how sustainable development should be understood in the (South) African context. This understanding is demonstrated in the case study of the Hawequas Straw Bale Volunteer Accommodation. Besides the general description of the concept of sustainable construction and sustainable transport, the focus lies on the accession, description and evaluation of the actual construction project in South Africa where

- possibly the whole life cycle of planning, realisation, utilisation and servicing/ repair as well as deconstruction has to be taken into account,
- the related infrastructure systems have to be considered,
- the sustainability aspects of the transport (visitors/ users, staff) generated by the resort have to be examined,
- the requirements of the stakeholders (client, planner, user etc.) have to be outlined.

In particular, the following issues have to examined in this thesis:

- In what ways does the African understanding of sustainable construction and transport differ from the European perspective?
- What optimisation potentials existed/ exist in the concrete construction project which could be exemplary for other projects in Africa?
- What is the meaning of the concept of transport development in relation to sustainability and what possibilities exist in the specific local context?
- Which particular auxiliary material (guides, tools, computer applications) would make sense for the African construction and transport sectors and which should be developed or could be adopted from existing tools?

These main focuses are not to be considered as final and can be adapted in the course of the work in mutual arrangement between the candidate and the professors Weidmann and Wallbaum.

## 1.3 Methodology

### 1.3.1 Understanding of sustainable construction in South Africa

The first focus lies on the understanding and state of the art of sustainable construction in Switzerland. It turns then to the South African understanding of sustainability. An evaluation of available literature on sustainable development in general and sustainable construction in particular is combined with interviews of leading stakeholders in South Africa.

### 1.3.2 Ecological performance of the Straw Bale construction project in South Africa

The relation between the construction process and the transport, in terms of their environmental impacts, need to be examined. A tested method is a Life Cycle Assessment (LCA) which identifies and quantifies all environmental impacts during the lifetime of an object.

In this case, the ecological impact is measured in embodied energy. The building materials, the construction process on site (with its machine uses) and generated transport are examined. For the utilisation stage, matter and energy use for buildings and people as well as all transport (matter, staff and visitors) are considered.

LCA Inventory Tables with values of embodied energy for different materials and services are used. They are merged with data about the construction project which is sampled and processed carefully. Future events are estimated, based on a scenario which is developed from the vision for the project.

Different elements of the LCA are combined and compared to analyse two main questions: The ecological performance of the Straw Bale construction is compared to a fictive conventional design to assess the environmental impact of the said construction method. The ecological impact of the transport is compared to the impact of the building to examine its importance in the total ecological performance.

# 2 Sustainable building and construction

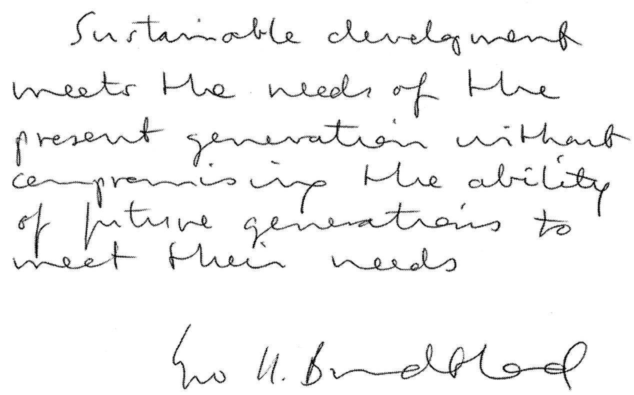
## 2.1 Sustainable development

### 2.1.1 Understanding of sustainable development

At the beginning of the new millennium the world is at a critical point. Natural disasters are more frequent. The evidence for climate change is compelling (IPCC 2006), its impact on economies is more widely understood (Stern 2006). Awareness and concern about environmental issues are growing. There is a developing willingness to voice these concerns, creating increased pressure on world leaders (G8 summit Heiligendamm, 2007).

Sustainable development (SD) has been widely accepted as a way (or the way) to tackle the future. Hardly a company can be found which does not include SD in its PR brochure. Sustainability has become fashionable. Nobody wants to be un-eco friendly. Yet the broad acceptance of SD is based on a vague concept. Generally, we refer to the definition of the 1987 Brundtland Report of the World Commission on Environment and Development (WCED 1987):

Figure 2.1: Autograph Gro Harlem Brundtland



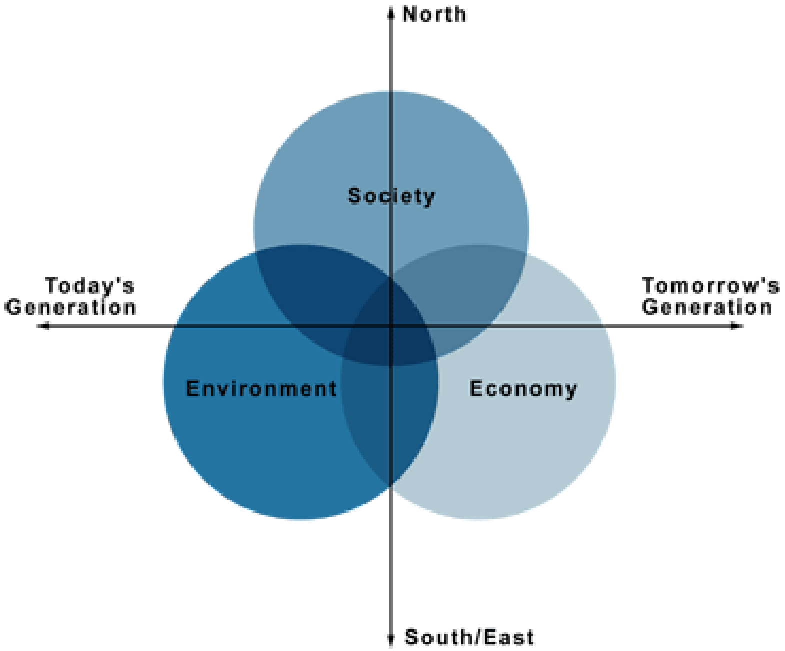

Source: Keiner 2006

It is a small consensus which leaves room for interpretation and adaptation. And it is a controversial term which is used in contradicting ways (Bartlett 2006), e.g. when speaking about sustainable growth in a material context. The term is regularly used as lip-service, speaking SD, but meaning economic growth.

Included in the concept of SD is the concept of locality. There is not one solution but a variety, in respect of the local context. Local implications must therefore be carefully considered. Major differences should be visible when assessing SD in different contexts.

The triple bottom line is the most common approach to include all implications in a holistic approach. These are the economic, the social and the ecological sphere. Nowadays, the time and north-south dimension are often underlined to these three target dimensions.

Figure 2.2: The three target dimensions (economy, society and environment) underlined by the time and north-south-dimensions




Source: www.are.admin.ch

Depending on the nature of a project or a policy, the criteria can be found and adapted to the three spheres. Ideally, the concerned stakeholders are included in the process of defining the assessment criteria. Firstly, the project is more likely to answer to the needs of the concerned community. Secondly, decisions are much more transparent and accessible. And thirdly, the learning process during the assessment process increases awareness and support of a project (Kaatz 2005). This is mainly valid for community development projects.

The Earth Summit in Rio de Janeiro in 1992 stated the common responsibility of all nations and established SD as the new paradigm. The experience since Rio has shown that it is not possible to define ‘sustainable society’ absolutely and exactly. There is not one solution. SD should not be understood as a normative concept but rather as a regulative idea, comparable to the leading ideas like freedom, equality and justice. SD should act as guidelines for our behaviour and our actions (Umweltbundesamt Deutschland 2002).

Yet, the transition towards a more sustainable society is extremely slow; with our current behaviour critical tipping points are likely to be reached. *“If we want meaningful change, we will need to start doing things differently from a different point of departure.“* (du Plessis 2006) Or as William McDonough says: *„Doing a bad thing less bad, doesn't make it good“* (McDonough, 2004). Many authors are asking for a paradigm shift in our thinking. One new paradigm (called the ecological paradigm by Capra 1996) is based on *„the fundamental interdependence of all phenomena and the fact that, as individuals and societies, we are all embedded in (and ultimately dependent on) the cyclical processes of nature“* (Capra 1996). SD as a whole-systems concept in a complex and interconnected environment responds to this demand.

In order to take the necessary steps towards a sustainable world, we need to be more radical and more idealistical in our visions (du Plessis 2006). The focus should not lie on the question ‘what is possible?’ but rather ‘what is needed for our common future?’.

### 2.1.2 Sustainable building and construction

The building and construction sector has huge responsibility and potential when it comes achieving real sustainability. *“This sector accounts for around one-tenth of the world's GDP, at least 7% of its jobs, half of all resource use, and up to 40% of energy use and greenhouse gas emissions.“* (Halls 2003)

Additionally, building and infrastructures are conceived for a long period of time, up to 50 or even 100 years. What is built today will have an impact for future generations. Many stakeholders have therefore started to talk about “sustainable building and construction” (SBC) to include the entire life cycle. Or they talk not even about cradle-to-grave life cycle but about cradle-to-cradle life cycle. This concept comes closer to natural networks where every output of a process is the input of the next process, forming an intertwined net of life (Capra 1996).

The ongoing population growth creates a need for housing and infrastructure, especially in developing countries. Yet, the natural resources would not be sufficient for everybody to live like the industrialized world in terms of resource- and energy-intensity. The building sector has got a very important role in the implementation of SD. We spend so much time in the built environment; it affects us directly. SBC can thus be a catalyst to promote SD.

### 2.1.3 Sustainable mobility

Mobility is essential to our social life. In the last few decades there has been major change in modes of transport. More distant places are accessible as the velocity of transportation has increased. Besides all social development, human beings move for the same reasons – working, shopping, meeting friends etc. And despite all technical improvement and motorised transport, the time we spend on transportation has increased (www.bfs.admin.ch).

Mobility means more and more individual motorised mobility. Although there is a highly developed public transport system, 42% of all trips in Switzerland are happening in individual motorised vehicles. It is 49 % in Cape Town, with only basic public transport, even though a large part of the population cannot afford a car (McKenzie 2003). Rush hour starts ever earlier in the morning and lasts longer. What would the situation look like with a motorisation like Switzerland where 80% of all households own a car? (www.bfs.admin.ch)

Transport uses about a third of all primary energy consumed, which consists mostly of fossil fuel. Just replacing fossil fuels by other energies would not solve the problem. A little mind experiment: If the Chinese population reached 2050, the same motorisation as the Western world (about one car for two people) but drove solely on hydrogen produced with electricity, it would need more than 1'000 1-GW-nuclear power plants to supply that amount of electricity; not to mention how many wind generator would be needed. Today, there are 435 existing nuclear power plants worldwide with an installed electric net capacity of about 369 GW (www.euronuclear.org). Sustainable mobility can thus not only be a question of fuels.

## 2.2 Statistical comparison between Switzerland and South Africa

The following table shows selected statistical values indicating a very different background.

Table 2.1: Statistical comparison between Switzerland and South Africa

| | Switzerland | South Africa |
|---|---|---|
| Area[A] | 41'290 sq km | 1'219'912 sq km |
| Population[A] | 7'554'661 | 43'997'828 |
| Population density | 183 habitants/ sq km | 36 habitants/ sq km |
| GDP per capita[B] | 33'040 US$ | 11'192 US$ |
| HDI - ranking[B] | 9 out of 177 | 121 out of 177 |
| Unemployment rate[A] | 3.3% | 25.5% |
| Life expectancy at birth[A] | 80.7 years | 47.0 years |
| Biocapacity[C] | 1.5 global ha/person | 2.0 global ha/person |
| Ecological Footprint[C] | 5.1 global ha/person | 2.3 global ha/person |
| Primary focus SBC | Resource – and energy-efficiency | Employment, capacity building, empowerment |

Sources: [A] ww.cia.gov/cia/publications/factbook/geos/sf.html; [B] Human Development Report 2006; [C] http://www.footprintnetwork.org/index.php

## 2.3 Sustainable building and construction in Switzerland

### 2.3.1 Sustainable development at governmental level

The government participated actively at the Earth Summit in Rio de Janeiro in 1992. In the following years, it worked out strategies for SD. A commission was created to coordinate and implement SD on a governmental level. A key moment was in 1999 when SD was included as a central state objective in the new constitution: *„[The Swiss Confederation] shall promote [...] sustainable development [...] . It shall strive to secure the long-term preservation of natural resources [...]"* (Art. 2 of the Federal Constitution of the Swiss Confederation). As no supplementary legislation has followed, it serves primarily as a vision for future action.

Ten years after Rio, a status report was issued before the World Summit on Sustainable Development in Johannesburg. It states that problems arose on implementing SD on a practical level. The new strategy included more concrete formulations and new domains of activity for SD. The report recognizes the importance of the building industry in the consumption of resources and energy but fails to go into detail. Land use and mobility take a prominent part. An updated strategy is published at the end of 2007. Although there has been improvement in some parts of SD, the general outcome has been insufficient. To achieve objectives like the reduction of greenhouse gas emissions according to the Kyoto-protocol, drastic measures will be needed. Political will is often lacking.

### 2.3.2 Institutions

In the field of research, the Materials Science and Technology Research institution EMPA[1] has been active for years, in close contact with the building industry. Energy-efficient materials or Life Cycle Inventory tables for building materials[2] are only a few examples of the research done there. On an educational level, the newly created Chair of Sustainable Construction at the Swiss Federal Institute of Technology in Zurich (ETHZ) shows that the need for serious concern has been recognised. It is a big step forward as an instrument to coordinate research and to arouse sensitivity for sustainable construction among students as future decision-makers (Wallbaum 2006).

1 www.empa.ch

2 www.ecoinvent.ch; www.bauteilkatalog.ch

The Swiss society of engineers and architects SIA declared sustainability a main issue when the Government and the Constitution had stipulated its importance. In the recommendation SIA 112/1, a tool was created to communicate and define a set of objectives between clients and planners. It allows one to address all three dimensions of SBC, society, economy and ecology in a sophisticated way. Other tools have been added although their use is only recommended and not compulsory.

### 2.3.3 Focus of SBC

Switzerland can rely on a stable economy, a long tradition of democracy and freedom and an equal society – combined with a large ecological footprint (see Table 2.1). The main focus of SD lies naturally on the environmental side. Today's main focus lies in uncoupling well-being from resource-use.

In the last few years, the focus of SBC has been on energy consumption, a fair point in a climate where heating is essential for well-being in housing. Heating consumes a large part of energy used in households. Various processes have led to low-energy standards such as Minergie[3] or passive heated houses. Ever-increasing oil-prices have made people focus on their insulation. Life cycle thinking is applied more often.

The topic of material use has been fairly neglected so far. *„[Certain building] materials – like copper and steel – are not available in infinite supply. This fact is reflected in the current explosion of raw material prices."* (Wallbaum 2006). Half of all resources are used for building processes. Half of all waste materials are due to building activities, including soil movements, generating immense transport. Recycling of building materials is not yet very common or elaborate and the embodied energy in building materials gains in importance as energy consumption for the utilisation of building decreases. Many advances need to be made in this field.

Another main focus will be land use. Especially in extremely densely inhabited Switzerland, the resource land has become scarce. The built environment has spread enormously in recent decades. This problem will have to be tackled firstly on a spatial planning level. One part will be new mobility concepts.

[3] www.minergie.ch

## 2.4 Sustainable building and construction in South Africa

### 2.4.1 Sustainable development at governmental level

For decades, South Africa has been a divided and unequal society. Differences concerning economic power and social standards were enormous and continue to be so. Since the end of Apartheid, huge efforts have been made to establish equality not only legally but in real life. The constitution and national policies do note SD but concentrate on development understood as economic growth, to raise the standards of previously disadvantaged parts of society.

The environmental pillar of SD is mostly left out of focus. Representatives argue that the limited financial resources must be used where it is most necessary, e.g. for fighting poverty. This position lacks understanding of the concept of sustainability. Holistic policies for sustaining development could be worked out by taking into account ecological considerations.

For example, severe housing shortage has led to a huge national housing project aiming at providing parts of the population with subsidised houses. In their haste to protect people from substandard housing, the National Home Builders Registration Council (NHBRC) severely restricts innovation in alternative building methods and materials; although some of these options have proved not only to be environmentally friendly but also enriching for the involved communities. The situation is worsened by the hastened provision of unsustainable services (settlement pattern, water policy, energy supply, mobility concept etc.) making a sustainable society even further out of reach.

### 2.4.2 Institutions

Research on SBC has been taken place for more than a decade, at the Council for Scientific and Industrial Research (CSIR) and at various universities. Their focus has primarily been on sustainable building assessment tools and methods (CSIR 2001, Kaatz 2005, Ugwu 2005). South Africa as a developing county does not have the same needs as a developed country. Assessment tools and methods are thus important to identify the local major needs. “Agenda 21 for sustainable construction in developing countries” (du Plessis 2002) provides a framework for research and development in this very context.

The biannual conference "Sustainable Built Environments"[4] has been held since 1998 as the primary get-together for green professionals. Its central aim is to map the growth of sustainability in the building sector. The conference and the parallel running workshops intend to address sustainability on a conceptual and a practical level.

### 2.4.3 Focus of SBC

When examining the focus of SBC, one must bear in mind that South Africa is a developing country. As Professor Daniel Irurah from the University of the Witwatersrand says: *"Developers and government and other stakeholders would emphasize more on the social and socio-economic development and delayed on the environmental and ecological development. […] Whatever ecological solutions you are proposing, they also have got socio-economic benefits. So you must demonstrate the socio-economic benefits first."* (Irurah, appendix 1)

This statement shows the priorities in the South African society and therefore in the South African construction industry: promote economic development, supply communities with basic infrastructure needs, create jobs, train local people; empower previously disadvantage groups, include local communities, strengthen institutions. Ecological considerations come second:

*„In developing countries like South Africa, where the majority of the population lack the basic human needs of food, shelter and security, people do not perceive man as posing a threat to the environment, but are prone to view the environment as posing a threat to man. The demand is for utilisation and intense exploitation of living resources, and society's interests are judged in terms of immediate benefits. Aesthetic, scientific, educational and future needs are considered an unaffordable luxury."* (Fuggle, 1992)

This statement is still generally valid today for large parts of the society. Future needs not being considered indicates that life cycle thinking is not yet established, whether it concerns costs or environmental impacts. To advance SBC, awareness and understanding of the concept of sustainability concerning intergenerational responsibility must first be achieved. A low education level in large parts of the population, rooted in an unequal society hinders fast progress and makes it important to train stakeholders and integrate the sustainability concept in education.

[4] www.sustainablebuiltenvironments.com

Eyes must not be closed to bad governance. South Africa is an emerging developing country with a big potential but an uncertain future. Often, it is not lack of ideas, commitment and funds which restrict and slow down socio-economic uplifting of the poor, but protection of personal interest by the educated and established members of the society.

A key issue is the promotion of labour-based, rather low-tech and low-energy building techniques. Capacity building and social uplifting of the local communities is the key to achieve a long-term effect (Horn 1998). Alternative, natural building methods (like cob, adobe, straw bales) could fit these criteria. Environmental high-tech solutions would respect similar criteria as in developed countries, with a strong emphasis, again, on the integration of the local community.

South Africa is running towards a severe energy shortage. Having an intense solar radiation throughout the year, it is essential to integrate the sun into design and energy-supply (electricity and hot water). Most houses are neither heated nor insulated. Using insulating materials combined with passive solar design would not only increase the occupants comfort but minimize medical expenses due to unsuitable temperate conditions in houses.

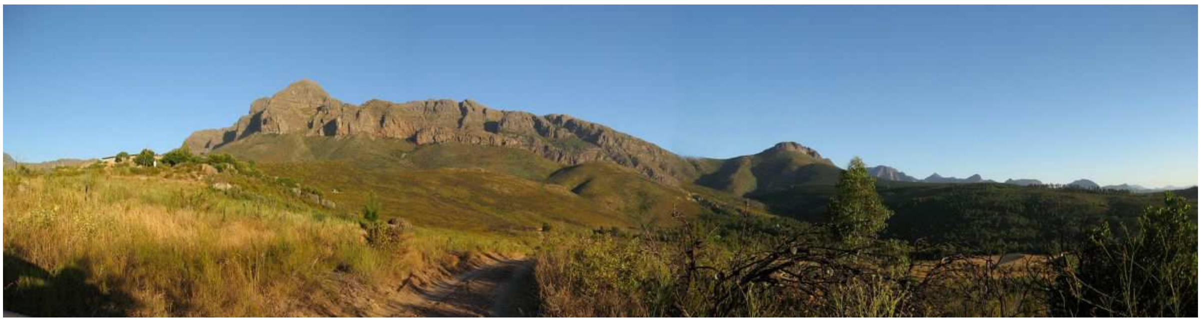
# 3 Case study: Hawequas Straw Bale Accommodation

## 3.1 Hawequas Scout Farm

### 3.1.1 Background and current situation

Hawequas is a 233 ha farm in the foothills of the Hawekwa mountains, south-east of Wellington, a small farming town in the Western Cape province of South Africa. Wellington lies north-east of central Cape Town, about an hours drive or 80 km away. Situated in the heart of the Western Cape's wine region, it is surrounded by vineyards, wheat fields and mountains. Access to the farm is by two dirt roads. The condition of the roads and several gates make it about a 15-minutes-drive to Wellington.

Figure 3.1: Hawequas Scout Farm



Hawequas has been owned by the South African Scout Association since 1985 and has been developed over the years to serve as their premier outdoor training and activity area for members of the Scout Association in the Western Cape province. The farm is open to the public as a camping and venue facility.

Over 90% of the farm falls upon undisturbed fynbos, the vegetation type unique to the Cape Floristic Region, the smallest of the planet's 6 plant kingdoms in physical area, yet one of the richest in terms of biodiversity[5]. The government takes action to conserve the biodiversity of the Cape Floristic Region. The Western Cape provincial branch of the South African Scout Association (SASA-WC) is committed to meeting these needs on the farm.

5 www.capeaction.org.za for more information

Figure 3.2: Fynbos vegetation: protea (left), pincushion (right)


Existing facilities include bunk-rooms for 40 people, several ablution facilities, a large kitchen, a lecture room, an undercover outdoor activity area, numerous secluded outdoor areas and campsite accommodation for up to 300 campers. The farm offers hiking trails, swimming spots (a concrete dam and beautiful natural rock pools), floodlit grass playing field, campfire circles and equipment for Scout activities. Appendix 2 gives an overview over the farm facilities. Figure 6.2 in appendix 6.2.4 shows the occupancy of the farm in 2006.

The farm used to be managed by a voluntary committee. For the last 2 years, day-to-day management and development has been done by a farm-manager. Everyday maintenance and requests by visitors are handled by a warden. The farm-manager Andrew Purnell lives on a farm nearby and the warden Tess Pettiquin and her family live on the farm premises.

### 3.1.2 Future development

The impact of the Hawequas Scout Farm on society and the environment depends strongly on their future development. The usage of the farm has gradually developed since the SASA-WC acquired the property. In 2005, it set up the Hawequas Vision to concentrate their resources on common ground:

> *"To be a self-sustaining world-class nature-based education facility providing children and youth with: memorable and life-changing nature experiences; the opportunity to achieve personal growth by triumphing over challenges in a fun and safe environment; knowledge and experiences that nurture an understanding, respect and love for the environment; the motivation to be proactive local agents of change in meeting global environmental challenges."* (Andrew Purnell)

In order to provide education facilities, cover the general maintenance costs and meet the natural conservation aims by implementing a conservation management plan, shortly to be financially sustainable, the farm needs to generate income. The SASA-WC has therefore started on a few income generating activities:

- increased occupancy by members of the Scout community,
- donor funded midweek environmental education youth camps (Land Care camps),
- venue and facility hire for outside youth groups, corporate and non-profit organisations,
- corporate team building and conferences,
- micro enterprises: indigenous plants nursery, organic produce, firewood, furniture made of alien wood.

Because of these new programmes Hawequas requires the service of people to assist in the management of the property and the implementation of the programmes. Hawequas has therefore set up a volunteer programme for local and international volunteers. Local unemployed school leavers will participate in a year long, funded learnership programme. International volunteers will get the opportunity to gain experience in diverse fields, possibly development-related, in their voluntary service at Hawequas. One paid South African team-leader will be responsible for all volunteer activities and coordinate the youth camp programmes under the guidance of the farm manager. New accommodation needs to be built for the volunteers. This is the starting point for the personal involvement of the author as the construction manager of the volunteer facilities.

## 3.2 Design Straw Bale Accommodation

### 3.2.1 Design principles

The volunteer accommodation is based on a self-sustaining eco-village/ permaculture concept. It should be a living example of ecological design and eco-friendly living, built, maintained and further developed by volunteers. It should serve as an example of good practice for the environmental education activities.

Design principles include the following points:

- use of local resources
- passive solar design (to keep the sun out in summer and let it in in winter), materials with high insulation
- sustainable sources of energy like solar water heating, photovoltaic and wind generator for electricity (no connection to the grid); gas-driven cooking and fridge
- eco-friendly sanitation and sewage systems; integrated permaculture principles like food gardens, grey-water systems and rainwater catchment.

Limited financial resources make it necessary to use low-cost building methods. Labour-intensive building methods are possible by integrating the Scout community into the building process. The volunteer accommodation itself is designed and built by volunteers.

The choice for the building structure was a load-bearing Straw bale structure. Numerous reasons include readily available wheat bales from nearby farms with superb insulation values, possibly low-cost, low-tech building techniques, a labour-intensive building process suitable for building workshops of larger groups (Scout community).

### 3.2.2 Straw bale construction – an overview

There is good literature for Straw Bale structures. „The Straw Bale House“ from Steen, Steen and Bainbridge (Steen 1994) is the classic for self-builders and novices. „Der Strohballenbau. Ein Konstruktionshandbuch“ from Gernot Minke and Friedemann Mahlke (Minke 2004) is a good choice in German. And Bruce King's recent opus (King 2006) shows the state of the art from a technical engineering side. This chapter is only an insight into Straw Bale structures.

#### *History of Straw Bale structures*

Historically, the appearance of Straw Bale buildings goes together with the invention of the baling machine. In Nebraska USA, settlers would use straw bales (which were lying around anyway) to build temporary shelters. They soon experienced the main benefits of this kind of structure: thermic insulation from the burning sun, thermic insulation from the bone-chilling cold and acoustic insulation from the howling winds. After disappearing as a common building method, this technique has grown in popularity and is spreading in many parts of the world. The oldest, still inhabited house was built in 1903.

#### *Design principle*

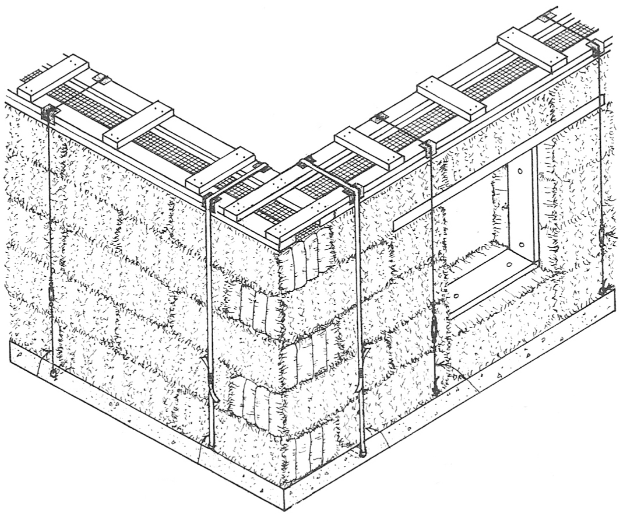
In general, we can distinguish two types of structures: In load-bearing structures (see Figure 3.3), the bales serve as support for roof and upper floors. In a non-load-bearing structure, the bales are placed in between a pole structure which holds roof and upper floors. The construction of a straw bale wall can be compared to a normal brick wall: The bales are stacked upon each other like bricks, only the bales are much larger. And instead of mortar, stakes are driven through the bales to hold them together.

#### *Strengths and concerns*

The main advantage of Straw Bale structures is their excellent insulation value – thermical and acoustical. Building methods are reasonably low-tech to include owners and communities into the process. It is an eco-friendly building method; detailed considerations of its environmental performance follow. And it is simply fun to build!

Some believe that moisture, fire-safety and insects are a concern. The latter are kept away by an earthen plaster. The compression of the bales allows them to no more than smoulder, providing that the wall of exposed bales remains intact. It actually increases the fire resistance similar to heavy timber structures (King 2006). However, special care is necessary to keep moisture out of the bales!

Figure 3.3: Load-bearing Straw Bale wall system



Source: Steen 1994

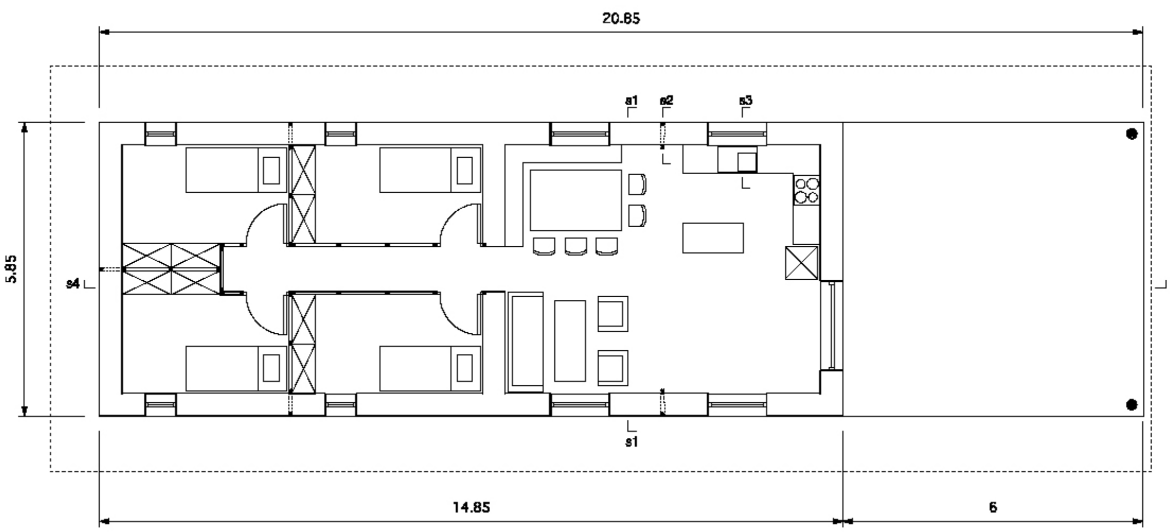
### *Potential*

Given its environmental strengths and cosy and healthy living atmosphere inside, a continuation of the remarkable growth of Straw Bale construction seems logical. The use of a natural waste product which is often burned represents a huge potential. The annual (!) production of wheat bales in SA would be sufficient for 1'000'000 low-cost houses (Prinsloo 2005). A drawback is the experimental and "hippie" reputation still floating around this unconventional and unknown construction type. For example would poor people in South Africa, being given a Straw Bale house, not ask whether it is a good option but whether rich people would build such a house. Another drawback is the specific building process, different to standardised building materials. As it is a non-industrial material, the building industry would not push it as there is little money to make from straw bales with current industry structures. On the other hand, the open spirit of people involved in Straw Baling, ready to share their knowledge for free, makes sure that knowledge is passed on and spread steadily – similar to open source programming.

### 3.2.3 Design

The Hawequas Volunteer Accommodation facilities include two buildings: the main house to accommodate eight people and an ablution facility large enough for future development of the eco-village. The accommodation building consists of a sleeping part with four small double-bunked rooms, a living room with kitchen and a large covered outside area.

Figure 3.4: Floor plan accommodation building

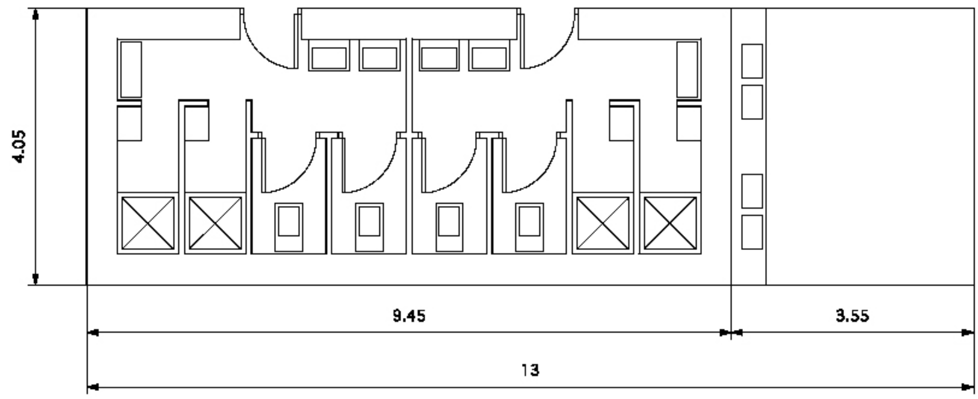



Design: Rebekka Eiholzer, Marcel Bruelisauer

The ablution block is based on the same design as the main house but smaller. It houses four toilets and four showers. The covered outside area provides washing basins and washing lines to dry clothes during rain. The dimensions are based on the dimensions of straw bales: 90 cm long, 45 cm wide and 35 cm high; length and width are multiples of bales.

The buildings are almost north-facing. The large overhang fulfils two functions: passive solar design and protection of the walls against rain. As with most natural building materials, the general rule is: “A good hat (roof) and a good pair of boots (foundations)“.

Figure 3.5: Floor plan ablution block

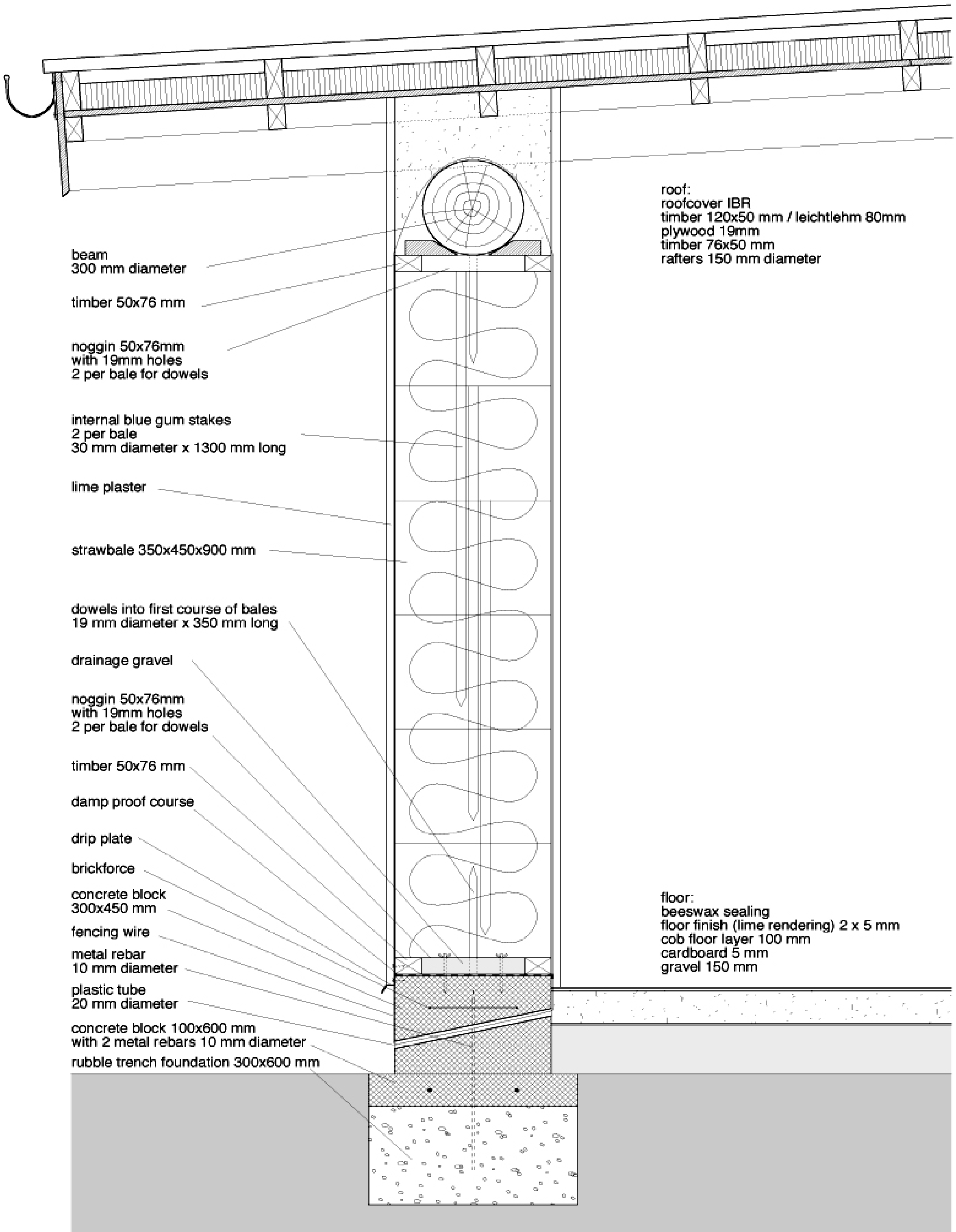



Design: Rebekka Eiholzer, Marcel Bruelisauer

The excellent insulation value of the Straw Bale walls make roof insulation even more important. Without good insulation the heat would come through the roof, would be stuck inside and make room conditions unbearable. The accommodation roof is insulated with a layer 100mm Thermguard, recycled newspaper with household chemical additives to make it fire retardant and insect and rodent resistant. For the ablution block, good ventilation through a gap between wall and roof covers up for the lack of roof insulation; moisture from showers exits through those gaps as well. The roof is built as a shed, made of corrugated iron to collect rainwater.

The section through the wall reveals the basic knowledge of a Straw Bale construction. A framed concrete slab (bale width, 30 cm high) lifts the bales off the ground and protects them from splashing rainwater. The bottom part of the foundation trench below is filled rubble to use less concrete. A damp proof course prevents moisture from rising from below into the bales. A timber ladder is fixed onto the concrete; gravel in between the ladder rungs serves as drainage for possible moisture in the bales. The Straw Bales (from a nearby wheat farm) are placed on top, secured together by wooden stakes (alien blue gum harvested on the farm). A wall plate, identical to the bottom timber ladder goes on top. A thick longitudinal log serves as support for the roof, necessary for the overhang.

Figure 3.6: Section through Straw Bale wall




Design: Rebekka Eiholzer, Marcel Bruelisauer

Figure 3.7: Design details

Concrete foundation with timber base ladder with gravel drainage and damp proof course

Timber wall plate on top of the wall, dowels to fix laterally to the bales

A tie-down-system is applied around the entire wall, running over the longitudinal beam and through plastic pipes in the foundation. This system is set up to hold against uplifting forces (wind) and to pretension the walls. Settlement of the wall is forced before the plastering. Initially, fencing wire was used as the tie-down-system. Problems and uncertainties led the author to search until an ideal solution was found with polyester strapping, normally used for packaging.

Figure 3.8: Different tie-down systems

Fencing wire, home-made tool

Fencing wire, wire strainer

Polyester strapping for packaging, strapping tool

The cross beams of the roof are blue gum logs, harvested on the farm. A system of perlins on top of a ceiling made of shutterboards ensures structural stability and creates space for the insulation. Any gaps, especially between wall and ceiling are filled with cob, a clay-earth-straw mix often used in natural building. For the plastering of the walls, locally extracted clay from the foundation is used. 2 – 3 layers of clay plaster (mixed with chopped straw) are applied. On the outside, one layer with lime creates a harder and more resistant surface. Very importantly, this plaster leaves the walls free to breathe whereas cement plaster would trap moisture inside and doom the bales to rot.

The internal walls are set up as drywalls, using standard products. The ablution floor is tiled to deal with the water. The accommodation floor is made of cob, with a lime-finish and beeswax-rendering. This creates good thermal mass to store the day's heat for the night, completing the insulation properties of the Straw Bale walls.

A few key figures for the two buildings are listed in the table below:

Table 3.1: Key figures of the buildings

| | Accommodation | Ablution | Total |
|---|---|---|---|
| Length | 14.85 m | 9.45 m | |
| Width | 5.85 m | 4.05 m | |
| Height (average) | 2.90 m | 2.80 m | |
| Floor space | 86.9 $m^2$ | 38.3 $m^2$ | 125.2 $m^2$ |
| Roof space (inclusive overhang) | 179.4 $m^2$ | 84.7 $m^2$ | 264.1 $m^2$ |
| Surface | 293.8 $m^2$ | 253.1 $m^2$ | 446.0 $m^2$ |
| Volume | 186.6 $m^3$ | 72.6 $m^3$ | 259.2 $m^3$ |
| Ratio surface / volume | 1.17 $m^{-1}$ | 1.42 $m^{-1}$ | 1.24 $m^{-1}$ |

## 3.3 Construction process

### 3.3.1 Principles and ideas

The main idea for the construction process, formulated in the vision for Hawequas, is to use construction students and other volunteers to build. These volunteers would handle the entire construction process, from design and planning, to the execution of the actual construction. Later, volunteers living in the finished buildings would be concerned with maintenance and ongoing upgrading.

Scout groups would be involved in the construction process, especially on “construction weekends”. Different age groups would be addressed depending on the tasks. Youth groups from local communities would be involved as much as possible. Workshops would be set up for volunteers interested in green building. The entire workforce being voluntary help to keep expenses to a minimum.

### 3.3.2 Account of actual construction process

Starting at the end of November 2006, the construction of the accommodation was not finished at the moment of the composition of this paper, June 2007. The account of the experiences sets a base for the assumption of the future construction process to finish the buildings.

Four different main phases may be identified: design and planning, preparation, construction and finishes. Change in construction management necessitates a second preparation phase coupled with another construction phase. The phases could be distinguished by effected work (no clear borderline visible) or better by involved people, as their impacts on the advance of the building are quite different. Table 3.2 shows an overview of the entire construction process. Appendix 4 includes a collection of pictures from the construction process and allows an insight into site, tasks and involved people. The following paragraphs give a quick résumé:

When the construction manager and the architect arrived on site end of November 2006, nothing had been fixed except basic ideas and a few sketches. Neither had any experience in Straw Bale constructions. Books, documentations, internet and discussions with experienced architects served as background for the design. The preparation of the site proved laborious, especially the foundation.

In mid-February, unemployed school-leavers from townships volunteered for a month to finish the preparation of the site in time. The collaboration with the Wellington Youth Care centre was set on two pillars: regular collaboration on site with a chosen group and woodwork conducted in classes at the youth-hostel. Both proved to be very important.

Figure 3.9: Construction process

Top left: setting the first bale; top right: hammering a stake through the bales; bottom left: clay plaster on Straw Bale wall; bottom right: roof construction with Thermguard insulation

In March the construction weekends started; three were planned initially to set up the walls and roof of both buildings. Volunteers from various backgrounds, generally interested in natural building, were recruited mostly through personal relations. With time, as the project got known, more and more people joined in. Unfortunately, Scout groups were basically non-existent. The workforce on weekends consisted of 5 to 30 people.

The walls of both buildings and the roof of the ablution block were finished after three weekends. The roof of the accommodation was much more laborious than expected; another two weekends could not finish it. Rain season arrived and the only partly covered walls were badly damaged. Posts had to be placed to support a part of the roof structure; the straw bales were taken out again. Present situation: The ablution block is covered and has even received the first coat of plaster. The accommodation house is mostly covered, half load-bearing, ready to be plastered and half non-load-bearing where the walls need to be raised again. So far, over 120 people have been actively involved in the construction work on site.

Figure 3.10: Damage inflicted by rain and its consequences

|  |  |  |
|---|---|---|
| Rotting straw bales | Taking the bales out | Braced columns as roof support |

### 3.3.3 Future construction process

The oncoming construction process to complete the houses can only be assumed. Much depends on the volunteer serving as the construction manager and the people he or she can get involved. An overview of the assumed process is stated in Table 3.2. It could look like this:

Two or more volunteers are staying permanently at Hawequas, working on site. As unknown building techniques are used, orientation and preparation is necessary, as is time to re-establish old contacts and establish new contacts, especially to the Scout community and other youth groups. After that, construction weekends and workshops can be set up again. Tasks include: finishing walls and roof, plastering and the floor. These are most important, enabling other volunteers to live in the buildings on a very basic standard but upgrading it constantly. The focus can now be placed on the interior design, toilets and showers, energy- and water-supply, kitchen and furniture. It is assumed that the process will take about half a year.

Table 3.2: Construction process phases

| Phase | Tasks | Time | Workforce | Working/ collaboration method |
|---|---|---|---|---|
| 1. Design/ planning | Design, planning and organisation of construction process, site preparation | 6 weeks | 2 permanent volunteers (construction manager, architect) | continuous work |
| 2. Preparation | Site preparation, foundation, preparation and prefabrication of construction elements for walls and roof, organisation materials and future workforce | 6 weeks | 2 – 3 permanent volunteers | continuous work |
| | | | 3 – 6 additional building helper | for foundation and preparation |
| | | | Youth Care Centre, Wellington | 10 youth twice a week plus work effected in classes at wood-workshop |
| 3. Construction | Straw Bale walls, roof preparation, roof construction, plastering | 8 weeks | 2 permanent volunteers | preparation construction weekends |
| | | | 5 – 25 building volunteers on each construction weekend | 6 construction weekends with concentrated work efforts |
| | | | Collaboration with Cape Nature, Paarl | Specific tasks |
| *4. Preparation* | Site preparation, wall preparation | 4 weeks | 2 or more permanent volunteers | continuous work |
| *5. Construction* | Straw Bale walls, roof, plastering, floors | 10 weeks | 2 or more permanent volunteers | continuous work and preparation |
| | | | volunteers, Scout groups (!) | construction weekends |
| | | | Youth Care Centre, Wellington | regular collaboration |
| | | | youth groups, schools | construction workshops |
| *6. Finishing* | interior walls, windows and doors, equipments (electricity and water), kitchen and furniture | 10 weeks | 2 or more permanent volunteers | continuous work |
| | | | Youth Care Centre, Wellington | regular collaboration |

Phases 1–3: finished, *phases 4–6: future phase*

## 3.4 Alternative design: conventional brick building

A fictive, alternative building is designed, using conventional building methods to assess the environmental performance of the Straw Bale construction. Following parts of the design are altered:

- Foundation and floor: The same dimensions have been kept for the foundation trench. Instead of rubble, concrete have been used to fill the trench. A 20cm thick ground plate in concrete has been cast for the entire ground space. The concrete is been reinforced with steel (20kg/m3). A 7cm cement floor has come on top of the concrete.

- Walls: Fired clay bricks (15cm thick) have been used to build the walls. To achieve similar insulation values as with the straw bales, in order to have a similar room comfort, the walls would need thick insulation. This is not standard technique in South Africa. Nevertheless, 20cm of mineral wool have been used for the insulation of the accommodation building; it is still less insulated than with straw bales. The ablution block has not been insulated. The walls have been plastered with a mineral plaster inside and out.

- Roof: The roof design has changed only for two elements: The blue gum logs which had been used as cross beams have been replaced by structural timber, 20cm high and 10cm wide. The insulation made of 10cm recycled paper, Thermguard, has been exchanged for 12cm mineral wool.

The other parts of the design are the same. A major issue would be the utilisation stage, concerning electricity, hot water and appliances, in terms of efficiency and supply. In this part, it is intended to compare the construction methods and not the use of energy during the utilisation stage (compare chapter 4.2.1). No design changes are thus made in that respect. The life expectancy is 50 years, compared to 25 years for the Straw Bale structure. The construction process is not specified.

## 3.5 Utilisation stage

### 3.5.1 Volunteer Accommodation

As discussed in chapter 3.1.2, the Straw Bale Accommodation will host 8 permanent volunteers. They will be engaged in everyday activities for the farm as a camping site, in maintenance, in natural conservation projects and youth development projects. A variety of other activities are possible depending on the expertise of the volunteers.

The accommodation facilities are set up as an eco-village which will be more and more developed by the volunteers. Electricity does not come from the grid but from photovoltaic-panels and wind turbines. Hot water is heated with a solar water heater. The fridge and cooking facilities run on natural gas; at a later stage, it might come from a biogas digester. Rainwater is collected and used for toilets and showers. The water supply from the stream is only used for drinking water. To be able to supply the facilities, efficiency measures must be taken: low-energy light bulbs or LED lighting, water saving shower heads, tap aerators, water saving toilets. A vegetable garden and other projects are to follow.

### 3.5.2 Visitors

The activities of the volunteers will generate more visitors. Firstly, they will increase the general attractiveness, such as hiking trails, adventure spots, better basic infrastructures and tended indigenous vegetation. And secondly through the Land Care camps which will be much intensified. In order to estimate the additional impact, a scenario needs to be developed. The scenario is built upon the situation in 2006 and developed from the vision for Hawequas, formulated in chapter 3.1.2. It is assumed that an additional 20 % of general visitors are attracted to spend their time at Hawequas to use the infrastructures. Instead of 4 Land Care camps as in 2006, 20 camps will be held at Hawequas in future. Most of the funding is already confirmed. The outline of the camps has been well approved and will thus stay the same – 60 children for 3 days in a midweek education camp.

Table 3.3: Scenario future utilisation

| Group | Situation today | Future development | Additional impact | |
|---|---|---|---|---|
| Volunteers | none | 8 volunteers | 8 volunteers | |
| General Visitors | 1411 people | + 20 % | + 282 people | + 17 % |
| Land Care camps | 4 camps = 276 people | + 16 camps | + 1104 people | + 65 % |
| Total Visitors | 1687 people = 100 % | 3073 people | + 1386 people | + 82 % |

Sources: SASA-WC Headquarters, Vision for Hawequas, Andrew Purnell

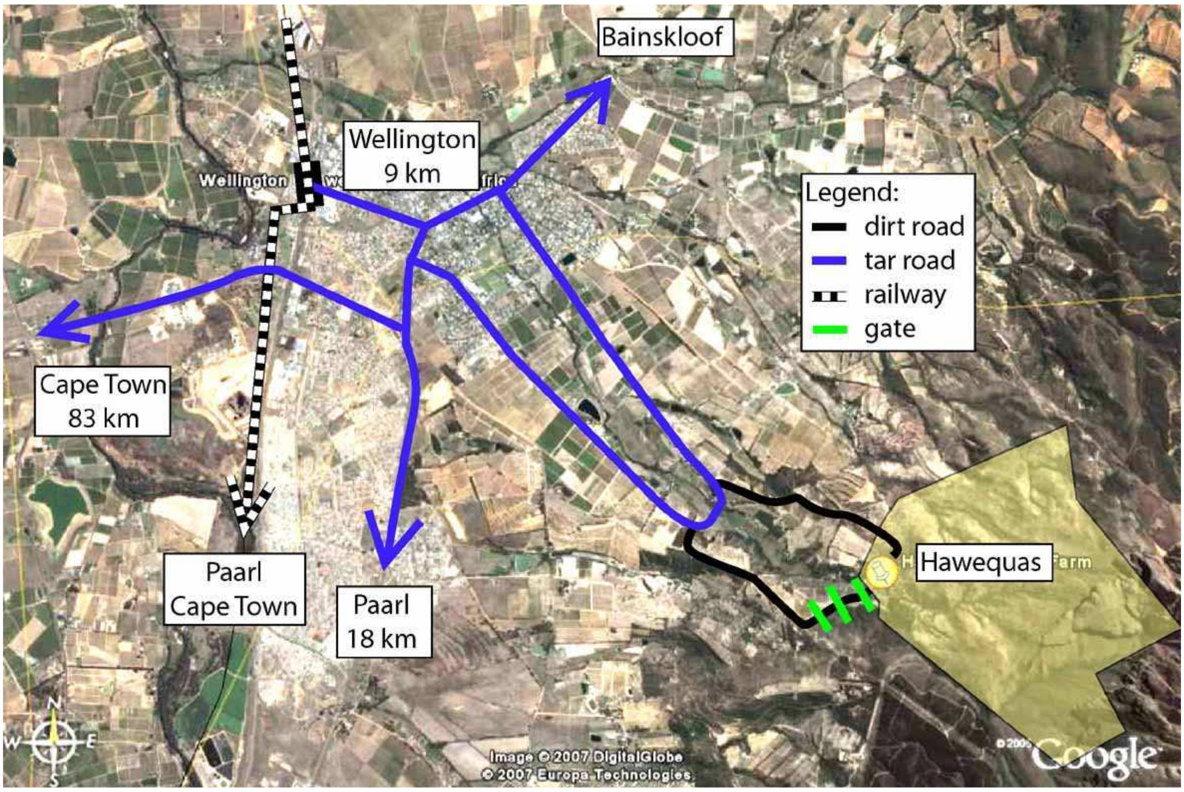
### 3.5.3 Transport

Important for the utilisation stage is the access for transport. The situation is outlined in Figure 3.11.

Two dirt roads provide access to the farm. The upper (north) road is in such a bad condition that only 4 x 4s should drive on it. The lower road is in much better shape but still not meant for speed. Apparently, the warden needs to change their car every year, when the springs are done. There are 3 gates which all have to be opened and closed again. These conditions make the 9 km journey to Wellington town easily a 15 to 20 minutes drive. Buses are not allowed on the dirt road, for safety reasons. Truck-drivers mostly refuse to drive to the farm because the one bridge truly needs reconstruction.

There is a direct train line from Wellington to Cape Town and a mainline bus service from Paarl to Cape Town. A train ride to Cape Town takes between 1.5 and 2.5 hours, depending on the train. The schedule is irregular. It is said not to be safe to travel after nightfall. Few people who can afford a car take the train. Minibus taxis operate between Wellington and Paarl. Public transport does not serve the farm.

Figure 3.11: Transport situation Hawequas



## 3.6 Evaluation and Outlook

This chapter cannot be objective due to the deep personal involvement of the author as construction manager. To make the subjectivity transparent I write this chapter in first-person.

In my opinion, the choice of the Straw Bale structure makes sense for economic, ecological and participatory reasons. The last point is particularly important when working on a voluntary basis. The enthusiasm, the passion and the fun I experienced through and with the participating volunteers especially on the construction weekends was overwhelming! This would be a great opportunity for team building experiences and workshops.

The costs will be between R 1000 and R 1200 per square meter. Budgets are normally based on a value between R 3500 and R 5000 per square meter. Little machinery, deliberately low expenses, labour-intensive techniques, locally harvested free blue gum and, above all, free workforce keeps the costs at a very low level. The Scout Headquarters does not seem to agree me here though. Having the financial resources, I would spend the money more easily to upgrade the infrastructure. Many alternatives had to be excluded from the start for financial reasons and pressure not to spend any money was always present. However the cheapest solution at the start is not always the cheapest at the end; life-cycle thinking would help here.

I would not build the ablution block with straw bales any more. Moisture being the biggest enemy, why conceive of a building with straw bales which is permanently humid (showers!) and bound to be flooded from time to time. Another natural building method would be more appropriate.

The load-bearing system proved to be rather delicate. It is a very interesting way to build, using the Straw Bales both as carrying structure and insulation. The rain inflicted major damage upon the bales, making it necessary to take them out. To use the load-bearing system, I would recommend the following points to be fulfilled:

1. The structure must be simple, for ground plan and roof.
2. Effective and easy rain cover is essential. It must be possible to cover the walls quickly and with little effort at the end of any working day; no leaking; wind resistant.
3. Workforce and tools must be available to finish the walls AND the roof in a short time. Prefabrication and machinery can be of vital help.

If any of these points are not satisfied it makes sense to use a non-load-bearing system. The roof would be constructed first, supported by posts. The covered space underneath makes it possible to pace the construction process depending on available workforce and tools; and independent from weather conditions.

Even though over 120 different people have been working on site, the workforce has been insufficient. Constituting a building site workforce with 2 people for most of the time is just not enough. That would be enough to organise weekly work parties during which the actual work is executed. Particularly the Scouts groups did not get involved. One reason is lack of or inappropriate communication, having a communication system based on email in a country where most of the people do not have internet access at home; if they have a computer. In particular scout groups from townships cannot be reached in this way, although they might be more interested in being involved. At least for the one (and only) Scout group from Khayelitsha (a township in the east of Cape Town), waiver of camping fees in exchange for some working hours was a good enough reason to participate in the construction process. A big potential of workforce lies there to be awoken.

To conclude, I think the outline of the project is inspiring! The dedication of the Scouts to educate the youth in a natural environment is combined with the need to conserve the biodiversity. This ethos is valid both for utilisation of the farm and for the building project, the latter being a solution of how to tackle the tasks. The entire development now needs to prove its financial sustainability.

# 4 Life Cycle Assessment of Hawequas Straw Bale Accommodation

The objective of this chapter is to analyse the environmental performance of the presented Straw Bale building project. Life Cycle Assessment (LCA) methods investigate environmental impacts over the entire life cycle, allowing one to identify and evaluate potentials for environmental improvements. For a building process, life-cycle stages would generally include extraction and processing of building materials, construction, utilisation and maintenance, demolition and disposal.

## 4.1 Life Cycle Assessment – an overview of methodology

LCA have become widely used in various fields to investigate the environmental performance of a service or product and represents a sophisticated tool to compare alternatives. Different ways of conducting LCAs have emerged over time. The ISO 14040ff series of standards gives guidelines and a methodological framework, whilst leaving much space for adoption and interpretation (Friedrich 2001). It gives the following definition of LCA:

> *LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by*
>
> - *compiling an inventory of relevant inputs and outputs of a system*
> - *evaluating the potential impacts associated with those inputs and outputs,*
> - *interpreting the results of the inventory analysis and impact assessment phases in relation of the objectives of the study.*
>
> (ISO 14040, 1997)

The different stages of this LCA, derived from ISO 14040 are:

1. Defining the goal and scope of the study: Reason for carrying out the study, target audience and intended use; system boundaries, functional units, assumptions and limitations
2. LCA Inventory tables: Sources to quantify the environmental impacts
3. Data collection and impact calculation: data collection, calculation procedures, quantifying relevant inputs and outputs of the building and the transport
4. Impact assessment: Evaluation of potential impacts, comparison of results
5. Interpretation: Evaluation of their significance

## 4.2 Goal and scope of LCA

### 4.2.1 Goal of LCA

Although motives to use natural building methods, such as Straw Bale constructions may vary considerably in different countries and societies, they are generally considered to be environmentally friendly. Scientific proof is often lacking, as are comparisons to conventional building methods to quantify the environmental performance. As they are non-industrial construction methods, using local building materials and often manual construction techniques, it is difficult to state a general environmental impact. Their specific building processes have a huge effect. To know the environmental performance of this specific Straw Bale construction helps to evaluate its significance in the context of the building industry. The first goal of this LCA is to compare the environmental impact of the given Straw Bale building to a conventional building.

Construction generates transport – during the building process and during the utilisation of a building. The question arises, in what relation the energy used for the transport stands to the energy used for the building process and the embodied energy (EE) in the building materials. The second goal of this LCA is to identify the importance of transportation processes on the environmental performance of the given Straw Bale project, during construction and utilisation stages. This question examines the entire project, considering not only the physical buildings but all their implications during utilisation.

In short, this LCA should answer the questions: Does it make sense to use Straw Bale construction methods from an environmental point of view? What is its importance in a broader context? Is the difference to the total performance so small that we would better concentrate on other areas?

This study may be used scientifically as a case study on natural, non-industrial building materials. Shortage and problems of used methodology may be identified.

Depending on the outcome of the study, the conclusions may be used for architects, builders, developers, planners and politicians to promote natural building in general and Straw bale constructions in particular. Detailed results on parts of the building process may be used to improve the design and the building process in terms of embodied energy and energy use. The owner of the buildings, the SASA-WC may optimise the utilisation of their infrastructures.

### 4.2.2 Scope of LCA

The research concentrates on only one case study – the Straw Bale Accommodation at the Hawequas Scout Farm in Wellington, South Africa. Results are mainly interpreted for this case. The following life cycle stages are examined in detail: construction process and utilisation stage. Other stages like extraction and processing of materials, demolition and disposal are included in the ecological indicators taken out of the Inventory Tables but not examined in detail.

The embodied energy of the used building materials is calculated to identify the environmental impact, using Inventory Tables of building materials from various countries, Switzerland, South Africa and others. As the background of these countries is quite different, in terms of economic power, social welfare, natural environment and climatic conditions, the accuracy of the results is challenged.

Transportation is calculated separately. Concerning material transport, only the part from supplier to the building site is considered. Previous transportation processes are included in the ecological indicators of the material listed in the Inventory Tables. To analyse these transport processes would go beyond the scope of this study and represent an analysis of South Africans building industry. That information may be purchased and used by manufacturers and suppliers of the building industry to improve their environmental performance. For architects and planners however, it is of subordinate importance.

Future impacts during usage of the building is based upon a scenario which is derived from the vision formulated by the SASA-WC (refer to chapter 3.1.2). This describes the target SASA-WC is aiming for. The actual development may look considerably different due to unknown events and circumstances. However, these options do not form part of this study. The study compares two limited states: with and without the accommodation building, including additional impacts generated by the building on the farm.

### 4.2.3 Embodied energy (EE)

Embodied energy is referred to as the “cumulated energy demand” and is a measure of the total primary energy used to provide a service or a product, from all stages of the life cycle which are included in the study. For building materials and processes, this normally includes extraction, processing, manufacture and transportation. It has proven to be a useful, simple and reliable indicator for the “ecological rucksack” of construction materials and buildings. The embodied energy depends directly on the material flow.

A quantity survey of previous processes is necessary. System boundaries, classification, weighing and technological standards influence the result enormously. Coherent and transparent declaration of calculation procedures as well as a verification of plausibility are of utmost importance. Technical advances alter production cycles and the energy involved; continuous updating is required.

A classic application is the analysis of the energy demand of a building over the entire life-cycle, especially in countries where buildings are intensively heated and/or cooled. If a building is more insulated, it would use less energy for heating over the life-cycle but generally use more embodied energy for additional insulation materials. In South Africa, buildings are generally not heated.

Embodied energy is found to be the most suitable ecological indicator for this study. It allows comparisons to conventional buildings and to the environmental impact of transportation, easily expressed in energy use and from there in embodied energy. All energy uses can be condensed into an analysis over the entire life-cycle. Moreover, Inventory Tables with embodied energy values for building materials exist in different countries, allowing a simplified LCA. However, embodied energy is only one dimension of the environmental performance. Other ecological indicators may lead to different results.

### 4.2.4 Functional units

As there are two goals for this LCA, two functional units are defined. The functional unit to evaluate the Straw Bale building technique is defined as 1 MJ primary energy per square meter floor space and year = *1 MJ / ($m^2$*a)*. The total floor space of both building together is *125.2* $m^2$ . The embodied energy of the building materials is split over the life period of the Straw Bale Accommodation, assumed *25 years* although Straw Bale structures are known to live up over 100 years. Inexperience of the designers and builders and uncertainty over the long-term future uses are taken into account.

The functional unit to assess the importance of the transport in relation to the buildings is defined as 1 MJ primary energy per year = *1 MJ / a*. To distribute the used energy on floor space does not make sense here as the entire project of constructing any kind of accommodation is questioned here. The total energy use, due to the buildings is important.

## 4.3 Life Cycle Assessment Inventory tables

Conducting a LCA from scratch is a complex and laborious task. One would have to know and analyse all the processes involved in detail. Furthermore, comparisons would be very difficult as different LCAs would be based on different assumptions and values. Various LCA databases have therefore been established. Specific LCAs can be conducted much faster and more transparently, allowing comparisons. They need to be maintained and updated regularly in order to show an appropriate image of the actual industry and technology. The data sources presented below are described in detail in appendix 5.

In Switzerland, massive efforts have been undertaken since the late nineties to create a common public LCA database, covering various economic sectors (Frischknecht 2004). Based on these data, the authorities in collaboration with research and building industries established the “Bauteilkatalog” (catalogue of building components), covering fluxes of matter and energy in the building sector. This catalogue[6] (appendix 5.1), combined with an online-tool[7] serves as a base to assess the ecological performance of buildings. It was the main source used for this LCA.

The only LCA database specifically for South Africa found by the author, is extracted from the PhD-Thesis of Prof. Daniel K Irurah (Irurah 1997) (see appendix 5.2). Using a top-down-approach, he calculated the embodied energy for various building materials from input-output-tables for South Africa (from 1993). The database being rather old, it may not represent today's situation. Additionally, the values were never controlled by a detailed bottom-up analysis of the involved processes. The collection of data is very difficult as the industry does not know the energy for their processes themselves. It does though take into account the background of South Africa.

Additional sources with LCA inventory data were used for specific components. They are all listed in the table below and described in detail in the appendices.

---

[6] www.kbob.ch

[7] www.bauteilkatalog.ch

Table 4.1: Sources for LCA inventory data

| | |
|---|---|
| A | Oekobilanzdaten im Baubereich, 2006, value for fabrication and elimination of each material used, appendix 5.1 |
| B | Irurah D, 1997, An Embodied-Energy Algorithm for Energy Conservation in Building Construction as applied to South Africa, appendix 5.2 |
| C | Baird, 1997, The energy embodied in building materials - updated New Zealand coefficients and their significance, appendix 5.3 |
| D | LCA for water tanks from Australia, appendix 5.4 |
| E | DIY Home Insulation Kit Project from University of Cape Town, appendix 5.5 |
| F | Handbook Emission Factors for Road Transport from Switzerland, appendix 5.6 |

In order to adapt the different sources to the conditions of South Africa's economy, one may compare the energy intensities, expressed in energy consumption per GDP Units. South Africa is one of the least energy efficient economies worldwide, Switzerland one of the most efficient, due to major differences in the structure of their economies and the use of resources. For example, Switzerland produces electricity mostly from hydro electrics and nuclear power stations, South Africa mostly from coal which is much more energy intensive. The values for embodied energy were therefore multiplied with a correction factor depending on the energy intensities of the said economies.

Table 4.2: Energy intensities

| Country | Energy intensity [toe / million $ GDP] | Correction factor |
|---|---|---|
| South Africa | 265.1 | 1.00 |
| Switzerland | 122.3 | 2.17 |
| New Zealand | 206.4 | 1.28 |
| Australia | 208.3 | 1.27 |

Source: http://earthtrends.wri.org/text/energy-resources/variable-668.html

## 4.4 Data collection and impact calculation

### 4.4.1 Buildings

#### *Construction process*

The reader may be reminded that the buildings are not yet finished. Data for the past construction process was sampled by the author in his function as building manager, purchasing most building materials himself. Masses are estimated when weight or density values are unknown. Materials for the future building process are based on the design and on the experience of the past construction process. Knowledge of the specific situation is therefore included.

The procedure for the calculation of the embodied energy of building materials is shown in Figure 4.1. The quantities of building materials are listed as they were purchased. The corresponding material is drawn out of one of the LCA inventory tables. A Life Cycle coefficient takes into account the life span of the material in comparison to the life span of the entire building. This Life Cycle quantity is then multiplied with the specific value for the embodied energy from the LCA inventory table, including a correction factor to include the energy intensity of the related national economy. This procedure is repeated for every material, although the impact of some materials was considered negligible. Detailed calculation are accessible in appendix 6.1.1. They lead to the values of embodied energy in Table 4.3:

Figure 4.1: Procedure for the calculation of the embodied energy of building materials

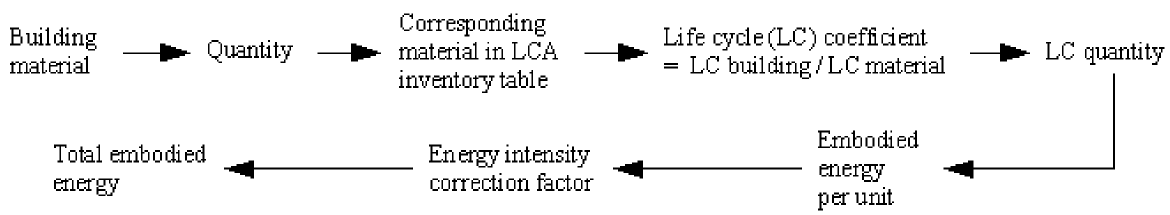


Table 4.3: Total embodied energy of the building materials

| Building elements | Embodied energy of building materials [MJ] |
|---|---|
| Foundation | 88174 |
| Straw bale walls | 24541 |
| Floor | 55853 |
| Roof | 137658 |
| Windows and doors | 119651 |
| Interior walls | 51641 |
| Electricity | 14498 |
| Water supply | 88651 |
| Sewage/ Sanitary | 64396 |
| Drainage | 13160 |
| **TOTAL** | **658000** |

Source: appendix 6.1.1, file: building materials.ods

During the construction process, various machines were used to assist the builders' manual work; larger machines like tractor or digger-loader and smaller machines like chainsaw, drill or generator. The author's chronicles are the base to include their impacts. They are summarised in Table 4.4 for each construction phase according to Table 3.2. Source for the specific embodied energy values is (Irurah 1997); a correction factor is thus not necessary. Detailed calculations are accessible in appendix 6.1.2.

Table 4.4: Machine use during construction process

| phase | timespan [weeks] | energy | amount | unit | EE per unit | EE [MJ] | subtotal EE [MJ] |
|---|---|---|---|---|---|---|---|
| design/planning | 6 | Petrol | 78 | lt | 127.5 | 9945 | |
| | | Electricity | 0 | kWh | 10.13 | 0 | 9945 |
| preparation | 6 | Petrol | 167.5 | lt | 127.5 | 21356 | |
| | | Electricity | 21.5 | kWh | 10.13 | 218 | 21574 |
| construction | 8 | Petrol | 166 | lt | 127.5 | 21165 | |
| | | Electricity | 22 | kWh | 10.13 | 223 | 21388 |
| preparation | 4 | | | | | | 14383 |
| construction | 10 | | | | | | 26735 |
| finishing | 10 | | | | | | 26735 |
| | | | | | | **total** | **121000** |

Source: appendix 6.1.2, file: building process.ods

### *Alternative design: conventional brick building*

In order to compare the influence of the Straw Bale construction method to conventional construction methods, an alternative building has been designed using fired clay bricks (see chapter 3.4). Only the embodied energy is calculated; no machine use or related transport are considered. The lifespan of the building is set as 50 years. The calculation procedure is exactly the same as for the calculation of the embodied energy of the Straw Bale building materials. It leads to the following values:

Table 4.5: Total embodied energy of the building materials for a conventional design

| **Building elements** | **Embodied energy of building materials** [MJ] |
|---|---|
| Foundation | 140379 |
| Walls | 572896 |
| Floor | 146341 |
| Roof | 305202 |
| Windows and doors | 136877 |
| Interior walls | 93722 |
| Electricity | 14498 |
| Water supply | 177303 |
| Sewage/ Sanitary | 128791 |
| Drainage | 26319 |
| **TOTAL** | **1742000** |

Source: appendix 6.3, file: building materials conventional.ods

### *Utilisation stage: Volunteer Accommodation*

The environmental impact of the building during its utilisation stage accrues from energy uses for electricity, hot water and cooking facilities; no heating system is considered. Although Hawequas is connected to the grid, it is intended not to connect the Volunteer Accommodation. Concentrating on energy efficient appliances is thus very important. Electricity will be produced from photovoltaic panels with a wind generator as a back-up. A solar water heating system is installed for hot water. Cooking appliances run on natural gas. Based on considerations described in appendix 6.1.3, following energy use can be expected:

Table 4.6: Utilisation stage: Volunteer Accommodation facilities

| Energy | amount | unit | EE per unit [MJ/unit] | Source | Correction factor | EE [MJ] |
|---|---|---|---|---|---|---|
| Electricity | 365 | kWh | 1.5 | A | 2.17 | 1188 |
| Hot water | 21 | MJ | 0.06 | A | 2.17 | 3 |
| Gas | 300 | kg | 29 | B | 1.00 | 8700 |
| | | | | | **total** | **10000** |

Source: appendix 6.1.3, file: matter and energy volunteers.ods

### *Utilisation stage: matter and energy flows at Hawequas*

The activities of the volunteers generates additional impact on the environment as more visitors are attracted to Hawequas. In order to estimate the related energy consumption, a scenario has been developed (see chapter 3.5.2). In accordance to the scope of the study, only implications due to the Volunteer Accommodation are considered. As the latter is both a condition for and an outcome of the planned income-generating programmes, all predictable impacts concerning the programmes are taken into account: Volunteer programme, increased occupancy in general, midweek Land Care camps (see Table 3.3). These impacts are independent from the design and the construction of the building.

Increased occupancy of the farm will have a major impact on the energy and matter flows. See Figure 6.1 in appendix 6.1.4 for notions on the correlation between visitors and electricity use. The energy and matter flows for current situation are extracted from accounts of the SASA-WC Headquarters from 2006. The data collection and impact calculation procedures are described in detail in appendix 6.1.4. They are then linearly extrapolated for future utilisation of the property (Table 4.7).

Table 4.7: Utilisation stage: matter and energy Hawequas

| Matters and energy | increase | amount | unit | EE per unit [MJ/unit] | Source | Corr. factor | EE [MJ] |
|---|---|---|---|---|---|---|---|
| Electricity | 82% | 28917 | kWh | 10.13 | B | 1.00 | 292932 |
| Gas | 82% | 590 | kg | 29 | B | 1.00 | 17122 |
| Petrol | 82% | 665 | lt | 127.47 | B | 1.00 | 84799 |
| +20 % for unquantifiables | 82% | | | | | | 78971 |
| | | | | | **total** | | **474000** |

File: matter and energy at hawequas.ods

### 4.4.2 Transportation

The embodied energy values used for the calculation of the environmental impact of transport are listed in appendix 5.7. They are extracted and put together from different sources.

#### *Construction process*

The calculation of the embodied energy of the transport of the building materials is based on the same list of building materials. The procedure for the calculation is shown in Figure 4.2. Most of the materials were purchased in the surrounding towns, in hardware stores. This distance between the supplier and the building site is taken into account. Any other transport processes before are included in the value for the embodied energy of the materials itself. The process is described in more detail in appendix 6.2.1. The list with the building materials and their correspondent transport can be found at the same place. There is not a trip for every point on the material list as some of the materials have been purchased together. The calculated values of embodied energy are listed in Table 4.8.

Figure 4.2: Procedure to calculate the embodied energy of the transport of building materials

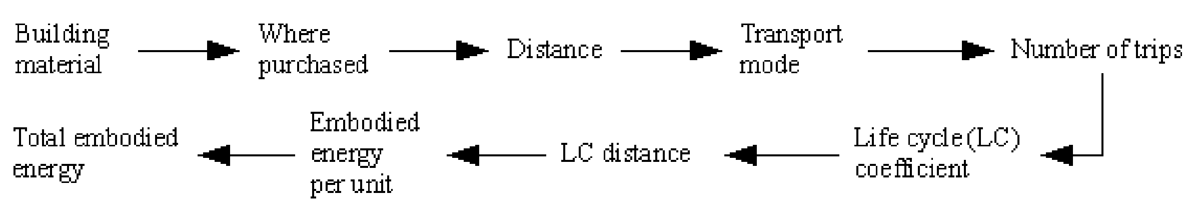


Table 4.8: Embodied energy of the transport of the building materials

| Building elements | Embodied energy of the transport of the building materials [MJ] |
|---|---|
| Foundation | 21506 |
| Straw bale walls | 18773 |
| Floor | 18719 |
| Roof | 12478 |
| Windows and doors | 15664 |
| Interior walls | 2534 |
| Electricity | 12531 |
| Water supply | 21196 |
| Sewage/ Sanitary | 1267 |
| Drainage | 2128 |
| **TOTAL** | **127000** |

Source: appendix 6.2.1, file: building materials.ods

The transportation of the building materials is not the only transport related to the construction process. Trips went to different locations for various reasons such as material search and inspection, internet research, meetings, transport of people and provision. The author's chronicles are again the base to include these trips. They are summarised in Table 4.9 for each construction phase according to Table 3.2.

Table 4.9: Non-delivery trips effected during construction process

| phase | timespan [weeks] | transport mode | amount | unit | EE per unit | EE [MJ] | subtotal EE [MJ] |
|---|---|---|---|---|---|---|---|
| design/planning | 6 | Car | 4733 | pkm | 7.36 | 34835 | |
| | | Heavy goods | 0 | km | 43.90 | 0 | |
| | | Light goods | 83 | km | 17.60 | 1461 | 36296 |
| preparation | 6 | Car | 1404 | pkm | 7.36 | 10333 | |
| | | Heavy goods | 0 | km | 43.90 | 0 | |
| | | Light goods | 700 | km | 17.60 | 12320 | 22653 |
| construction | 8 | Car | 749 | pkm | 7.36 | 5513 | |
| | | Heavy goods | 0 | km | 43.90 | 0 | |
| | | Light goods | 478 | km | 17.60 | 8413 | 13925 |
| preparation | 4 | | | | | | 15102 |
| construction | 10 | | | | | | 17407 |
| finishing | 10 | | | | | | 17407 |
| | | | | | | **total** | **123000** |

File: building process.ods

### *Trips by builders*

Generally, trips taken by the workforce are considered negligible. To know the importance of their environmental impact, these trips were counted in this case. The author in his function as construction manager had organised most of the workforce himself. As stated in chapter 3.3 about the construction process, many different people were supposed to get involved in the construction process. Their increasing number could presumably have a remarkable impact. Additionally, some volunteers came on purpose from overseas to assist in the process.

Everybody involved actively in the construction process is thus listed, the travel distance determined and his/her embodied energy in terms of transportation calculated. See Table 4.10 for the condensed list for the entire construction process.

### *Utilisation stage: mobility of staff and volunteers*

Calculations concerning the mobility of the staff is based on discussions with the staff. It consists of the farm facility manager Andrew Purnell and the warden Tess Pettiquin. The latter lives with her family on the premises. Their trips are listed in appendix 6.2.2. 20 % of their mobility is accounted for the Volunteer Accommodation.

Virtual volunteers with related mobility are created to estimate their impact on energy use. 4 different volunteer types, 2 local and 2 international, are distinguished to take into account different needs, different behaviour and different economic possibilities. Table 6.12 in appendix 6.2.2 shows the assumptions made. They are based on the Hawequas Volunteer Programme and personal experience. Table 4.11 shows the embodied energy of all staff and volunteers.

Table 4.10: Builders' trips to participate in the construction process

| phase | timespan [weeks] | transport mode | distance [pkm] | EE per pkm | EE [MJ] | subtotal EE [MJ] |
|---|---|---|---|---|---|---|
| design/planning | 6 | Plane | 38220 | 6.05 | 231231 | |
| | | Car | 180 | 7.35 | 1323 | |
| | | Bus | 0 | 2.45 | 0 | |
| | | Train | 0 | 1.39 | 0 | 232554 |
| preparation | 6 | Plane | 22279 | 6.05 | 134788 | |
| | | Car | 546 | 7.35 | 4013 | |
| | | Bus | 1200 | 2.45 | 2940 | |
| | | Train | 332 | 1.39 | 461 | 142203 |
| construction | 8 | Plane | 0 | 6.05 | 0 | |
| | | Car | 14628 | 7.35 | 107513 | |
| | | Bus | 0 | 2.45 | 0 | |
| | | Train | 2324 | 1.39 | 3230 | 110743 |
| preparation | 4 | Plane | | | 89859 | |
| | | Car | | | 2675 | |
| | | Bus | | | 1960 | |
| | | Train | | | 308 | 94802 |
| construction | 10 | Plane | | | 0 | |
| | | Car | | | 134391 | |
| | | Bus | | | 0 | |
| | | Train | | | 4038 | 138429 |
| finishing | 10 | Plane | | | 0 | |
| | | Car | | | 134391 | |
| | | Bus | | | 0 | |
| | | Train | | | 4038 | 138429 |
| | | | | | **total** | **857000** |

File: building process.ods

Table 4.11: Mobility of Hawequas staff and volunteers

| Transport impact | number of people | total distances [pkm] | EE [MJ] |
|---|---|---|---|
| Staff | 20% | 13800 | 110400 |
| Type 3, local, coordinator | 1 | 8000 | 27000 |
| Type 4, local | 4 | 12000 | 152000 |
| Type 1, international, busy | 1 | 48000 | 306000 |
| Type 2, international, calm | 2 | 84000 | 498000 |
| | **total** | | **1093000** |

File: mobility hawequas.ods

### *Utilisation stage: transport related to farm use*

The managing of the farm induces transport; the matters considered in Table 4.7 must be moved. Their consideration is therefore based on the same sources, the accounts of the SASA-WC Headquarters. The assumptions and calculation procedures are described in appendix 6.2.3. It leads to the following values for embodied energy:

Table 4.12: Transport of matters and energy at Hawequas

| **Matters and energy** | **increase** | **EE** [MJ] |
|---|---|---|
| Regular visitors | 17% | 44710 |
| Land Care camps | 65% | 170950 |
| | **total** | **216000** |

Source: appendix 6.2.3, file: matter and energy hawequas.ods

### *Utilisation stage: transport of visitors*

Hawequas serves as a camping and activity facility. It therefore attracts a large number of visitors in its primary function. In order to estimate their environmental impact in terms of embodied energy, a detailed analysis of visitor fluxes has been conducted. The data for the visitors is extracted from the reservation registry at the SASA-WC Headquarters. The analysis of the year 2006 leads to the figures in Table 4.13. More information is given in appendix 6.2.4. It distinguishes between general visitors (which include Scout groups and any other visitors) and the Land Care camps, a kind of youth development camps. The first visit the farm mostly on weekends, the latter are strictly midweek-camps, to fill that occupancy gap. Their distribution is visible in Figure 6.2 in appendix 6.2.4.

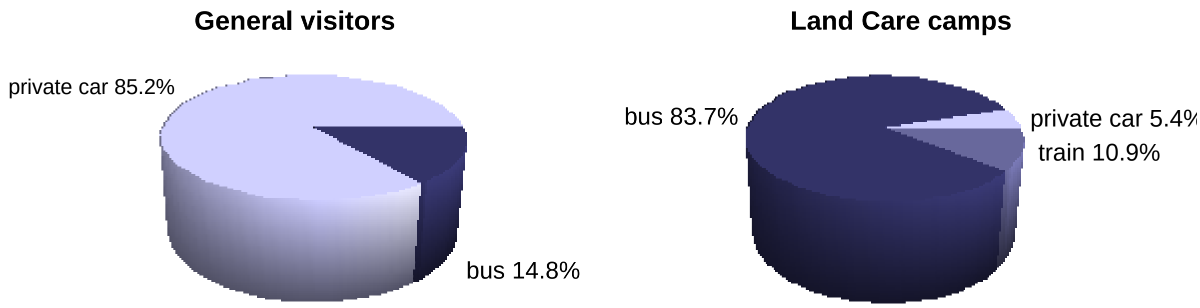
Table 4.13: Summary visitors 2006

| Visitor group | Number of people | Average travel distance | Average stay duration |
|---|---|---|---|
| General visitors | 1411 people | 77.6 km | 2.5 nights |
| Land Care camps | 276 people | 30 km* | 2.0 nights |

Source: SASA-WC Headquarters, file: transportation visitors.ods, * assumed

Beside the number and distance of journeys, it is important to know the transport mode. The warden's diary from January to March 2007 served as base to estimate the modal split. It is differentiated between general visitors and Land Care camps.

Figure 4.3: Modal split visitors




Source: Tess Pettiquin, file: transportation visitors.ods

With the information about additional visitors in the future (Table 3.3), the average distance travelled (Table 4.13) and their modal splits (Figure 4.3), it is possible to calculate the impact in embodied energy. The results are given in Table 4.14:

Table 4.14: Embodied energy of future visitors

| **General visitors** | **modal split** | **distance** | **EE per unit** | **EE** |
|---|---|---|---|---|
| | [%] | [pkm] | [MJ/pkm] | [MJ] |
| private cars | 85.2% | 37309 | 7.36 | 274591 |
| buses | 14.8% | 6461 | 1.64 | 10596 |
| train | 0.0% | 0 | 1.39 | 0 |
| | | | **subtotal** | **285000** |
| **Land Care camps** | **modal split** | **distance** | **EE per unit** | **EE** |
| | [%] | [pkm] | [MJ/pkm] | [MJ] |
| private cars | 5.4% | 3597 | 7.36 | 26472 |
| buses | 83.7% | 55450 | 1.64 | 90938 |
| train | 10.9% | 7193 | 1.39 | 9999 |
| | | | **subtotal** | **127000** |
| | | | **total** | **412000** |

File: transportation visitors.ods

### 4.4.3 Summary of embodied energy calculations

Table 4.15: Summary of embodied energy

| | **construction process** | | | | | **utilisation stage** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *total [MJ]* | *per year [MJ/a]* | *per year and floor space [MJ/m2*a]* | | | *per year [MJ/a]* | *per year and floor space [MJ/m2*a]* | *total* |
| **buildings** | building materials | 658'000 | 26'320 | 210 | | operation volunteer accommodation | 10'000 | 80 | |
| | machines | 121'000 | 4'840 | 39 | | operation hawequas | 474'000 | 3'786 | |
| *subtotal* | | 779'000 | | | | | | | |
| | | | 31'160 | | *6% 94%* | | 484'000 | | 515'160 [MJ/a] |
| | | | | 249 | | | | 3'866 | 4'115 [MJ/m2*a] |
| | | | *41%* | | | | *22%* | | *23%* |
| | | | *59%* | | | | *78%* | | *77%* |
| **transports** | transport building materials | 127'000 | 5'080 | 41 | | mobility staff/ volunteers | 1'093'000 | 8'730 | |
| | transports construction process | 123'000 | 4'920 | 39 | | transports hawequas | 216'000 | 1'725 | |
| | transport builders | 857'000 | 34'280 | 274 | | transport visitors | 412'000 | 3'291 | |
| *subtotal* | | 1'107'000 | | | | | | | |
| | | | 44'280 | | *3% 97%* | | 1'721'000 | | 1'765'280 [MJ/a] |
| | | | | 354 | | | | 13'746 | 14'100 [MJ/m2*a] |
| *total* | | 1'886'000 | 75'440 | 603 | *3% 97%* | | 2'205'000 | 17'612 | 2'280'440 [MJ/a] |
| | | [MJ] | [MJ/a] | [MJ/m2*a] | | | [MJ/a] | [MJ/m2*a] | 18'214 [MJ/m2*a] |

File: summary embodied energy.ods

## 4.5 Impact assessment

### 4.5.1 Construction materials: Straw Bale vs. conventional bricks

The first point to consider is the impact of the different life spans which was defined for the two construction methods: 25 years for the Straw Bale construction and 50 years for the brick building. Both are chosen rather conservatively; the buildings may last much longer. However, the impact is important: While the conventional design has got a total amount of embodied energy of 1851 GJ, the Straw Bale construction has got only 658 GJ, less than half. Over their lifetime (and divided by the floor space), the embodied energy is 296 MJ/m2*a respectively 210 MJ/m2*a. The Straw Bale design leads to a *reduction of 24 %* in embodied energy per year of the building materials. This sounds like a small difference in the first place.

Table 4.16: Comparison Straw Bale construction vs. conventional design with bricks

| | **straw bale** | | **conventional** | |
|---|---|---|---|---|
| | [MJ/m2*a] | [%] | [MJ/m2*a] | [%] |
| Foundation | 28 | 13% | 22 | 8% |
| Walls | 8 | 4% | 92 | 33% |
| Floor | 18 | 8% | 23 | 8% |
| Roof | 44 | 21% | 49 | 18% |
| Windows and doors | 38 | 18% | 22 | 8% |
| Interior walls | 16 | 8% | 15 | 5% |
| Electricity | 5 | 2% | 2 | 1% |
| Water supply | 28 | 13% | 28 | 10% |
| Sewage/ Sanitary | 21 | 10% | 21 | 7% |
| Drainage | 4 | 2% | 4 | 2% |
| **total [MJ/a*m2 floor space]** | **210** | **100%** | **278** | **100%** |

Source: appendix 6.3, file: summary embodied energy.ods

Which parts contribute to that effect? The big counters of the Straw Bale design are the roof with 21 %, the services (electricity/ water supply/ sanitation) with 25 % and windows/ doors with 18 %. The largest contributors of the conventional design are the walls with 33 %, the roof with 18 % and the services with 18 %. In absolute values of embodied energy, the latter two stay about the same for both designs. The reduction is almost entirely due to the change of the wall system. This is the building element which is largely non-industrial: straw bales, blue gum stakes, earth plaster. The other elements are more conventional, using industry products (like concrete foundation, corrugated iron roof sheets, OSB-board-ceiling, new windows, plastic water tank, standard sanitary fittings etc.).

By far the largest contributor of the conventional design are the walls: fired clay bricks and mineral wool insulation. This large embodied energy of industrial insulation materials is one of the main reasons to carry out embodied energy-calculation in Europe. The question would be: How long does it take until the embodied energy of additional insulation is compensated using less energy for heating. However, there is normally no heating system installed in South Africa although it becomes rather cold; (energy intensive) mobile electric heaters are then often used. The insulation contributes therefore to a comfortable room climate and a reduction of electricity use.

In the total picture of the building materials, a reduction of 24 % is quite remarkable. The brick wall assembly incorporates 33 % of the total embodied energy. By using the Straw Bale construction, almost all that embodied energy is freed. The overall performance of the Straw Bale construction is weakened by the lower assumed life expectancy. As other building elements (such as foundation, windows and doors) do not have to be renewed during the life time of the brick building, their impacts per year are smaller for the conventional design.

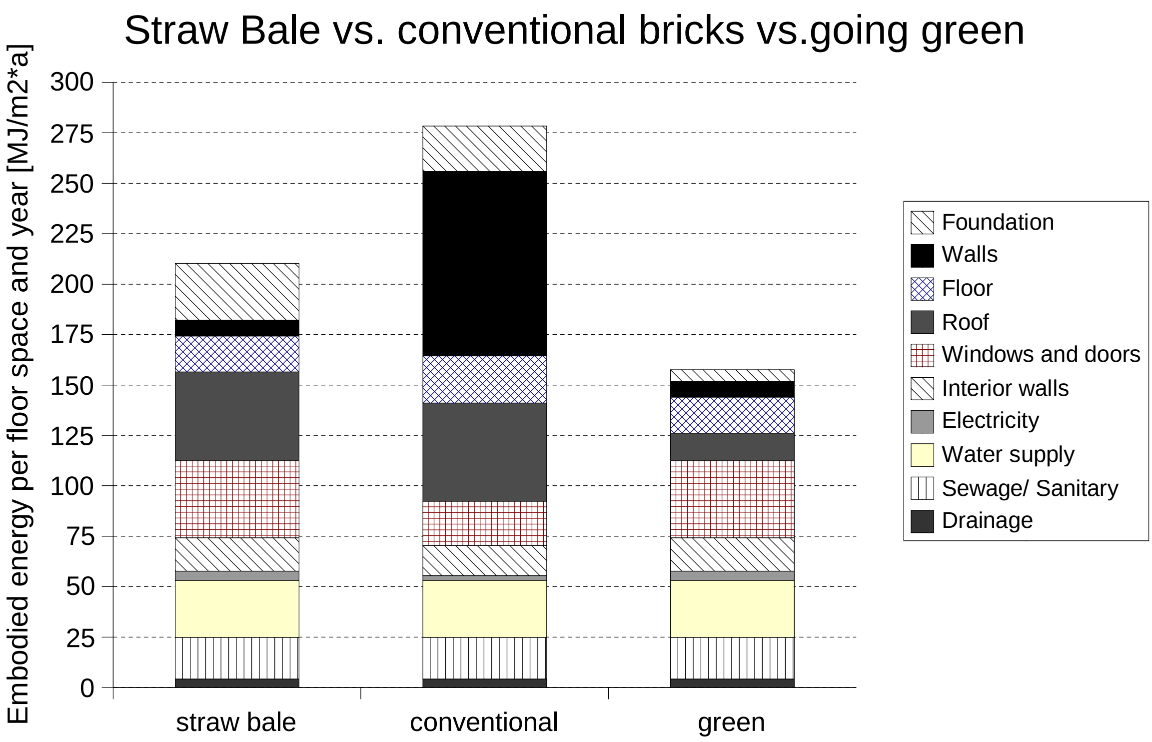
The construction process of the conventional design is not examined in detail. The machines used for the Straw Bale construction would be used as well for the conventional design. Additional machinery would be used for the larger foundation and the wall assembly, mainly cement mixers for mortar and concrete. It is thus estimated that the embodied energy of the construction process adds another 5 to 10 % to the conventional design.

Research in Switzerland (SIA Effienzpfad Energie) has shown that the influence of the building form, its compactness, has a decisive influence on embodied energy. The larger and more compact a building is (ratio surface to volume), the less energy intensive building hull is needed. This ratio is rather bad in this case, with two separate, longish one-storey buildings. Two little, fictive calculations (see appendix 7.1):

- If the two buildings are under one roof, one-storey, the surface is reduced by 8 %.
- If the two buildings are under one roof, double-storey, the surface is reduced by 30 %.

The embodied energy is a function of the surface of the building hull. The building form and the change of the construction method have thus a similar impact on the total embodied energy of the building. One must recognise that a Straw Bale construction is not only a different material but a different construction type. It changes from an energy intensive and industrial wall assembly to a natural building technique. It is more labour intensive but less energy intensive!

Figure 4.4: Straw Bale vs. conventional (bricks) vs. fully green




File: summary embodied energy.ods

One could drive this further and exchange more of the industrial parts of the building with natural building techniques to reduce the embodied energy (see appendix 7.2):

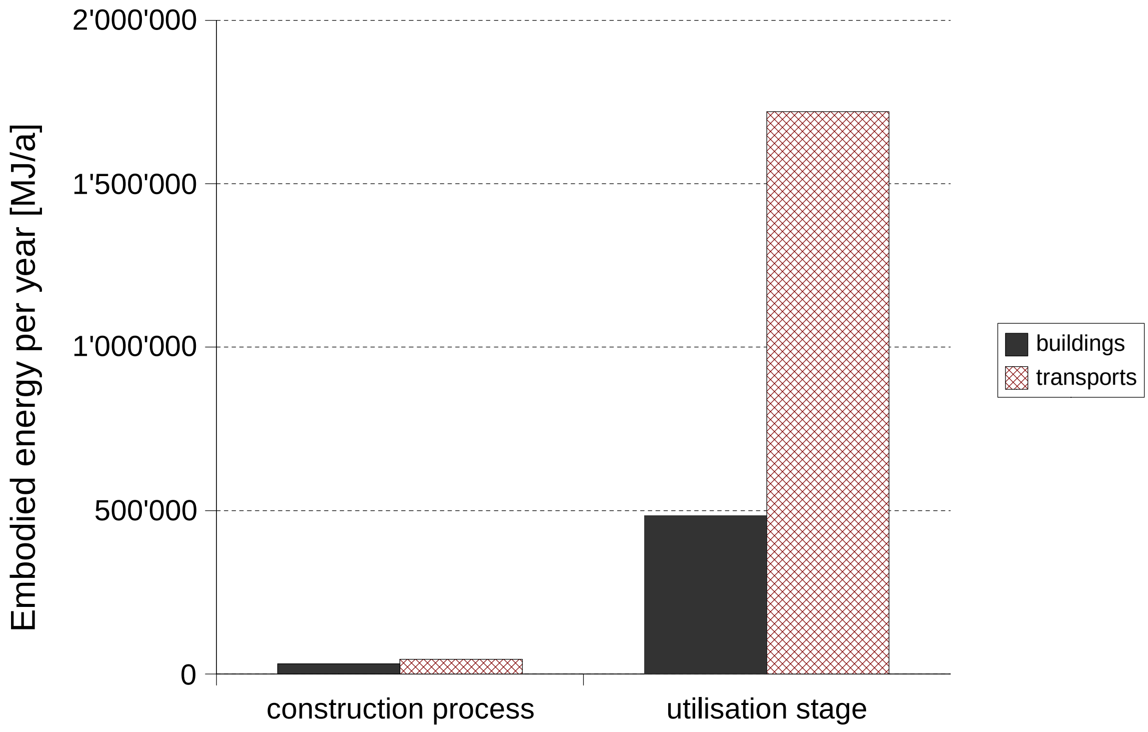
- stone foundation instead of concrete slab (no concrete, form work): - 70'000 MJ
- reed ceiling instead of OSB boards: - 70'000 MJ
- thatched or planted roof instead of corrugated iron: - 25'000 MJ

This results in a building structure with very little embodied energy left. The big parts are services, windows and doors. Compared to the conventional design, it reduces the total amount of embodied energy per year by 43 %.

### 4.5.2 Construction process vs. utilisation stage

There is one striking impression when comparing the construction process with the utilisation stage (see Figure 4.5 and Table 4.15): the embodied energy for the utilisation is far bigger than for the construction! The entire embodied energy for the construction (1886 GJ, for a lifespan of 25 years) is less than the embodied energy through the use of the Volunteer Accommodation with all its implications per year (2196 GJ/a). Whether the construction is made of straw bales, timber, bricks or concrete matters very little. The utilisation stage must thus be considered carefully.

Figure 4.5: Life Cycle stages – buildings vs. transport




File: summary embodied energy.ods

**Commentary: Embodied energy for transport and energy uses**

Embodied energy is the cumulated energy demand from all life cycle stages (compare chapter 4.2.3). For elements like building materials which are not used in an energetic way, this is the only notion about their energy demand. When dealing with fossil fuels, the situation is slightly different. Again, there is the energy used for extraction, refinement and transport. On top, there is their calorific energy to drive machines and processes. That part is mostly so big that there is only a small difference between the calorific value and the total embodied energy. In this study, even when speaking about energy use, it is always referred to as the cumulative energy demand.

The latter will rise in future for fossil fuels. The easily accessible oil fields have already been exploited; the ones to come will be more laborious to exploit. Electricity is again another story: As electricity is an energy medium but not an energy source, there is other energy involved to produce it, today, for large parts, fossil fuels. When the electricity production becomes sustainable one day, not relying on any fossil fuels but on the sun and derived processes, only the energy to construct these energy production systems is needed; the production process itself is running free (apart from maintenance). The notion of embodied energy is thus suitable, for electricity from sustainable sources as well.

### 4.5.3 Construction process

The transport part counts with 59 % of the total embodied energy of the construction process. Only 41 % falls on building materials and machine use on site. This is a very high part for the transport.

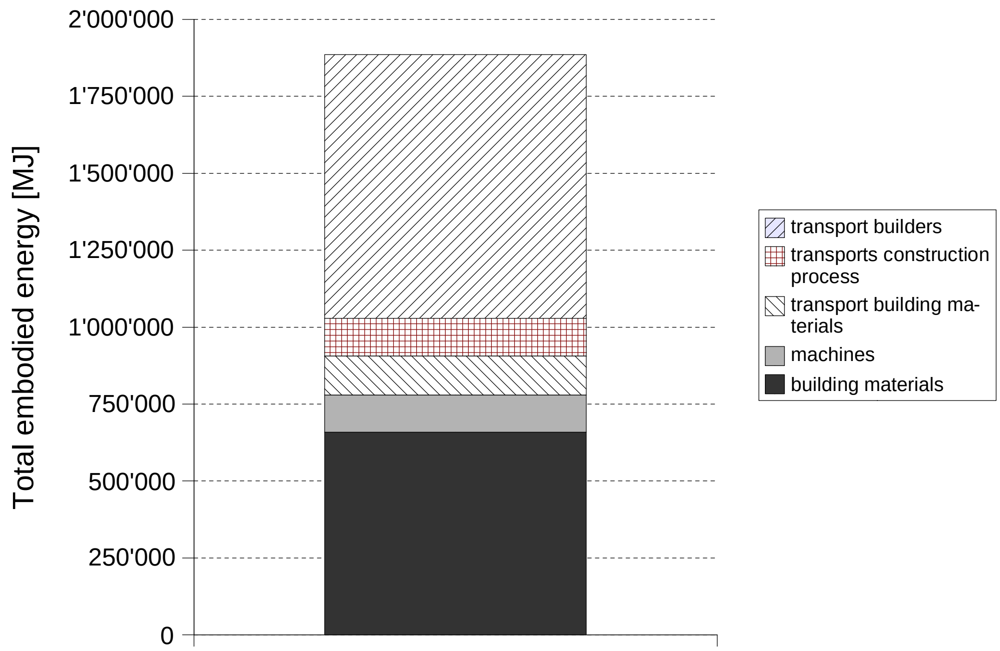
The transport are normally considered negligible. For a conventional building in Europe, one would count for extraction, levelling, elimination of waste from the construction site and the transport for the building materials, all together, maximum 10 – 15 % of the total embodied energy (Kasser 2001). The equivalent here are machine use on site, transport building materials and transport construction process; they account for 20 % of the total embodied energy, or 36 % of the embodied energy without taking into account the transport of the builders, thus considerably more. The transport of the builders are generally not counted. In this case, their impact is larger than that of the building materials!

There are several reasons which make the transport of the people so important:

1. Low energy intensity of the building materials: As the embodied energy of the materials becomes smaller, other aspects become more important.
2. Labour-intensive building technique: The Straw Bale construction requires many hands on the building site, provoking many trips. The construction weekends, as building workshops, attracted many people, mostly from the Cape Town area, driving by car.
3. The site is out of town and off the track: To get into the next town, Wellington, already requires a journey of 9 km. From Cape Town, it is more than 80 km. The notion of distance is quite different in this large country South Africa compared to Switzerland or Europe in general. One would easily spend hours to drive a few hundred kilometres for a weekend. One could assume that transport has a larger impact here because people drive long distances more easily.
4. A few volunteers, including the author, came from overseas to participate in the construction process, some only for that purpose. The impact of the journeys made in aeroplane is really important. Half of the embodied energy of the builders trips “comes from overseas”. Or to express it even more pointy: The impact of the energy used for the aeroplanes is twice as much as was gained by building with straw bales instead of bricks.
5. No elaborate public transport system: There is a railway to surrounding towns and to Cape Town. Few people who can afford a car use it. Irregular timetables, safety problems and slow travel velocity make it laborious. There is no public transport to the farm except with a taxi. The condition of the roads would hold off many taxi drivers. The few people arriving by train have therefore have to be fetched at the train station.

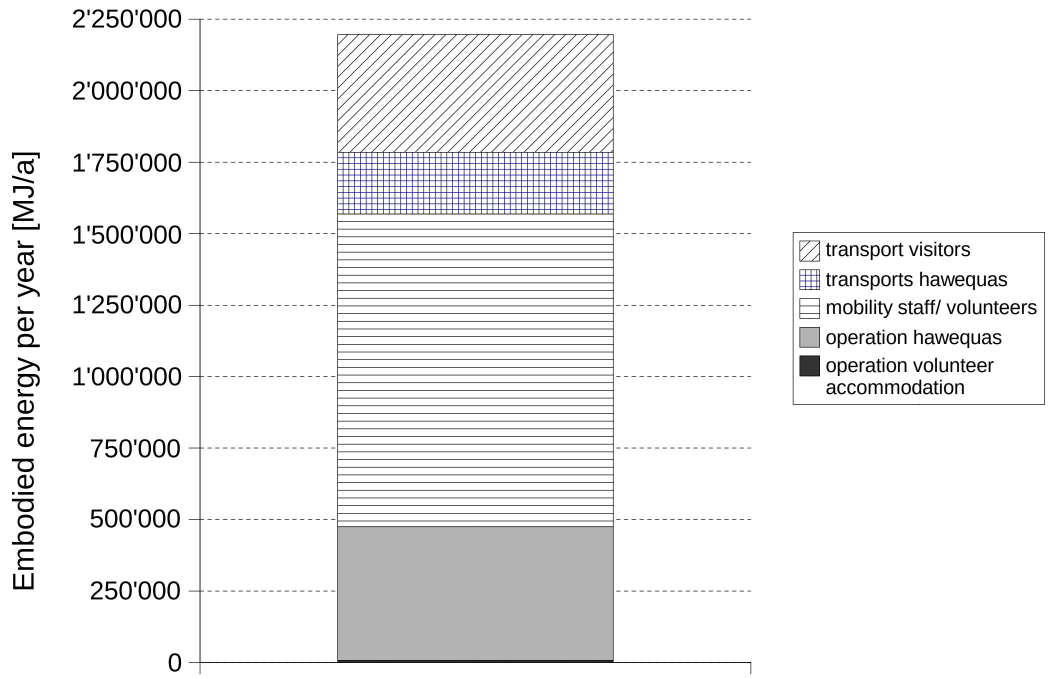
If we assume a “normal” construction process where not volunteers but local labourers are building a Straw Bale house, the relation between materials and transport changes. Taking only a fourth of the builders' transport impact (no planes, half distances of builders), the impact of transport is half as important than of the materials.

Figure 4.6: Construction process, total embodied energy




File: summary embodied energy.ods

Figure 4.7: Utilisation stage, embodied energy per year




Source: summary embodied energy.ods

### 4.5.4 Utilisation stage

The transport is predominant as well for the utilisation stage. They represent 78 % of the total embodied energy per year, 3 to 4 times more than the energy and matter use on the farm.

The impact of the Straw Bale Accommodation itself is negligible (10 GJ/a) in this comparison. It can not even be seen in Figure 4.7. The two basic principles of sustainable energy use are applied:

1. The energy demand is held to a minimum, maximising the energy efficiency: The less you use, the less you need. This step is taken automatically as soon as one does not just pull the power out of the plug but ...
2. ... supplies the energy locally, using photovoltaic panels, wind generator and solar water heater. Only the embodied energy in these equipments needs to be considered. If there was a biogas-digester as a sewage system, even the gas used for cooking and the fridge would be supplied locally, thus rendering the accommodation totally independent from outer supplies.

To operate Hawequas as a camping and activity facility requires a lot more energy. Two thirds is used for electricity. Figure 6.1 in appendix 6.1.4 shows the distribution over the year. The peak of visitors and electricity-use in September falls together with Land Care camps. It can be expected that the electricity demand will rise similarly with the intended intensification of these youth development camps. Electricity is mainly used for lighting and water heating. There is a floodlight which immerses a grass playing field in daylight; its energy consumption must be huge. Water is heated with electricity; if a few dozen people want to take a hot shower every day, it is visible on the electricity bill. The other peak in that figure is during the cold winter season when the warden is heating their house with several small electric heaters. That house is neither insulated nor wind proof; both would reduce the energy consumption considerably.

The energy used for everyday maintenances is remarkable. It has increased strongly since the arrival of an ancient donated truck. Ever since, many more trips are being made, in a very energy intensive vehicle. Acknowledging the use of such a vehicle on a farm, a smaller one would be sufficient. Additionally, it would need fewer repair and may well be less expensive in the long run.

Hawequas obviously attracts visitors. Their impact is relatively small, a fourth of all energy used for transportation. It is less than expected, given the vast increase in numbers of visitors (see Table 3.3). The major part of the anticipated increase in occupancy is due to the extended Land Care camp activities. The modal split for these youth development programmes looks quite different from the general visitors modal split (see Figure 4.3). These children would travel by coach, and not individually in cars. So even though many more children will be coming to the farm, their impact in terms of energy use for transport is quite small.

The largest part is the mobility of staff and volunteers. Here again, the volunteer programme with volunteers from overseas blows the biggest horn. Only the impact of the aeroplanes bringing three permanent volunteers, staying each half a year from overseas, equals 650 GJ embodied energy a year. That is the same as all embodied energy in the building materials. It is thus difficult to reason the overseas volunteer programme with ecological considerations. Preserving the biodiversity was the starting point of the volunteer programme; playing an active role in water resource conservation endangered by climate change was considered a main task. This would not fit with the greenhouse gas emissions of the volunteers. However, the foreign volunteers are important to transfer knowledge for the learnership programmes of local volunteers. Their numbers could be restricted to a minimum, or the programme could run mainly with foreigners who are already in the country, looking for a creative break.

### 4.5.5 Transport

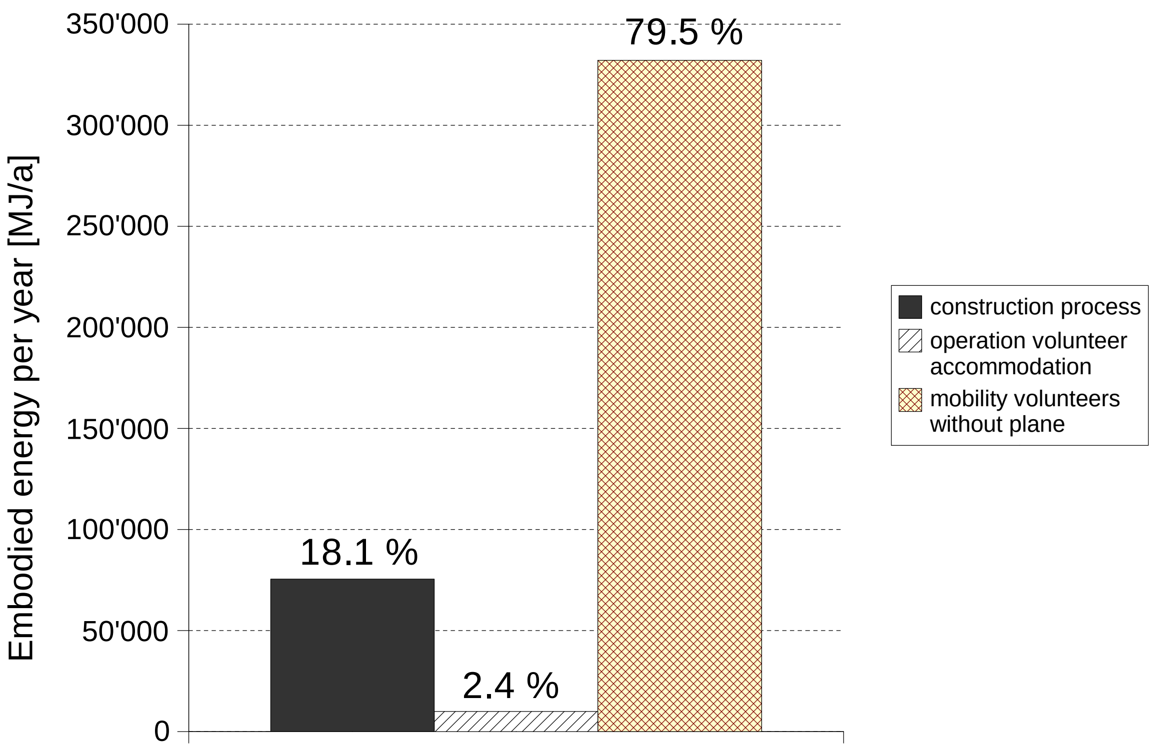
The impact of the transport has already widely been discussed in the last two chapters. It has been seen that the impact of the transport is much larger than the impact of the buildings, with a ratio of 4 : 1. Much of its impact is due to the specific function and use of Hawequas as a camping and activity facility, running a volunteer programme. It would be interesting to see the ratio of the construction process to the transport in general conditions.

Following figures are condensed and compared:

- The construction process is taken as a whole, including the transport of people and materials: 75'440 MJ/a.
- The energy use for the Volunteer Accommodation is considered, representing the utilisation stage save transportation: 7'000 MJ/a.
- The mobility of the volunteers is considered, without the impact of the overseas flights (reduction of 650'000 MJ/a). It is thus considered an accommodation for 8 local people. The same mobility patterns are applied as before; people do not travel very often, representing a lower boundary value: 332'080 MJ/a.

The results are drawn in Figure 4.8:

Figure 4.8: Construction process and volunteer activities, embodied energy per year



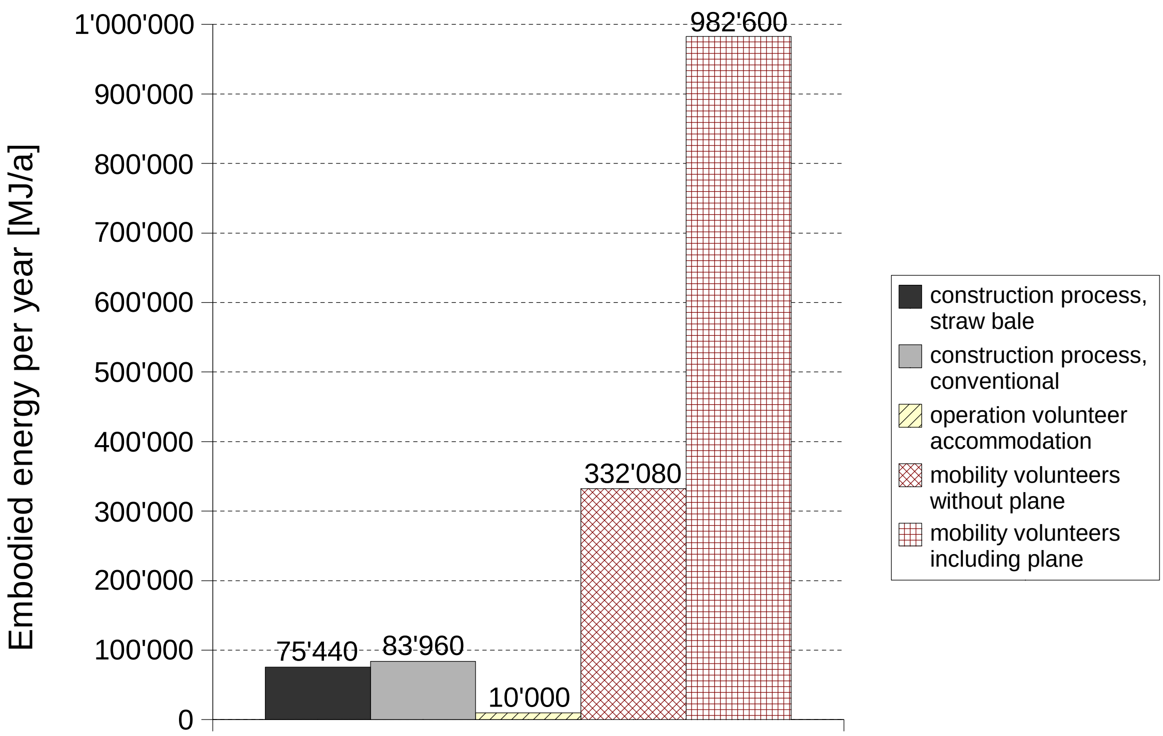

File: summary embodied energy.ods

Transport has the largest influence by far. Its energy use is 4 times bigger than for the building materials. The Straw Bale construction has got little influence here. It has decreased the part of the construction process from 19.7 % to 18.1 % in comparison to a conventional construction. The energy use for the buildings is small as expected. This part is energetically minimised but could be much larger.

Most of the trips are made in a private motorised car. The average travel distance per year is 5525 km / (a * person), showing quite low mobility patterns. To assume an average travel distance twice as high would still be reasonable. The related energy use of the transport could thus be considerably higher, 10 times the embodied energy of the building process.

If the overseas flights of the volunteers are included in the comparison, the importance becomes even more accentuated. The embodied energy for the mobility of the volunteers would exceed the embodied energy of the construction process by a factor 13.

Figure 4.9: Construction process and volunteer activities, different variants




File: summary embodied energy.ods

All these comparisons show the prevailing influence of the transport in terms of embodied energy and energy consumption. Mobility patterns and concepts needs to be given high priority!

# 5 Interpretation LCA

## 5.1 Straw Bale construction vs. conventional construction

There is 24 % less embodied energy in the Straw Bale construction in comparison to a conventional brick construction. This is a massive improvement on a material level, especially if one considers that the alteration of the wall system has got an even larger effect. Most other parts of the buildings are still designed in an industrial way. If the design was more radically green, the use of industrially manufactured products even more reduced, the embodied energy could be halved.

Part of the gain in embodied energy of natural building methods is compromised by additional transport. These building methods are less energy intensive but more labour intensive. If the workforce travels often and from far, it has got a big effect. Using local labour is therefore very important to reduce the energy use. It simultaneously allows the integration and empowerment of the local community.

## 5.2 Transport

The influence of the utilisation stage on embodied energy is much larger than the influence of the construction process, partly due to the function of the property as a camping and activity facility. A major part is transportation, both from farm visitors and the volunteer programme. Two thirds of the energy used by volunteers is due to the overseas flights. One return flight per year has got an impact more than 10 times as strong as the energy gain of using straw bales instead of bricks.

When we considered the Straw Bale Volunteer Accommodation as a normal house for 8 people (without the overseas flights and without the generated visitors), transport still use 4 times more energy than the construction process with all materials. In order to reduce the ecological footprint, top priority needs to be given to mobility patterns and mobility concepts!

The question of whether it does or does not make sense to use natural building methods is clearly answered with yes, despite its seemingly little influence in total. Once the decision for the Volunteer Accommodation project with its visitors and volunteers is taken, that part is fixed; efforts must now be concentrated on what can be influenced. However, before one thinks about the construction methods, serious thoughts must be given to the mobility concept! This is particularly important for housing developments.

## 5.3 Methodology

The system boundaries in this LCA are quite complexly drawn. It is not always clear what effect is examined, a building or development project? The comparison of embodied energy of materials with the embodied energy of energy use and transport opens room for confusion. However, the applied method allows one to make different statements by combining various elements and effects.

Embodied energy may not be the best indicator for a farming waste product like straw bales. It is mainly used because the environmental impact is often correlated to the energy input during the production. For renewable natural resources, fertilization and pesticides are striking ecological issues; neither of them are represented through embodied energy. It may be more appropriate to use other ecological indicators (like UBP = Environmental Impact Point) to compare the Straw Bale construction (or any natural building method) to conventional construction methods. The impact of the straw bales would have to be developed especially as there is no such value known. However, embodied energy is a suitable indicator to compare the construction to the utilisation stage. Transport issues can be well expressed in energy use.

The collection of data for the calculations proved rather difficult. Missing data is estimated; future uses are based on projections and assumptions. This leaves room for uncertainties.

The Inventory Tables used for the calculation of the environmental impact are another source of uncertainties. The only South African values have never been confirmed in audits. The Swiss values are based on a different background, in terms of economic power, social welfare, natural environment and climatic conditions. The building industry may as well exhibit a considerably different structure. All these effects are taken into account by one single correction factor representing the energy intensity of the national economies. The results are thus probably not exact. The applied method is sufficient for a first estimation. The results give a correct indication of the magnitude of the examined problems but do not pretend precision.

# 6 Conclusion

## 6.1 Sustainable construction in South Africa

In South Africa, as a developing, post-apartheid nation, the main focus lies on the socio-economic side of sustainable development e.g. fighting poverty and empowering communities. Capacity building and social uplifting of the local communities is the key to achieve a long-term effect. Ecological considerations come second. But by neglecting the environmental side, policies nurture unsustainable services, aggravating the situation and making it more difficult to transform into a sustainable society. Developing Africa now has the challenge and the opportunity to base its socio-economic development on a smaller ecological footprint right from the start, rather than copying the huge ecological footprint of the developed world.

## 6.2 Evaluation and optimisation of the Hawequas Straw Bale Accommodation

It does make sense to use Straw Bale construction to for this Volunteer Accommodation for various reasons: It allows one to build with little financial resources, particularly because labour is free. The splendid ecological performance in comparison to conventional methods has been shown in the Life Cycle Assessment. The construction method allows one to integrate a large community into the construction process, very important for a volunteer-based construction process. It is a great opportunity for community building experiences and workshops!

From a practical perspective, it is rather delicate to use the load-bearing Straw Bale construction system. It is a very interesting way to build, using the straw bales both as carrying structure and insulation. A frame structure is obsolete and the loaded walls have a better integrity. This technique makes it necessary to finish the construction process very quickly once it has started to protect the structure from weather while the bales are exposed.

If the right conditions (stated on page 34) are not fulfilled it makes sense to use a non-load-bearing system. The roof would then be constructed first, set on a frame structure. This creates a sheltered construction site to synchronise the working pace to available workforce and tools.

The entire project and vision for Hawequas is very promising and inspiring. It integrates practical education with natural conservation and youth development. Much will depend on the volunteers who are getting involved. They will have the freedom to shape the different processes and show initiative for good. The entire development now needs to prove its financial sustainability. If it works, the Scouts will have created a new kind of eco-village.

## 6.3 Optimisation of the mobility concept

The mobility concept today is entirely based on private motorisation. It is difficult to see any viable alternatives. The farm lies just underneath the mountains, at the end of a valley. It is very unlikely that any public transport system can be set up. Taxis could serve the farm in theory and create the missing link to town centre and train station. Better maintenance of the dirt roads would then be needed. At the moment, as little money as possible is spent on maintenance, resulting in ever-bad-shaped roads. This makes every drive demanding for driver and car; access for coaches is interdicted, due to safety concerns. The bridge on the main access road should get reconstructed. In the present state, it restricts activities.

Improvements of the transport system concern therefore the uplifting of the present infrastructure. The other starting point is to improve the efficiency. This is quite good already. The drive in and out of the farm is so tedious that one tries to minimize them by always combining several purposes and people on one drive. And it is an advantage to have a passenger, to open and close the gates. Transport for the Land Care camps is in coaches; this is already the best solution.

The challenges for sustainable mobility concepts in general in South Africa are huge. The current transport system is laid out for individual motorisation. Other factors play an important role too. For example is the private car a safety measure as well. Most people (who can afford it) do not move without a car, not even for very short distances. And the emerging parts of the society have got big aspirations for a car. When getting enough money, they want to have their own car, the embodiment of freedom. Who can deny them that? But the transport infrastructure will not be able to cope with everyone driving their own car. Other ways will need to be found.

## 6.4 Tools for sustainable development

The question: "What tools would be necessary and appropriate for sustainable development in South Africa?" can here not be answered in full satisfaction. The author did not concentrate enough on that question. However, several efforts have been undertaken in South Africa to create or adapt tools for sustainable building assessment. As Ewelina Kaatz has shown (Kaatz 2005), focus should rather be laid on participatory processes. To answer the needs of the community in socio-economic uplifting, the specific situation is primordial.

To advance sustainable development, focus must be laid on education and communication. The concept of sustainability and life cycle thinking need to be communicated on various levels. There is one big danger of misunderstanding between promoters of sustainability and emerging poor people: For a long time, a poor person may have struggled to achieve the possibility for a higher standard of living. And now, various goods should not be accessible any more; because the ecological capacity is limited. This can be frustrating and misunderstood. The big challenge is therefore to communicate sustainable development not as hindering but as a positive, long-term and equitable development. This importance of communication does not change whether it is in a developing or a developed country.

## 6.5 Sustainability of Straw Bale constructions

The ecological capacity of Straw Bale constructions has been shown in the Life Cycle Assessment. From an environmental perspective, there are even more striking advantages than embodied energy. Straw bales are made out of a waste product from a renewable natural resource. Using the bales instead of burning the fields reduces air pollution and greenhouse gases. The resource is re-grown in one year, supplying the building industry with huge amounts of potential building materials. And the bales integrate themselves perfectly into the natural system after its use by just rotting away. The straw bales should be locally available. It would not make sense to transport them from far.

It is possible to build much less expensively with straw bales. The construction methods is very suitable for self-building. The construction principles and required tools are relatively simple. By participating in the construction of their own house, the owners can save money and become personally connected to their living space. It all adds to a cosy and healthy living atmosphere in a tremendously well insulated but still breathing house.

The biggest challenge is the social acceptability of Straw Bale constructions. It needs to be communicated that it is as much a viable construction method as any other when used for its strengths. It might help to make the buildings look like any other, e.g. with straight walls. Whereas certain people involved in Straw Baling would strictly reject that, it might help to overcome the reluctance of others. The experimental, “hippie” reputation needs to be addressed, as does its lack of integration into the normal building industry.

The potential social benefits for a community could be large and diverse, in particular in low-cost housing: integration of the community into the construction process, low-tech, transfer of skills, identification with the houses, personal maintenance, healthy atmosphere, better temperature conditions, less medical expenses, less time spent on collecting firewood and many more. For all these points, it is important that Straw Bale structures do not appear as a cheap solution (because that is all one can afford) but as a viable option because it is the best choice in the specific local context.

## 6.6 Importance of transport

The Life Cycle Assessment has shown the prevailing influence of transport on the ecological footprint, at least in terms of embodied energy. For a normal building setting in South Africa, about 4 times as much energy is used for transport as for the building, for the construction and the utilisation. The mobility concept requires serious thoughts. Any small improvement may have a big influence. Public transport systems, alternative transport, dense developments, short distances, integrated communities with mixed uses are just a few keywords towards less energy intensive settlements.

Already well known, the influence of overseas flights has been clearly shown. One return flight per year uses 10 times as much energy as is gained by using straw bales instead of bricks as construction material. Minimization of aeroplane travels should be generally anticipated.

## 6.7 Recommendations for the Hawequas Scout Farm

The energy use for the farm facilities is very large. In perspective of increasing the occupancy of the farm, the energy use is bound to rise too. Increasing the energy efficiency has got a big potential. Main issues are probably water heating and the floodlight. It would be wise to consider energy supply alternatives, probably from a financial point of view as well. Investments in solar water heater and photovoltaic (PV) panels should be viable options. As it will soon be possible to feed electricity into the grid, PV cells may be an additional income generator. Hawequas could for example even run training camps where youth learn how to install and maintain PV systems. It would then become an ever growing solar power farm.

The volunteer programme should be run with as many locals as possible. Foreigners from overseas should only be included if they can bring clear benefit and knowledge to the learnership-programmes of the unemployed school leavers. The impact of the overseas flights is simply huge. If they are already in the country for other reasons, it is a different question.

The light duty truck Dennis which was donated to Hawequas earlier this year is very useful for maintenance tasks on the farm. It is though questionable whether this is the right kind of vehicle. It is so old that it needs to be repaired almost once a week and it uses big quantities of fuel – probably both reasons why it was donated. A new bakkie (pick-up) would be much more appropriate and may well be less expensive in the long run, reducing maintenance and fuel costs considerably.

Maintenance of the roads and the bridge are other important tasks. The access to Hawequas is very intricate at the moment. A better road quality would wear to cars and reduce fuel use. The management could then also work towards reopening the access for buses and coaches. Large groups would rather come in coaches if they did not have to walk the last 2 kilometres.

Future facilities should all follow ecological design principles; existing facilities could be uplifted. Once the accommodation is finished, the gained knowledge could be carried on by continuous exchange and interaction of the volunteers. Hawequas could become a knowledge centre for ecological design, in various fields such as natural building techniques, energy supply, sewage treatment and permaculture gardening. The learnership programmes and the Land Care camps make sure that the message is steadily spread.

# 7 Literature


Baird G, Alcom A and Haslam P (1997) *The energy embodied in building materials - updated New Zealand coefficients and their significance*, Centre for Building Performance Research, Victoria University of Wellington, New Zealand

Barker G and Kaatz E (2001) *Environmental Sustainability Assessment Methods for Buildings in South Africa*, Department of Environmental and Geographical Science, University of Cape Town, South Africa

Bartlett AA (2006) Reflections on Sustainability, Population Growth and the Environment – 2006, in Keiner M (ed.), *The Future of Sustainability*, 17-37, Springer, Nederlands

Capra F (1996) *The Web of Life. A new synthesis of mind and matter*, Flamingo, London

Council for Scientific and Industrial Research (CSIR) (2001) *The Sustainable Building Assessment Tool (SBAT) Housing*, CSIR Boutek, Pretoria

du Plessis C (2002) *Agenda 21 for Sustainable Construction in Developing Countries, A discussion document*, CIB & UNEP-IETC, CSIR Boutek Report No Bou/E0204, Pretoria

du Plessis C (2006) 'Thinking about the day after tomorrow. New perspectives in Sustainable Building'. *Rethinking Sustainable Construction 2006 Conference*, September 2006, Florida

Environmental Evaluation Unit (EEU) (2004) *DIY Home Insulation Kit Project, Final Report*, EEU Report number 8/255/04, University of Cape Town

Federal Constitution of the Swiss Confederation (1999), accessible at http://www.admin.ch/org/polit/00083/index.html?lang=en

Friedrich E (2001) *The Use of Environmental Life Cycle Assessment for the Production of Potable Water*, Master of Science in Engineering Thesis, School of Chemical Engineering, University of Natal, Durban

Frischknecht R, Jungbluth N, Althaus H-J, Doka G, Dones R, Hellweg S, Hischier R, Humbert S, Margni M, Nemecek T and Spielmann M (2004) I*mplementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000 No. 3.* Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland, (accessible on www.ecoinvent.ch)

Fuggle RF and Rabie MA (1992) Environmental Management in South Africa, Juta & Co, Wetton

Greening the Building Life Cycle, http://buildlca.rmit.edu.au/ (accessed on 02.06.2007)

Halls St, and Rovers R (2003). *The building and construction sector: cornerstone of sustainability.*" Industry and Environment 26(2-3): 3-4.

Holm D, Irurah DK and Ströh A (2000) *Application of the input-output method of energy analysis in estimating process energy intensities*, Journal of Energy in Southern Africa

Horn A (1998) *A manifesto for green architecture, 6 broad priciples for a greener approach to architecture*, Conference paper at the South Africa's first conference of Sustainability in the Built Environment, Cape Town

Intergovernmental Panel on Climate Change (IPCC) (2007) *Fourth Assessment Report "Climate Change 2007" (AR4)*, (soon available at: www.ipcc.ch/)

Irurah DK (1997) *An Embodied-Energy Algorithm for Energy Conservation in Building Construction as applied to South Africa*, PhD Thesis, Faculty of Science, University of Pretoria, Pretoria

ISO 14040 (1997) *Environmental LCA – Management Principles and Framework*

Kaatz E (2005) *Developing a building sustainability assessment model for the South African built environment, Searching or new approaches to improve the effectiveness of building assessment*, PhD Thesis, Department of Construction Economics and Management, Faculty of Engineering and Built Environment, University of Cape Town, Cape Town

Kasser U, Preisig H and Wydler J (2001) *Unsichtbarer Energieverbrauch*, tec 21, 10.07.2001

Keiner M (ed.) (2006), *The Future of Sustainability*, Springer, Nederlands

King B (2006) *Design of Straw Bale Buildings. The State of the Art*, Green Building Press, San Rafael

McDonough W (2004) 'All Sustainability is Local: A Global Strategy', Keynote paper, *Sustainable Resources Conference*, 30 September 2004, Boulder Colorado

McKenzie K (2003) Cooperative governance is needed to tackle transport problems, *Engineering News*, www.engineeringnews.co.za, (accessed on 02.06.2007)

Meadows DH, Meadows DL, Randers J and Behrens WW (1972), *Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind,* Universe Books, New York

Minke G, Mahlke F (2004) *Der Strohballenbau. Ein Konstruktionshandbuch*, oekobuch Verlag, Staufen bei Freiburg

Prinsloo JDG (2005) *Wheat Straw Bales as building material: A study of the physical and economical properties of wheat straw bales as an alternative to certain construction materials*, 3rd Postgraduate Conference 2005, Construction Industry Development, Johannesburg, 9-11 October 2005, 159-168

Republic of South Africa (RSA) (2000) National Housing Code (available at: www.housing.gov.za) (accessed on 14.05.2007)

SIA (2001) *SIA 380/1 Thermische Energie im Hochbau*

SIA (2004) *SIA Effizienzpfad Energie Statusbericht Graue Energie, Grundlagen zur Dokumentation SIA D 0216*

SIA (2005) *SIA 112/1 Nachhaltiges Bauen – Hochbau*

Steen Swentzwell A, Steen B, Bainbridge D (1994), *The Straw Bale House*, Chelsea Green Publishing, USA

Stern N (2006) *Stern Review: The Economics of Climate Change* ,accessible at www.hm-treasury.gov.uk/ (accessed on 05.06.2007)

Ugwu OO, Haupt TC (2007) Key performance indicators and assessment methods for infrastructure sustainability – a South African construction industry perspective, *Building and Environment*, 42, 665-680

Umweltbundesamt Deutschland (2002), *Nachhaltige Entwicklung in Deutschland, Die Zukunft dauerhaft umweltgerecht gestalten*, Erich Schmidt Verlag, Berlin

United Nations Development Programme (UNDP) (2006) *Human Development Report 2006*, accessible at http://hdr.undp.org/hdr2006/

Wallbaum H (2006), *Communication is the key to change*, extract from the magazine „Foundations6“ of the Holcim Foundation for Sustainable Construction

World Council on Environment and Development (WCED) (1987) *Our Common Future* – Brundtland Report, Oxford University Press, Oxford

www.are.admin.ch

www.baubiologie.at

www.bauteilkatalog.ch

www.bfs.admin.ch

www.bluescopesteel.com.au/go/building-products/rainwater-harvesting/life-cycle-analysis-for-rainwater-tanks www.brabys.com

www.capeaction.org.za

www.cia.gov/cia/publications/factbook/geos/sf.html

www.eco-bau.ch

www.ecoinvent.ch

www.empa.ch

www.euronuclear.org

www.footprintnetwork.org/index.php

www.grat.at

www.hbefa.net

www.ipb-news.ch

www.kbob.ch

www.minergie.ch

www.nachhaltiges-bauen.ch

www.openoffice.org

www.scouting.org.za/capewest/hawequas

www.sustainabilityinstitute.net

www.sustainablebuiltenvironments.com

# APPENDICES

## Sustainable construction in South Africa –

### Theoretical and practical analysis of sustainable infrastructures in the case study of the Hawequas Straw Bale Accommodation


**Marcel Bruelisauer**


**Diploma thesis in Civil Engineering** **June 2007**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A - II

# Table of contents

# 1 Interview with Prof. Daniel Irurah

Interview with Prof. Daniel Irurah (DI) from the University of the Witwatersrand, by Marcel Bruelisauer (MB)

20.1.07, 20:00, Village Hotel @ Spier, Stellenbosch, SA

Introduction of Marcel Bruelisauer, Presentation of Hawequas Volunteer Accommodation Project, Outline of Diploma Thesis about Sustainable Construction in South Africa (SA)

MB: What is sustainable building (SB) in SA? What are the important issues?

DI: The SB and sustainable construction (SC) will differ because what is sustainable for one area is not going to be sustainable in another area and what is sustainable in one type of construction will not be sustainable in another type. The example you are giving now of the straw bale construction: In an area like this one, there are interests in getting straw bale constructions seriously. But when you go to Cape Town, when you go to Johannesburg, when you go to Pretoria, you wouldn't build in straw bales. So if you want to have a general understanding of what sustainable construction in SA would mean, you would have to first address what the development needs are and then looking at how to meet those development needs, in relation to a sustainable way, in relation to what does not harm the environment but at the same time also contributes to the socio-economic improvement. Because you must recognize that SA is a developing country. So there are a lot of socio-economic development needs. It is not like Switzerland where the big question is just ecology and the ecological and environmental impact. Here, we look at projects with a lot of attention to what they contribute to socio-economic development besides the environmental issues as well. So it is more challenging here in SA compared to what you would have in Switzerland because the development needs are a big priority. So in most cases you find that developers and government and other stakeholders would emphasize more on the social and socio-economic development and delayed on the environmental and ecological development. The sustainability question of what is sustainable and what is SC and sustainable development (SD), it would vary. So it is not a common thing.

In general, what is important is to first look at what you contribute to the overall objective of the project, so you must know what you are trying to develop for, if it is a school, if it is a hospital… There is not only one type of design and construction that will fulfil that objective.

There are proprieties of the solution of the design to the ecological, the environmental and socio-economic needs of the region and the context in which you are developing. And especially, we look at that in terms of job creation issues, that's very important, skills, how does it contribute to the skills of the people and the community around there, how does it contribute to empowerment of other groups around there like women […] because women are particularly disadvantaged when it comes to income opportunities. And then, you also have to consider the environmental and ecological side especially in terms of minimizing the impact on the environment and then using more sustainable materials, materials that you can evaluate as materials that are not heavily processes and so on. But what would be suitable for, let's say an office building in Johannesburg would not necessarily be suitable for a primary school in a rural area, for example. So it is not one simple answer but there are many, many different solutions. But I think the big difference between what you encounter in a developing country like SA compared to Switzerland, is that you have to address both the socio-economic as well as the ecological and environmental issues.

MB: So are these principles only applicable to larger projects like community projects but not to a single house?

DI: Even if it is a simple house, you are still able to do a lot of things. The example you have given now is the case where you are addressing one aspect and that is the materials, the choice of materials. But when you take that aspect, there are a lot of other things like water conservation, like energy conservation when you start using that building. And there is the relationship with the community there: Is it going to be contributing to the economic empowerment? Is it going to be contributing to the skills? Is it going to leave behind an economic activity that the people can engage with and earn income? Is it going to leave the community better off, in terms of a long-lasting effect? So, if it is not leaving that benefit, it is just an experiment you are doing. And it is not clear that there is going to be a long-term benefit for the community. So you might be doing it and it will possibly be good for ecological reasons and environmental reasons. But if it is not going to be leaving something long-lasting for the community, then it is not [sustainable].

What are the skills that are going to be used? Are you training anybody? Will those people be able to sustain the production of such houses and buildings? Where are they going to be getting the straw bales? […] So it is going to be a whole chain-effect? But if you are interested in the ecological side, in embodied energy used for transport and so, it is a good experiment. You can't always do everything, especially for a small dissertation or thesis. You have to focus on something. But you must be very sure what you are interested in.

MB: When we stay on the ecological side for a moment, what does ecological design mean for you? What I have seen in Switzerland is that you mustn't see ecological design from the outside. It has to be the same as if it was normal, except that the inside is different. Is it the same in SA?

DI: Even more because the people have not yet adapted to the need of ecological design. Anything that is not able to mark people's expectations then becomes very difficult to make people accept that. When you say ecological, I would not consider straw bales just by being straw bales as ecological. They are ecological to the extent that it is done within a place where straw bales can be made and it can be made easily and people are ready to learn the skills of doing straw bales. If you are doing it in place where people don't want to learn the skills and if they don't want to houses done with straw bales, you know, then it is not ecological because you cannot then reproduce it, you cannot then use it on a bigger scale. So it would not be sustainable because it will not be accepted. So, sustainability has got to relate to that question of gaining acceptance. Those who can use it and those who can utilize it must gain acceptance and therefore you must work towards ensuring that people will gain acceptance or will accept that technology once you have introduced it and you have made them familiar or aware about it.

MB: Would you like hide ecological design, so that people accept it because it looks normal?

DI: Not to hide it. You wouldn't consider it as hiding it; you would consider it as adapting it to people's expectations and people's desires in terms of how they want it to be and how they want it to be provided. So, a lot of people would not necessarily want to know that it is a straw bale construction. They don't want to know. But they want to know that if you give them a house no matter how it is built, if tomorrow they don't want it and they want to sell it to somebody else, they can sell it just as well as a brick house or something like that. So you must be able to make sure that it doesn't create any disadvantage to any of the people who are going to be beneficially from it. So even though it is ecological, it then doesn't mean that you force people to take it. You must do it in a way that people will find it OK, to accept it.

But what will be ecological in the city centre of Johannesburg will not be ecological in a rural context. So ecological in the city of Johannesburg, you are perhaps looking at materials that you can reuse, materials that you can recycle, materials that you can reprocess and that kind of things. It is very difficult to talk about one material that satisfies all the needs. It must be suitable for the context in which you are situated.

MB: A more technical question: Do you know anything about embodied energy in straw bales, clay and other alternative materials? Do you know about researches in that area?

DI: There isn't any specific research I know that covers those non-industrial materials. The question is whether it is really possible to calculate those materials which are not industrial because you would have to do very deep auditing in the field of what you are putting together. […]

The reason is that it is non standardizable because the process by which you produce the bales or the process by which you transport the bales is very varying.

Say for example that the bales are being transported by horse cars from the farm to the construction site. There is almost no embodied energy involved in because we don't count the energy of the horse and the energy of the human beings as part of the embodied energy. But if it is transported by a truck which uses diesel or petrol, you will count that. Because the main reason of embodied energy is to determine the greenhouse gas impact is, of the material. […] And that is why it is so difficult to have one common standardized figure for these alternative materials. […]

It only starts having embodied energy of significance when it comes to automatic processes like when electricity is used or a diesel motor. So that is why you cannot have an average statistic. […] But when you start using these alternative materials which you can process on site, you have to make on-site calculation and determination of what you really can count as embodied energy, depending on what processes you use.

MB: I know where the bales come from; I was there when the tractor was compacting them. I was on the truck when we were transporting them.

DI: Fine. So you can actually calculate how much per bale. So you find perhaps 1/10 of a litre of diesel for the tractor and perhaps another 1/10 of a litre for transport per bale.

[…]

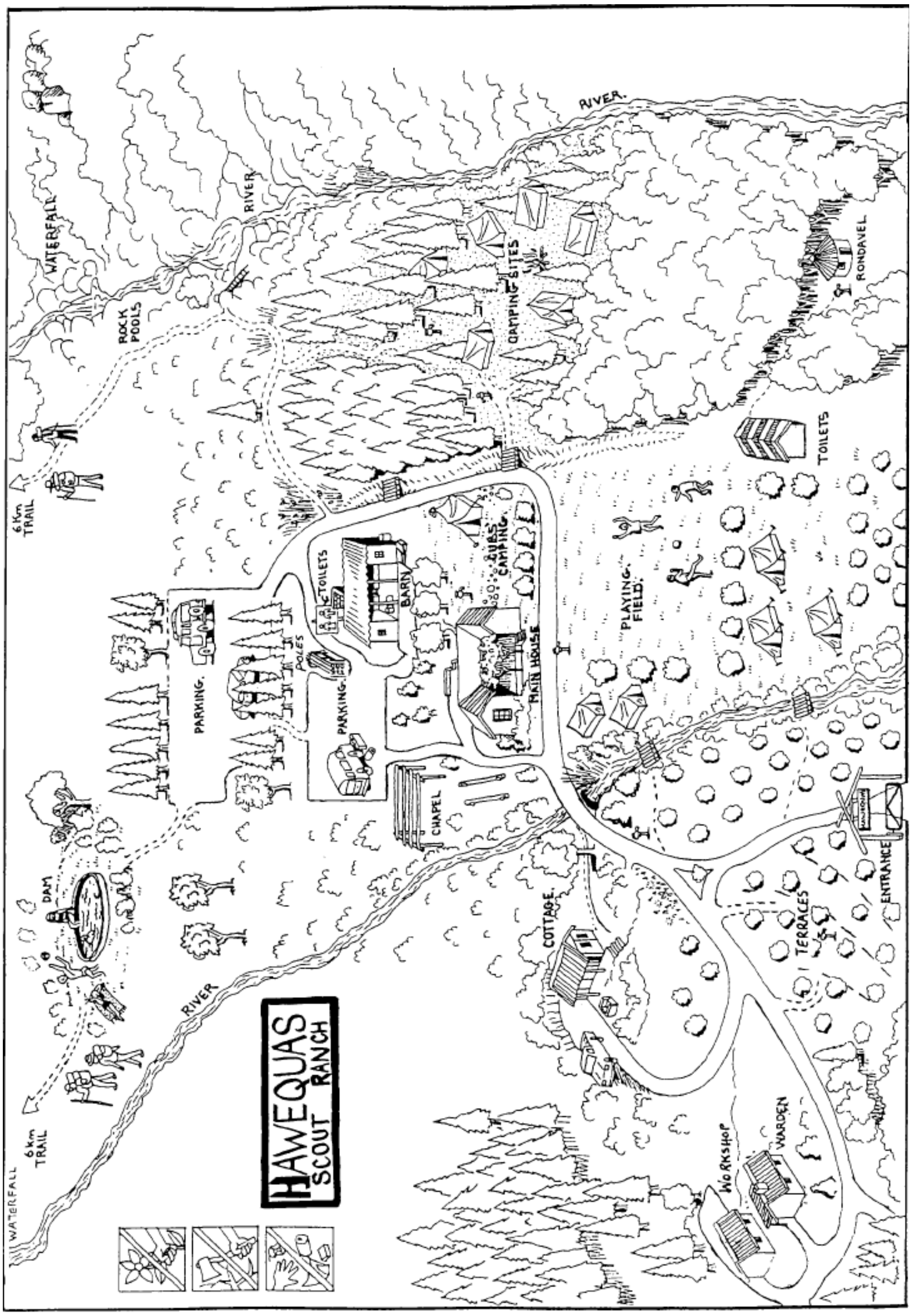
DI: If a government would commit itself to do straw bale housing or schools, it will be more for social and economic reasons, not so that of greenhouse gases. So, the reasons that will drive a sustainable project in Switzerland are not the same reasons that would drive a sustainable construction project in SA. The priorities are very different.

MB: The priorities here are the social and economic development here then.

DI: Yes, those are the top priorities. If you say that here is a technology that is able to do the same performance and it is well accepted with half the costs. The ecological benefits would be a bonus. If there is an ecological benefit, it becomes then a bonus. But the government or a community may not commit just because of the ecological benefit. It has to show a very strong socio-economic benefit before you go to the ecological. […] Whatever ecological solutions you are proposing, they also have got socio-economic benefits. So you must demonstrate the socio-economic benefits first. […]

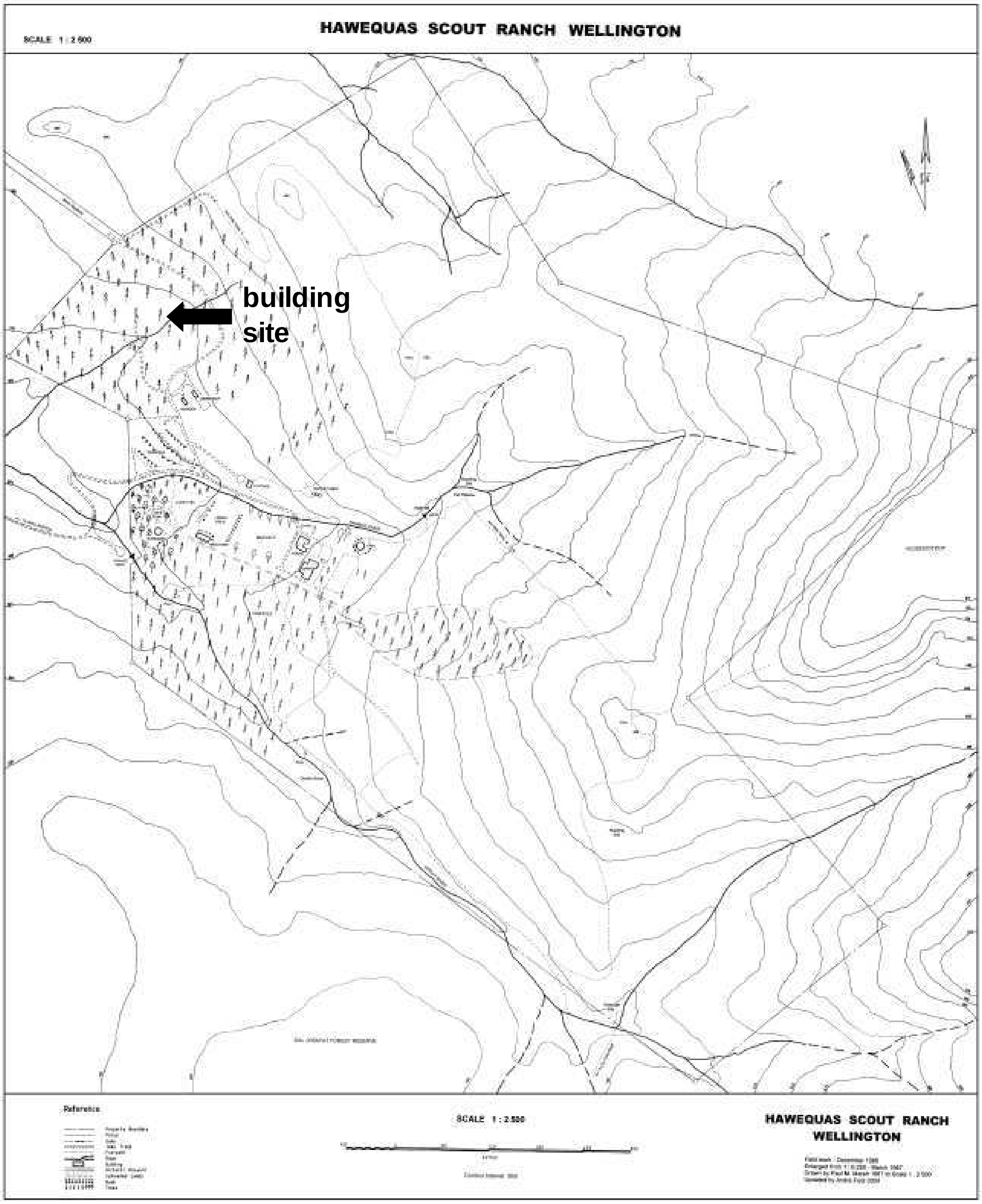
# 2 Hawequas: existing facilities

Figure 2.1: Hawequas Campsite map, drawing




Source: SASA-WC Headquarters

Figure 2.2: Hawequas Campsite map, plan

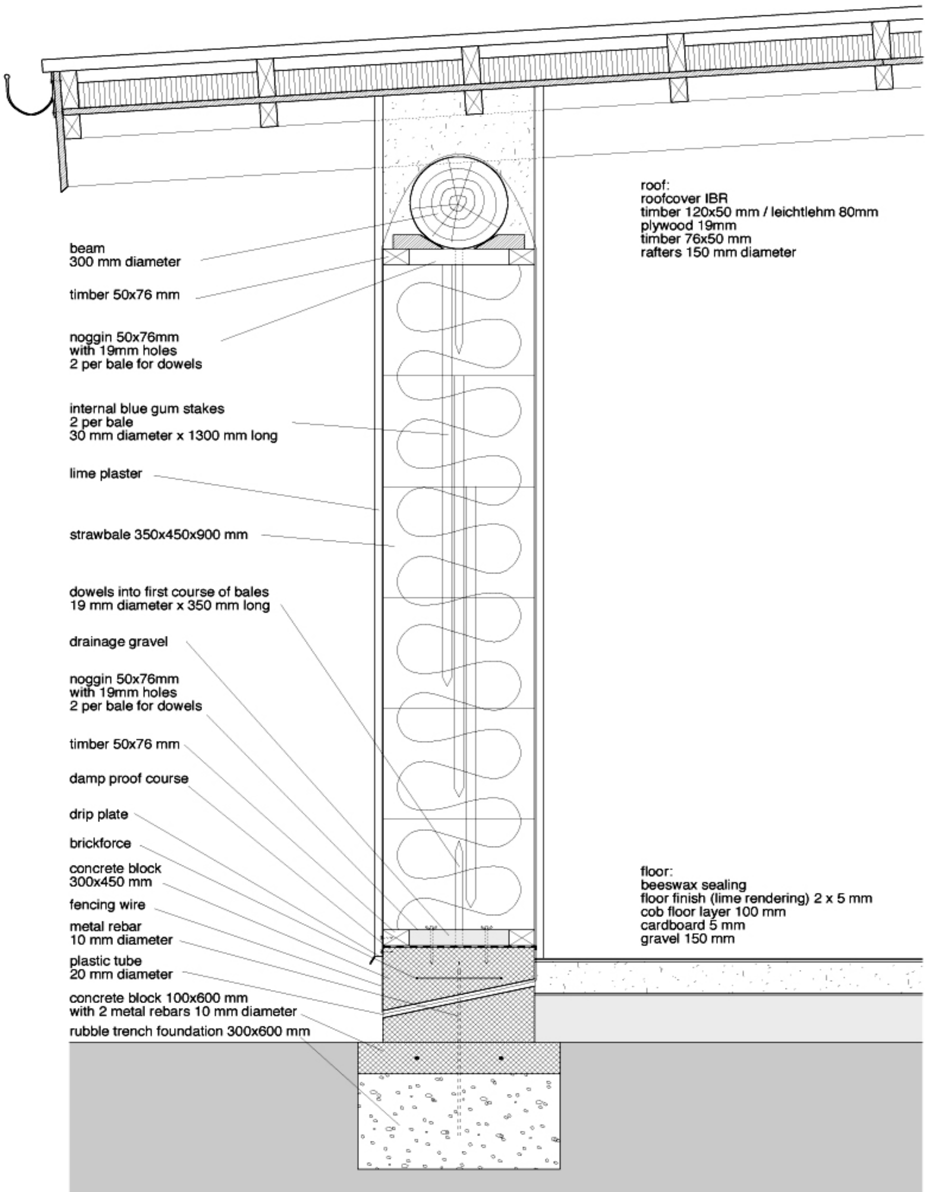



Source: SASA-WC Headquarters

# 3 Hawequas Straw Bale Accommodation – Plans[1]

## 3.1 Main Accommodation house

Figure 3.1: Section through wall




1 Design of all plans: Rebekka Eiholzer, Marcel Bruelisauer

Figure 3.2: Accommodation, ground floor layout

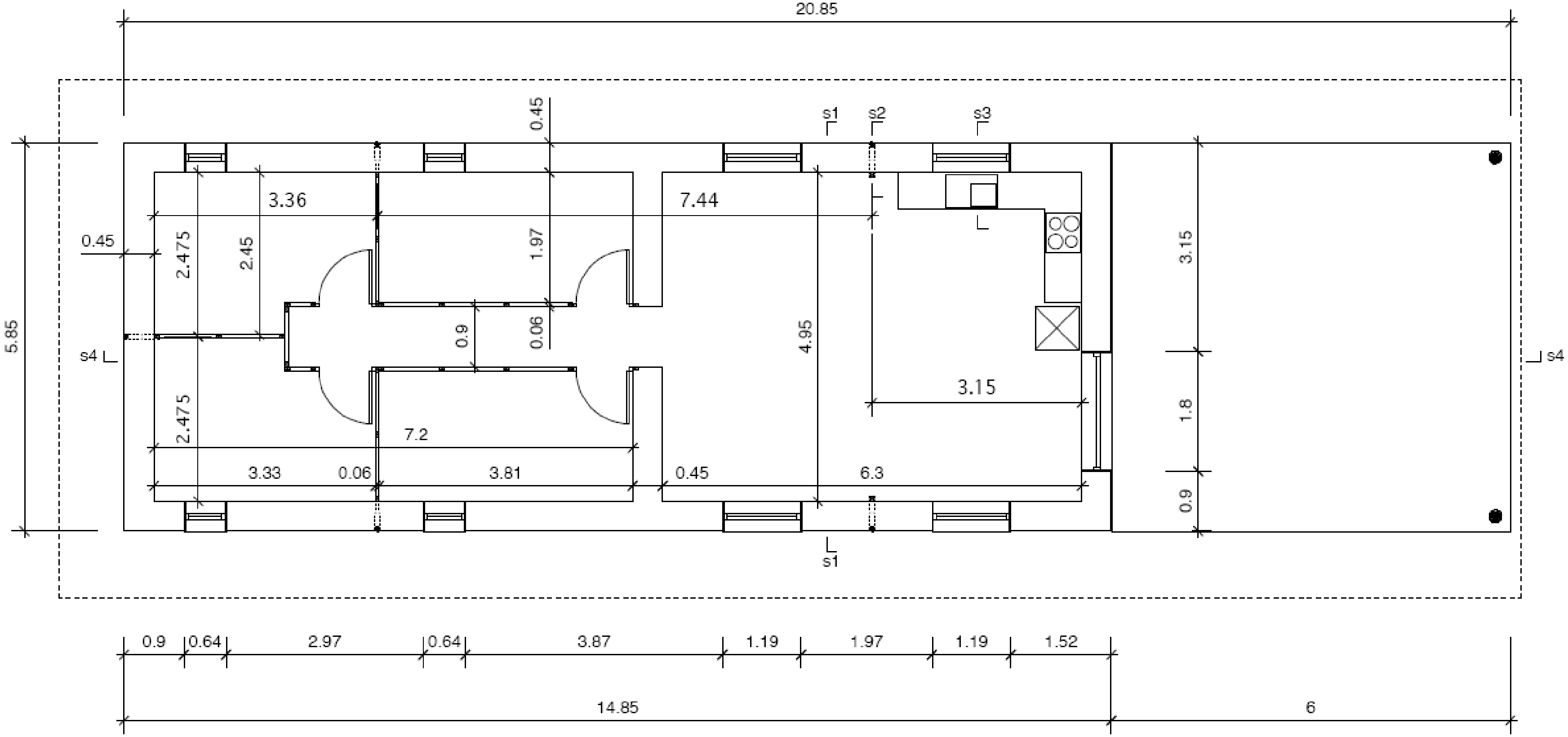
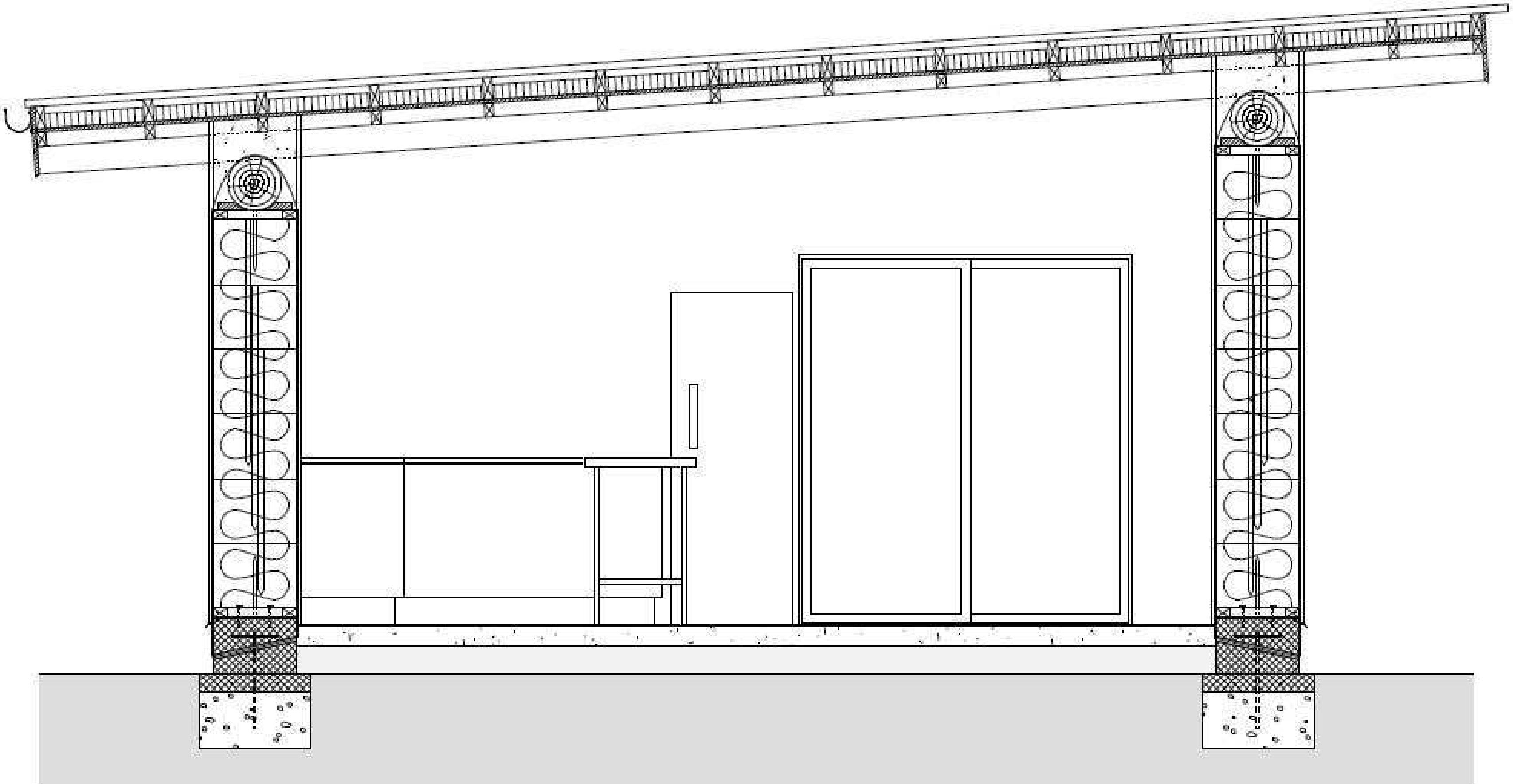
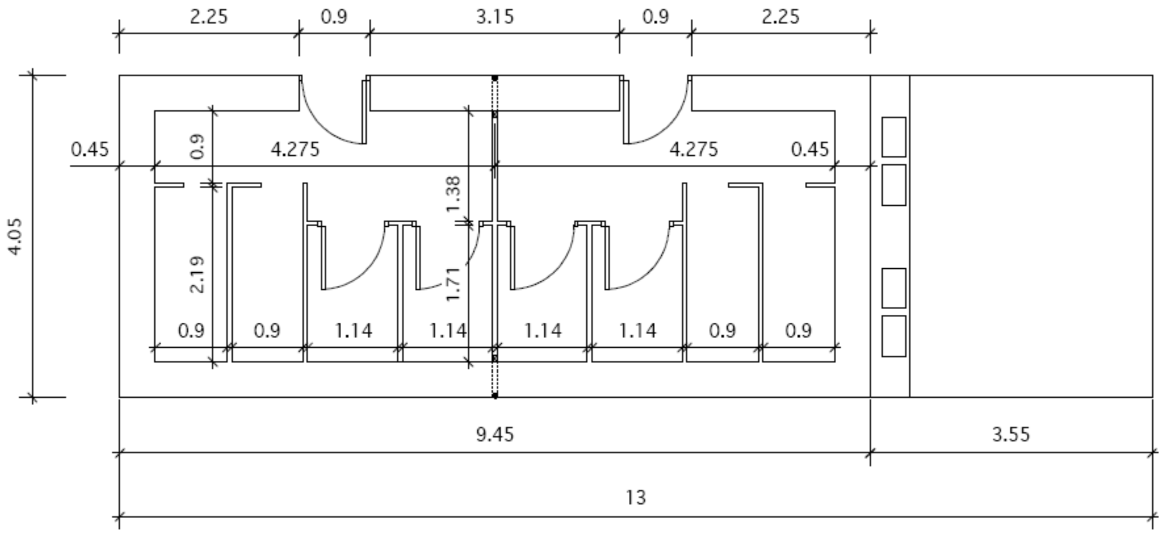


Figure 3.3: Accommodation, section S1



## 3.2 Ablution block

Figure 3.4: Ablution block, ground floor layout



# 4 Pictures from construction process

These pictures are courtesy of Rebekka Eiholzer, Andy Horn, Ansgar von Oertzen, Deon Prinsloo and Marcel Bruelisauer.

Hawequas Scout Farm, upper road entry

Building site at the start

Preparing the site

Site is levelled

Collecting straw bales

Transporting straw bales

Rubble trench with left-over half-bricks

Compacting the half-bricks

Working shed

Design office, straw bale headquarters

Preparing the rebars Ø = 10mm

Laying the rebars for concrete slab

Mixing the concrete

Vibrating the concrete by hand

Mixing more concrete

Volunteer workforce from a township

Finished foundation, accommodation

Finished foundation, ablution

Rungs for the bottom wall ladder with dowels

Fixing the ladder to the foundation

Ladder with gravel drainage in between

Ablution site ready for straw baling

Transport the bales with Dennis

Putting in the first straw bale

Flattening the long side of the bale

Making half bales

Sceptic observation of the technique


Making “pointies” out of blue gum stakes

“Stake monkeys” in action

Speeding up the staking of the bales

Ablution block, progress after 3 hours

Ablution block, progress after 6 hours

Airborne on bales

Live on air

Heaving up the beams

Ablution block after 1 weekend

Working on the ablution roof

Fixing the roof beams

Building site at 2nd weekend

Ablution block ready to be covered

Ablution block is covered

Ablution block inside

Put the wall plate in place

Wall plate

Shunting the wall

Fixing the wall plate to the bales

Reinforcement element for long wall

Detail of reinforcement element

Enjoying the view

Fencing wire tie-down system

Wire tie-down system with wire stainer

Polyester strapping

Mixing cob with school children

Harvesting the blue gum logs

Scouts carrying a log

“Last picture” before very dangerous tasks

Heaving up and positioning the roof beams

Holding the beam in place

Picking up the roof beams with a loader

Lifting the roof beams up

Main house with roof beams in place

Fixing the ceiling

"Does that work?"

"With a little help of my friends..."

Everybody helps

Roof workforce

Mixing up the roof insulation Thermguard

Laying a 100mm layer of recycled paper

Roof workforce

Covering the roof with corrugated iron

Get ready for the milling

Milling straw to mix into the clay plaster

Shave the walls

Mixing the clay plaster in a bath tube

Big plaster workforce

Plastering the walls

Plastering and chatting

Mudfight at the end of the plaster day

Plastered wall

Plastered ablution block

Heavy rain on partly covered accommodation

Soo much water

Taking out some wet straw

Taking out the rotting bales

Damaged bales, rain came from top, travelled down along stakes, rotting quickly started

Attacking the damaged walls

Accommodation with more light

Columns to support the roof

Cross-bracing necessary

Accommodation block

Building site

Lunch during a work party

After the work was done

# 5 LCA Inventory tables

Table 5.1: Sources for LCA inventory data - overview

| | |
|---|---|
| A | Oekobilanzdaten im Baubereich, 2006, value for fabrication and elimination of each material counted |
| B | Irurah D, 1997, An Embodied-Energy Algorithm for Energy Conservation in Building Construction as applied to South Africa |
| C | Baird, 1997, The energy embodied in building materials - updated New Zealand coefficients and their significance |
| D | LCA for water tanks from Australia |
| E | DIY Home Insulation Kit Project from University of Cape Town |
| F | Handbook Emission Factors for Road Transport from Switzerland |

## 5.1 Bauteilkatalog (A)

The “Bauteilkatalog” *(catalogue of building components)* is a catalogue with all standard building materials. It shows the environmental impact for following ecological indicators, split into fabrication and elimination:

- UBP: Umweltbelastungspunkte *(Environmental Impact Points),* based on the method of ecological scarcity, expressed in Points/unit
- embodied energy, expressed in MJ-Eq/unit
- greenhouse potential, expressed in kg $CO^2$-Eq/unit

The edition of this catalogue is a collaboration of KBOB[2] (Koordination der Bau- und Liegenschaftsorgane des Bundes), a official organ of the national administration; eco-bau[3], an association for sustainability in public construction; IPB[4] (Interessengemeinschaft privater professioneller Bauherren). The data is based on ecoinvent[5], a powerful database for LCA. The catalogue is linked to a online-tool to assess the ecological performance of building materials.

The catalogue can be downloaded as a pdf-file and as a spreadsheet from www.kbob.ch. The online-tool is accessible on www.bauteilkatalog.ch

## 5.2 Embodied energy for South Africa (B)

This list (see Tables 5.2 to 5.4) is extracted from the PhD-Thesis of Prof. Daniel K Irurah (Irurah 1997). It is the only database specifically for South Africa found by the author. It is calculated using input-output tables from 1993. The found values express therefore average values for the whole economy of South Africa. The single-step intensities are most appropriate; the total-embodiment intensities count some impacts multiple times. This is rectified, though not recalculated in (Holm 2000). The values using a top-down-approach were never validated in audits. The sectoral analysis of South Africa's economy shows a large impact of the building sector on energy use.

## 5.3 Embodied energy for New Zealand (C)

This paper updates an older list of embodied energy of building materials in New Zealand's context (Baird 1997). Only one value was used for this study: 0.24 MJ/kg for straw bales. This value goes back on a study from Long, Taylor and Berry (1978) *Hay Harvesting Costs in Texas*. College Station, Texas.

[2] www.kbob.ch

[3] www.eco-bau.ch

[4] www.ipb-news.ch/

[5] www.ecoinvent.ch

Table 5.2: South African energy intensities for various materials, part 1

**APPENDIX 8.06:** South African intensities versus those of other countries 225

**APPENDIX 8.06B**: Energy intensities for various materials

| MATERIAL/COMPONENT | | S. AFRICA INTENSITIES | | INTENSITIES OF OTHER COUNTRIES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SINGLE-STEP | TOTAL-EMBODIMENT | UK | | | | | USA | | CANADA |
| | | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | |
| 1 | Cement | 3,62MJ/kg | 9,35MJ/kg | 7,92MJ/kg | 5,59MJ/kg | 7,25MJ/kg | 7,81MJ/kg | 6,48MJ/kg | - | - | - |
| 2 | Aggregate (sand, crushed stone) | 0,14MJ/kg | 0,37MJ/kg | - | - | 0,03 to 0,3MJ/kg | 0,08MJ/kg | - | - | - | 0,14MJ/kg |
| 3 | Steel reinforcement | 7,82MJ/kg | 26,75MJ/kg | 47,52MJ/kg | - | 47,00MJ/kg | - | 28,0MJ/kg | 32,4MJ/kg | 36,8MJ/kg | - |
| 4 | Brick (average) | 1,33MJ/kg | 3,38MJ/kg | 1,80MJ/kg | 2,81MJ/kg | 2,50MJ/kg | - | 0,22MJ/kg | - | 4,6MJ/kg | 2,14MJ/kg |
| 5 | Timber (average) | 11,18MJ/kg | 35,65MJ/kg | 6,48MJ/kg | 1,79MJ/kg | 4,10MJ/kg | - | 0,41MJ/kg | - | 5,4MJ/kg | 7,38MJ/kg |
| 6 | Iron sheets | 26,62MJ/kg | 85,09MJ/kg | - | - | - | - | - | - | 52,8MJ/kg | 68,0MJ/kg |
| 7 | Asbestos-cement sheets | 6,93MJ/kg | 21,90MJ/kg | - | - | - | - | 7,92MJ/kg | - | - | - |
| 8 | Gypsum boards | 2,65MJ/kg | 8,38MJ/kg | - | - | - | - | 1,08MJ/kg | - | 5,6MJ/kg | 4,5MJ/kg |
| 9* | Flush door (average for hollow and solid core) | 721,19 MJ each | 2 300,28MJ each | - | - | - | - | - | - | 366,0MJ each | - |
| 10 | Vinyl tiles (average) | 126,36MJ/kg | 1 350,5MJ/kg | - | 115,60MJ/kg | - | - | - | 18,7MJ/kg | 64,9MJ/kg | 31,8MJ/kg |
| 11 | Structural steel | 10,38MJ/kg | 35,50MJ/kg | - | - | - | - | - | - | 56,9MJ/kg | - |
| 12* | Glass | 35,86MJ/kg | 99,67MJ/kg | - | 15,00MJ/kg | - | - | 26,8MJ/kg | 29,5MJ/kg | 55,9MJ/kg | - |
| 13 | Paint (average) | 53,31MJ/l | 182,86MJ/l | - | - | - | - | - | 9,7MJ/kg | 134MJ/l | 40,3MJ/kg |
| 14 | Pipes (plastic, average) | 86,42MJ/kg | 226,63MJ/kg | - | 115,60MJ/kg | - | - | - | - | 313MJ/m | 189MJ/kg |
| 15 | Pipes (metal, cast iron) | 11,09MJ/kg | 35,46MJ/kg | - | 22,80MJ/kg | - | - | - | - | 499MJ/m | 68,0MJ/kg |
| 16 | Sanitary fittings: wash hand basin (whb) | 2 265,37MJ each | 5 773,51MJ each | - | - | - | - | - | - | 830,3MJ each | - |
| 17 | Sanitary fittings (bath tub) | 5 991,67MJ each | 15 270MJ each | - | - | - | - | - | - | 1 055,0MJ each | - |
| 18 | Sanitary fittings (wc) | 4 169,09MJ each | 10 625,32MJ each | - | - | - | - | - | - | 835,56MJ each | - |
| 19 | Nails and wires | 20,13MJ/kg | 64,33MJ/kg | - | - | - | - | - | - | 79,7MJ/kg | - |
| 20* | Fibre glass insulation | 24,87MJ/kg | 71,04MJ/kg | - | 15,00MJ/kg | - | - | - | 3,4MJ/kg | 15,1MJ/kg | - |

Table 5.3: South African energy intensities for various materials, part 2

**APPENDIX 8.04**: Derivation of energy intensities of building conctruction materials by physical units 183

| SIC CODE | SECTOR AND MATERIAL OR COMPONENT | UNIT | UNIT COST (R) | SINGLE-STEP PRIMARY ENERGY ($MJ_S$/R) | ( $MJ_S$/UNIT) | TOTAL-EMBODIMENT PRIMARY ENERGY ($MJ_T$/R) | ($MJ_T$/UNIT) |
|---|---|---|---|---|---|---|---|
| | **Products of coal and pretroleum** | | | | | | |
| 2100 | Coke | ton | 213,67 | 88,94361 | 19 004,58 | 107,78182 | 23 029,74 |
| 353/4 | Petrol | litre (l) | 1,51 | 84,41968 | 127,47 | 109,06507 | 164,69 |
| | Diesel | l | 1,43 | 84,41968 | 120,72 | 109,06507 | 155,96 |
| | Bitumen (road surface) | l | 0,56 | 84,41968 | 47,28 | 109,06507 | 61,08 |
| 33110-33199 | **Wood and wood products** | | | | | | |
| | South African Pine (SAP), kiln dried, not impregnated | | | | | | |
| | 76 x 228 mm | $m^3$ | 1 040,79 | 7,11019 | 7 400,20 | 22,67848 | 23 603,53 |
| | 38 x 228 mm | $m^3$ | 898,85 | 7,11019 | 6 390,99 | 22,67848 | 20 384,54 |
| | 51 x 76 mm | $m^3$ | 937,90 | 7,11019 | 6 668,64 | 22,67848 | 21 249,73 |
| | Flooring boards, (SAP) | $m^2$ | 51,14 | 7,11019 | 363,61 | 22,67848 | 1159,73 |
| | Particle boards, 13mm | $m^2$ | 21,07 | 7,11019 | 149,81 | 22,67848 | 477,84 |
| | Hardwood (meranti) | $m^3$ | 4 181,42 | 7,11019 | 29 730,65 | 22,67848 | 94 828,21 |
| | Ceiling boards (SAP) | $m^2$ | 30,40 | 7,11019 | 216,15 | 22,67848 | 689,43 |
| | Plywood, 4mm | $m^2$ | 15,68 | 7,11019 | 111,49 | 22,67848 | 355,60 |

**APPENDIX 8.04**: Derivation of energy intensities of building conctruction materials by physical units 186

| SIC CODE | SECTOR AND MATERIAL OR COMPONENT | UNIT | UNIT COST (R) | SINGLE-STEP PRIMARY ENERGY ($MJ_S$/R) | ($MJ_S$/UNIT) | TOTAL-EMBODIMENT PRIMARY ENERGY ($MJ_T$/R) | ($MJ_T$/UNIT) |
|---|---|---|---|---|---|---|---|
| | **Non-metallic mineral products** | | | | | | |
| **3692** | Portland cement (50kg bags) | 100 (No.) | 1 195,50 | 15,13678 | 18 096,93 | 39,11986 | 46 770,14 |
| **3691** | Bricks, smooth semi-face | 1 000 (No.) | 479,80 | 11,54330 | 5 538,48 | 29,41917 | 14 115,31 |
| | Bricks, clinker | 1 000 (No.) | 397,60 | 11,54330 | 4 589,62 | 29,41917 | 11 697,06 |
| | Bricks, stock | 1 000 (No.) | 245,37 | 11,54330 | 2 832,38 | 29,41917 | 7 218,58 |
| **2800** | Crushed stone for concrete | $m^3$ | 22,16 | 10,20915 | 226,23 | 26,74986 | 592,78 |
| | Sand for concrete | $m^3$ | 30,18 | 10,20915 | 308,11 | 26,74986 | 807,31 |
| **3699** | Slaked lime | ton | 198,49 | 6,93886 | 1 377,30 | 21,91321 | 4 349,55 |
| | Unslaked lime | ton | 143,42 | 6,93886 | 995,17 | 21,91321 | 3 142,79 |
| | Reinforced concrete (305 mm ∅) | m | 41,72 | 6,93886 | 289,49 | 21,91321 | 914,22 |
| | Asbestos-cement pipes (152 mm ∅) | m | 27,66 | 6,93886 | 191,93 | 21,91321 | 606,12 |
| | Vitrified clay pipes (102mm∅) | m | 7,63 | 6,93886 | 52,94 | 21,91321 | 167,20 |
| | Corrugated asbestos-cement roofing (6mm) | $m^2$ | 17,50 | 6,93886 | 121,43 | 21,91321 | 383,48 |
| | Gypsum board ceiling (6mm) | $m^2$ | 5,85 | 6,93886 | 40,59 | 21,91321 | 128,19 |

# Table 5.4: South African energy intensities for various materials, part 3

**APPENDIX 8.04**: Derivation of energy intensities of building conctruction materials by physical units 187

| SIC CODE | SECTOR AND MATERIAL OR COMPONENT | UNIT | UNIT COST (R) | SINGLE-STEP PRIMARY ENERGY | | TOTAL-EMBODIMENT PRIMARY ENERGY | |
|---|---|---|---|---|---|---|---|
| | | | | ($MJ_S$/R) | ($MJ_S$/UNIT) | ($MJ_T$/R) | ($MJ_T$/UNIT) |
| | **Electricity, gas and water** | | | | | | |
| 4100 | **Electricity** | kWh | 0,10 | 101,25760 | 10,13 | 144,65114 | 14,47 |
| 4100 | **Gas** | GJ | 0,30 | 101,25760 | 30,38 | 144,65114 | 43,40 |
| 4200 | **Water** | kl | 0,80 | 15,60961 | 12,49 | 44,92437 | 35,94 |
| 3813 | **Structural metal products** | | | | | | |
| | Flat mild steel bars (60 x 12 mm) | ton | 1 299,40 | 6,95179 | 9 033,16 | 23,77228 | 30 889,70 |
| | Reinforcing steel (25 mm) | ton | 1 125,41 | 6,95179 | 7 823,61 | 23,77228 | 26 753,56 |
| | Rounds, mild steel | ton | 1 597,05 | 6,95179 | 11 102,36 | 23,77228 | 37 965,52 |
| | Angles (50 x 50 x 8 mm) | ton | 1 246,28 | 6,95179 | 8 663,89 | 23,77228 | 29 626,92 |
| | Joists (203 x 152 x 52mm) (1kg/m) | ton | 1 493,39 | 6,95179 | 10 381,73 | 23,77228 | 35 501,29 |
| | Rails (40 kg/m) | ton | 1 721,44 | 6,95179 | 11 967,09 | 23,77228 | 40 922,55 |
| | Rails (15 kg/m) | ton | 1 744,24 | 6,95179 | 12 124,76 | 23,77228 | 41 464,56 |
| 3720 | **Non-ferrous metal products** | | | | | | |
| | Copper, rods and rounds | ton | 13 237,94 | 14,76678 | 195 481,62 | 39,26492 | 519 786,79 |
| | Copper, sheet | ton | 14 246,44 | 14,76678 | 210 373,90 | 39,26492 | 559 385,47 |
| | Brass bars and rounds (70% copper) | ton | 9 696,78 | 14,76678 | 143 190,12 | 39,26492 | 380 743,39 |
| | Lead, sheets and strips | ton | 5 675,00 | 14,76678 | 83 801,42 | 39,26492 | 222 828,48 |
| | Lead, pipes (25 mm ∅) | ton | 6 225,00 | 14,76678 | 91 923,14 | 39,26492 | 244 424,19 |

**APPENDIX 8.04**: Derivation of energy intensities of building conctruction materials by physical units 188

| SIC CODE | SECTOR AND MATERIAL OR COMPONENT | UNIT | UNIT COST (R) | SINGLE-STEP PRIMARY ENERGY | | TOTAL-EMBODIMENT PRIMARY ENERGY | |
|---|---|---|---|---|---|---|---|
| | | | | ($MJ_S$/R) | ($MJ_S$/UNIT) | ($MJ_T$/R) | ($MJ_T$/UNIT) |
| 3819 | **Fabricated metal products** | | | | | | |
| | Iron sheets, uncoated (0,6mm) | ton | 2 123,41 | 9,17630 | 19 485,03 | 29;32948 | 62 278,51 |
| | Iron sheets, galvanised (0,6mm) | ton | 2 499,43 | 9,17630 | 22 935,50 | 29,32948 | 73 306,98 |
| | Iron Sheets, galvanised and corrugated (0,6mm) | ton | 2 901,13 | 9,17630 | 26 621,61 | 29,32948 | 85 088,63 |
| | Galvanised fencing wire, barbed | ton | 2 998,26 | 9,17630 | 27 512,90 | 29,32948 | 87 937,41 |
| | Wire netting, 76mm wide mesh, 1,2 m wide | 50m | 191,06 | 9,17630 | 1 753,22 | 29,32948 | 5 603,69 |
| | Down pipes, galvanised iron, (76mm ∅) | m | 9,49 | 9,17630 | 87,08 | 29,32948 | 278,34 |
| | Water tank, corrugated iron (1,8 x 1,2m) | each | 629,26 | 9,17630 | 5 774,27 | 29,32948 | 18 455,87 |
| | Door jab (2,0 x 0,2m, 108 mm) | each | 90,01 | 9,17630 | 825,96 | 29,32948 | 2 639,95 |
| | Steel window frame, residential, (1,2 x 1,0 m) | each | 131,29 | 9,17630 | 1 204,76 | 29,32948 | 3 850,67 |
| | Nails, wire, 75mm | ton | 2 193,26 | 9,17630 | 20 125,99 | 29,32948 | 64 327,18 |
| 3822 | **Construction plant** | | | | | | |
| | Grader, 110 kW, South African | each | 463 571,75 | 10,19423 | 4 723 778,30 | 34,35041 | 15 923 630,00 |
| | Crawler mounted excavator, (100 kW, 1mp) | each | 542 558,64 | 10,19423 | 5 528 686,40 | 34,35041 | 18 636 936,00 |
| | Vibratory compaction plant (10ton, 1mp) | each | 222 409,75 | 10,19423 | 2 266 357,90 | 34,35041 | 7 639 783,50 |

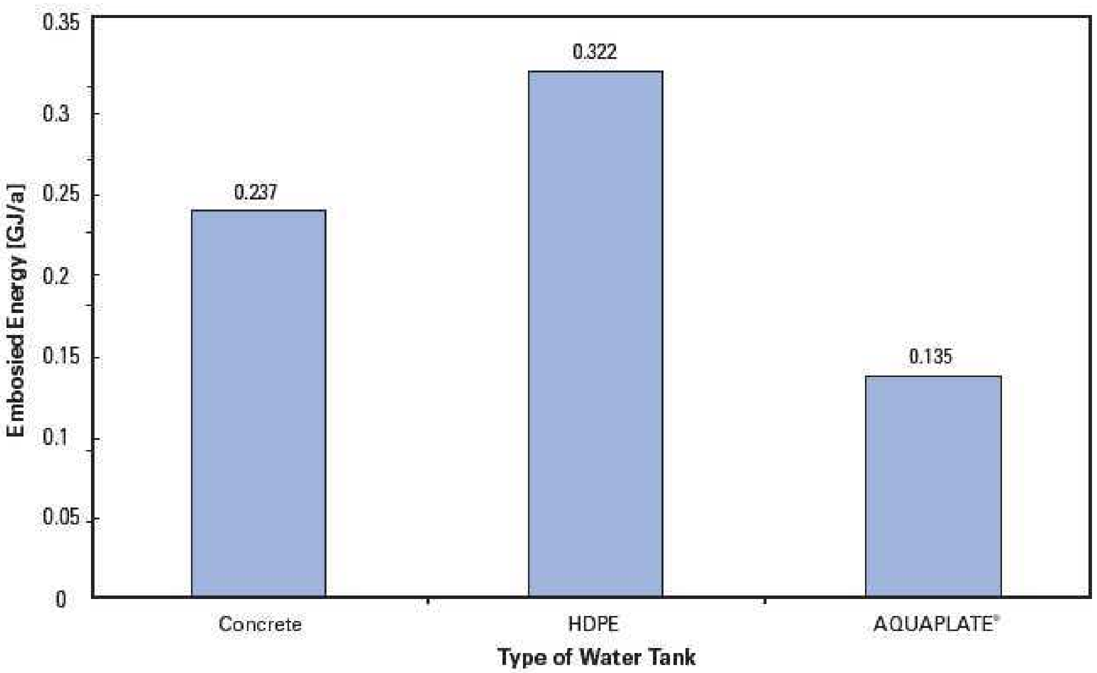
## 5.4 LCA on water tanks in Australia (D)

An independent study, conducted by the Centre for Sustainable Technology at the University of Newcastle, presents a comparison based on Life Cycle Analysis (LCA) of three types of rain water tanks. The LCA includes all stages in the life of the tank: extraction and processing of raw materials, transport to tank manufacturing site, tank fabrication, transport to customer's site, installation, operation and disposal at the end of the useful life.

The comparative LCA was can be found on the website of a manufacturer of steel water tanks in Australia: www.bluescopesteel.com.au/go/building-products/rainwater-harvesting/life-cycle-analysis-for-rainwater-tanks

Compared are following types: a water tank made of concrete, one made of plastic, High Density Polyethylene (HDPE) and one made of AQUAPLATE® steel. The plastic water tank used for the study has useful operational life of 25 years. Details can be found on the homepage.

Figure 5.1: LCA of water tanks




Source: www.bluescopesteel.com.au/go/building-products/rainwater-harvesting/life-cycle-analysis-for-rainwater-tanks

## 5.5 LCA for EnviroTouch (E)

This LCA was conducted for a study about alternative roof insulation for low-cost housing in South Africa, called “DIY Home Insulation Kit Project” in 2004 at the University of Cape Town. Of interest for this study is a specific, environmentally sound paint called “EnviroTouch”.

*“The locally manufactured ‘EnviroTouch’ paint was investigated as an alternative to conventional PVA paint. Based on the information that could be collected by the UCT researchers, its embodied energy would be similar to that in the ETH LCA case, at around 15-20 MJ/kg.”* (EEU 2004). The upper boundary value was used for this study.

## 5.6 Handbook Emission Factors for Road Transport (F)

The Handbook Emission Factors for Road Transport is a collaboration between Austria, Germany and Switzerland. It provides emission factors for all current vehicle categories (PC, LDV, HDV and motor cycles), each divided into different categories, for a wide variety of traffic situations, for different years. Detailed information can be found at www.hbefa.net. An online calculation-tool is accessible at www.hbefa.net/Tools/DE/MainSite.asp . The emission factors for Switzerland in 1990 were used in this study. No correction factor was used for the energy intensity as the values are combined with embodied energy values for petrol from South Africa.

## 5.7 Embodied energy values for transport

The embodied energy values used for the calculation of the environmental impact of transport are listed the table below. They are extracted from different sources, corrected and can therefore be used as they are.

Table 5.5: Embodied energy values for transport

| Transport mode | Name | Petrol use[a] | | Embodied energy per unit | |
|---|---|---|---|---|---|
| Passenger car | PC | 74.45 g/VehKm | 0.01 lt/VehKm | 12.8 MJ/VehKm[b] | |
| Light duty vehicle | LDH | 102.39 g/VehKm | 0.14 lt/VehKm | 17.6 MJ/VehKm[b] | |
| Heavy duty vehicle | HDV | 255.37 g/VehKm | 0.34 lt/VehKm | 43.9 MJ/VehKm[b] | |
| Coach | Coach | 285.95 g/VehKm | 0.39 lt/VehKm | 49.1 MJ/VehKm[b] | 1.64 MJ/pkm[c] |
| Train | Personenzug | | | 1.39 MJ/pkm[d] | |
| Passenger car | Personenwagen | | | 7.36 MJ/pkm[d] | |
| Plane | Passagierflugzeug | | | 6.05 MJ/pkm[d] | |
| Mini-Bus | Kleinbus | | | 2.45 MJ/pkm[e] | |

[a] source: F, density petrol = 742 g/lt; [b] source: B, EE petrol = 127.5 MJ/lt;

[c] assumption: 30 people/coach; [d] source: A, corrected by factor 2.17 for energy intensity

[e] assumption: 3 times smaller than a passenger car = 7.36/3

# 6 LCA Calculations

## 6.1 Buildings

### 6.1.1 Building materials

The procedure for the calculation of the embodied energy of building materials is explained in chapter 4.4.1. Tables 6.2 to 6.4 show the spreadsheet “building material.ods” with the calculations. Materials which are grey underlined have not yet been purchased; all other have.

The materials are grouped into following elements of the building: foundation, walls, floor, roof, windows and doors, interior walls, electricity, water supply, sewage/ sanitary and drainage.

The impact of certain materials was considered negligible. This is mostly the case for materials such as screws, drill bits and homeworker tools. Comments on selected materials are listed in Table 6.1 below:

Table 6.1: Comments on building materials

| | |
|---|---|
| Rubble/ half-bricks | waste product from brick factory, free of charge, not counted for embodied energy |
| Straw Bales | initially 550 bales, due to damage 200 additional bales |
| Blue gum (eucalyptus) stakes | harvested by hand, in own forest, as part of alien-clearing, no embodied energy |
| Cardboard | left-over from manufacturer, not counted |
| Blue gum logs | harvested with chain saw, in own forest, as part of alien-clearing, energy for chainsaw considered |
| Clay | locally excavated from foundation trench, energy for digger-loader considered in building process |
| Lime | last plaster coat for accommodation outside and ablution outside and inside, floor accommodation, 10mm thick, sand : lime = 4 : 1, purchased at Cape Lime in Robertson |
| Thermguard | insulation material made of 70% recycled paper, 30% household chemicals, exact composition is business-secret, as “Cellulosefasern (eingeblasen)” considered |
| EnviroTouch | environmentally sound paint, embodied energy calculated during research project at University of Cape Town, DIY Home Insulation Kit Project |
| Water tank | LCA on different water tanks in Australia |
| Photovoltaic/ wind generator/ solar water heater | embodied energy included in use-calculation |
| Soak-away | re-use of old water tank, better solution as soak-away must be found |
| Life cycles | most materials endure at least the entire life cycle of the building set as 25 years, materials with lower life cycles are paints, wood treatment, lime plaster and window sill |

# Table 6.2: Calculation of the embodied energy of the building materials, part 1

**Building Materials** **BUILDING PROCESS** **658223 MJ-Eq**

| Building element | Building material | Qty | Name or *Comment* | Source | Unit | Density [kg/m3] | Qty unit | Mass kg | Life cycle | Life cycle coefficient | Life cycle Qty | EE per unit [MJ-Eq] | Correction factor | EE total [MJ-Eq] | EE systems |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Foundation** | | | | | | | | | | | | | | | **88174** |
| **Trench** | Rubble/ half-bricks, 4m3 | 4 | *use of left-over product, not counted* | | kg | 1500 | 24000 | 24000 | 25 | 1.0 | 24000 | | | | |
| **Concrete** | Sand, m3 | 10 | Sand | A | kg | 2000 | 20000 | 20000 | 25 | 1.0 | 20000 | 0.303 | 2.17 | 13150 | |
| | Gravel, m3 | 20 | Kies gebrochen | A | kg | 2000 | 40000 | 40000 | 25 | 1.0 | 40000 | 0.319 | 2.17 | 27689 | |
| | Cement, 50kg | 70 | Cement | B | kg | 1800 | 3500 | 3500 | 25 | 1.0 | 3500 | 3.62 | 1.00 | 12670 | |
| | Iron poles | 1 | Stahlblech, blank | A | kg | 7850 | 24 | 24 | 25 | 1.0 | 24 | 35.5 | 2.17 | 1849 | |
| | Rebars 10mm, 6m | 10 | Armierungsstahl | A | kg | 7850 | 37 | 37 | 25 | 1.0 | 37 | 26.75 | 2.17 | 2148 | |
| | Rebars 10mm, 6m | 20 | Armierungsstahl | A | kg | 7851 | 74 | 74 | 25 | 1.0 | 74 | 26.75 | 2.17 | 4296 | |
| | Brickforce, 25m-roll | 4 | Armierungsstahl | A | kg | 7852 | 20 | 20 | 25 | 1.0 | 20 | 26.75 | 2.17 | 1161 | |
| **Framework** | shutterboards, 21mm x 1.2m x 2.4m | 3 | Sperrholz/ Multiplex | A | kg | 780 | 142 | 142 | 25 | 1.0 | 142 | 14.4 | 2.17 | 4437 | |
| | shutterboards, 21mm x 1.2m x 2.4m | 3 | Sperrholz/ Multiplex | A | kg | 780 | 142 | 142 | 25 | 1.0 | 142 | 14.4 | 2.17 | 4437 | |
| | shutterboards, 21mm x 1.2m x 2.4m | 8 | Sperrholz/ Multiplex | A | kg | 780 | 377 | 377 | 25 | 1.0 | 377 | 14.4 | 2.17 | 11780 | |
| | Pine beams, 22 x 44mm x 3m | 10 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 16 | 16 | 25 | 1.0 | 16 | 2.21 | 2.17 | 77 | |
| | Cut screws, 4.0x50 | 1 | *negligible* | | | | | | | | | | | | |
| **Pipe for tensioning** | Wood Drill 22mm | 1 | *negligible* | | | | | | | | | | | | |
| | Pipe 20mm x 5m | 10 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 20 | 20 | 25 | 1.0 | 20 | 78.6 | 2.17 | 3411 | |
| **Other** | Post brackets | | Chromnickelstahlblech 18/8 | A | kg | 7850 | 5 | 5 | 25 | 1.0 | 5 | 98.5 | 2.17 | 1069 | |
| | Wire and tools | | *negligible* | | | | | | | | | | | | |
| **Straw bale walls** | | | | | | | | | | | | | | | **24541** |
| **Straw bale structure** | Straw bales | 750 | Straw, baled | C | kg | 90 | 9570 | 9570 | 25 | 1.0 | 9570 | 0.24 | 1.28 | 2940 | |
| | Blue gum stakes | 600 | *locally harvested by hand* | | | | | | | | | | | | |
| | Baling twine, 500m | 1 | *negligible* | | | | | | | | | | | | |
| **Base plate/ wall plate** | treated beam 50mm x 76mm, 3m | 140 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 862 | 862 | 25 | 1.0 | 862 | 2.21 | 2.17 | 4134 | |
| | Dowels 19mm, 1.8m | 55 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 15 | 15 | 25 | 1.0 | 15 | 2.21 | 2.17 | 72 | |
| | Damp proof course 2.0 x 30m | 1 | Polyethylenfolie (LDPE) | A | kg | 940 | 25 | 25 | 25 | 1.0 | 25 | 91.5 | 2.17 | 4964 | |
| | Wood glue | 1 | *negligible* | | | | | | | | | | | | |
| | Silicone | 3 | Silicon-Fugenmasse | A | kg | 1700 | 1 | 1 | 25 | 1.0 | 1 | 61.6 | 2.17 | 134 | |
| | Pine beams, 32 x 44mm x 3m | 4 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 9 | 9 | 25 | 1.0 | 9 | 2.21 | 2.17 | 43 | |
| | Cut screws, 6.0 x 120mm, 60 pieces | 2 | Nails and wires | B | kg | 7850 | 4 | 4 | 25 | 1.0 | 4 | 20.13 | 1.00 | 81 | |
| | Cut screws, 6.0 x 100mm, 500 pieces | 1 | Nails and wires | B | kg | 7850 | 15 | 15 | 25 | 1.0 | 15 | 20.13 | 1.00 | 302 | |
| | Wood drill 19mm | 1 | *negligible* | | | | | | | | | | | | |
| | Nail in Nylon 8 x 100mm, 50 pieces | 3 | *negligible* | | | | | | | | | | | | |
| | Nail in Nylon 8 x 100mm, single pieces | 20 | *negligible* | | | | | | | | | | | | |
| **Tensioning** | Fencing wire, 50kg, 3mm | 1 | Galvanised fencing wire | B | kg | 7850 | 50 | 50 | 25 | 1.0 | 50 | 27.51 | 1.00 | 1376 | |
| | wire strainer | | *negligible* | | | | | | | | | | | | |
| | Polyester strapping, 500m | 1 | *negligible* | | | | | | | | | | | | |
| **Plastering** | Clay, m3 | | *locally excavated and directly reused* | | | | | | | | | | | | |
| | Lime, 25kg | 30 | Kalkputz | A | kg | 1500 | 750 | 750 | 15 | 1.7 | 1250 | 3.57 | 2.17 | 9684 | |
| **Other** | baling tools | | *negligible* | | | | | | | | | | | | |
| | Drill set | 8 | *negligible* | | | | | | | | | | | | |
| | Gewindestangen, 16mm x 1m | 4 | Rounds, mild steel | B | kg | 7850 | 6 | 6 | 25 | 1.0 | 6 | 11.1 | 1.00 | 67 | |
| | Gewindestangen, 12mm x 1m | 4 | Rounds, mild steel | B | kg | 7850 | 4 | 4 | 25 | 1.0 | 4 | 11.1 | 1.00 | 44 | |
| | Wood drill | 3 | *negligible* | | | | | | | | | | | | |
| | Chicken wire, 1.2m widel, per m | 20 | Wire netting | B | m | | 20 | 0 | 25 | 1.0 | 20 | 35.1 | 1.00 | 702 | |

# Table 6.3: Calculation of the embodied energy of the building materials, part 2

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Floor** | | | | | | | | | | | | | | | **55853** |
| **Drainage/ ground** | Stone 4m3 | 4 | Kies gebrochen | A | kg | 2000 | 32000 | 32000 | 25 | 1.0 | 32000 | 0.319 | 2.17 | 22151 | |
| | Sand 4m3 | 1 | Sand | A | kg | 2000 | 8000 | 8000 | 25 | 1.0 | 8000 | 0.303 | 2.17 | 5260 | |
| | Cardboard, 5mm | | *left-overs from manufacturer* | | | | | | | | | | | | |
| **Cob-floor acc.** | Clay | | *locally excavated and directly reused* | | | | | | | | | | | | |
| | Lime, 25kg | 8 | Kalkputz | A | kg | 1500 | 200 | 200 | 15 | 1.7 | 333 | 3.57 | 2.17 | 2582 | |
| | Beeswax | | *negligible* | | | | | | | | | | | | |
| **Tile-floor abl.** | Sand 4m3 | 1 | Sand | A | kg | 2000 | 8000 | 8000 | 25 | 1.0 | 8000 | 0.303 | 2.17 | 5260 | |
| | Stone 4m3 | 1 | Kies gebrochen | A | kg | 2000 | 8000 | 8000 | 25 | 1.0 | 8000 | 0.319 | 2.17 | 5538 | |
| | Cement, 50 kg | 20 | Cement | B | kg | 1800 | 1000 | 1000 | 25 | 1.0 | 1000 | 3.62 | 1.00 | 3620 | |
| | Tiles, m2 | 30 | Keramikplatten | A | kg | 1900 | 285 | 285 | 20 | 1.3 | 356 | 14.8 | 2.17 | 11441 | |
| **Roof** | | | | | | | | | | | | | | | **137658** |
| **Post and beams** | Blue gum posts, 3m | 12 | *locally harvested by chainsaw, verarbeitet by hand, transported by tractor* | | | | | | | | | | | | |
| | Blue gum beams, 6m | 7 | *locally harvested by chainsaw, verarbeitet by hand, transported by tractor* | | | | | | | | | | | | |
| | Blue gum beams, 8m | 24 | *locally harvested by chainsaw, verarbeitet by hand, transported by tractor* | | | | | | | | | | | | |
| | Blue gum beams, 12m | 4 | *locally harvested by chainsaw, verarbeitet by hand, transported by tractor* | | | | | | | | | | | | |
| | Wood treatment, 5lt | 4 | Alkydharz lösemittleverdünnt | A | kg | 1200 | 25 | 25 | 10 | 2.5 | 63 | 55.4 | 2.17 | 7514 | |
| | Hoop Iron, 10m | 9 | Stahlblech, verzinkt | A | kg | 7850 | 71 | 71 | 25 | 1.0 | 71 | 35.5 | 2.17 | 5469 | |
| **Ceiling** | Shutterboard, 1.2 x 2.4m, 21mm | 65 | OSB Platte | A | kg | 473 | 1860 | 1860 | 25 | 1.0 | 1860 | 18.1 | 2.17 | 73055 | |
| **Perlins** | SABS 38x76mm x 3m | 25 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 117 | 117 | 25 | 1.0 | 117 | 2.21 | 2.17 | 561 | |
| | SABS 38x152mm x 3m | 60 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 561 | 561 | 25 | 1.0 | 561 | 2.21 | 2.17 | 2690 | |
| | SABS 38x76mm x 2.7m | 35 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 147 | 147 | 25 | 1.0 | 147 | 2.21 | 2.17 | 705 | |
| **Insulation** | Thermguard, recycled paper, 25 kg bag | 40 | Cellulosefasern, eingeblasen | A | kg | 60 | 800 | 800 | 25 | 1.0 | 800 | 7.81 | 2.17 | 13558 | |
| **Roof sheeting** | IBR roof sheeting, 1m2 | 270 | Iron sheets, galvanised and corrugated | B | kg | 7850 | 981 | 981 | 25 | 1.0 | 981 | 26.6 | 1.00 | 26095 | |
| | Transparent roof sheeting, 1m2 | 10 | *no information* | | | | | | | | | | | | |
| | Roofing nails, 90mm, 50 pieces | 12 | Nails and wires | B | kg | 7850 | 24 | 24 | 25 | 1.0 | 24 | 20.13 | 1.00 | 483 | |
| **Guttering** | PVC Guttering, 6m | 7 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 35 | 35 | 25 | 1.0 | 35 | 78.6 | 2.17 | 5970 | |
| | Gutter brackets | 30 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| | Stop end | 4 | *negligible* | | | | | | | | | | | | |
| | Outlet | 2 | *negligible* | | | | | | | | | | | | |
| **Other** | 75mm cut screws x 125 | 10 | Nails and wires | B | kg | 7850 | 20 | 20 | 25 | 1.0 | 20 | 20.13 | 1.00 | 403 | |
| | Scorch screws, 90x8mm x 125 | 6 | Nails and wires | B | kg | 7850 | 10 | 10 | 25 | 1.0 | 10 | 20.13 | 1.00 | 201 | |
| | Washers | 400 | Nails and wires | B | kg | 7850 | 5 | 5 | 25 | 1.0 | 5 | 20.13 | 1.00 | 101 | |
| **Windows and doors** | | | | | | | | | | | | | | | **119651** |
| **windows** | Winsters Window frame WC2, 1200x1145 | 4 | Holzfensterrahmen U 1.5 W/m$^2$K (Rahmenfläche) | A | m2 | | 6 | 20 | 25 | 1.0 | 6 | 2670 | 2.17 | 34763 | |
| | Winsters Window frame WB1, 1200x595 | 4 | Holzfensterrahmen U 1.5 W/m$^2$K (Rahmenfläche) | A | m2 | | 3 | 16 | 25 | 1.0 | 3 | 2670 | 2.17 | 17382 | |
| | Glazing | 1 | Glas (Flach-) unbeschichtet | A | kg | 2500 | 104 | 104 | 25 | 1.0 | 104 | 15.1 | 2.17 | 3408 | |
| | Pine-shelves (for windows and doors) | | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 194 | 194 | 10 | 2.5 | 485 | 2.21 | 2.17 | 2326 | |
| | Enviro-Touch wood treatment, 5lt | 1 | Envirotouch | E | kg | 1000 | 5 | 5 | 5 | 5.0 | 25 | 20 | 1.00 | 500 | |
| | Silicone | 2 | Silicon-Fugenmasse | A | kg | 1700 | 1 | 0.6 | 5 | 5.0 | 3 | 61.6 | 2.17 | 401 | |
| **Outside sliding door** | Henderson Track 290, 3m | 1 | Innentüre, Holz | A | m2 | | 4 | 20 | 25 | 1.0 | 4 | 1440 | 2.17 | 12499 | |
| | Henderson Track 290 Brackets | 6 | *included* | | | | | | | | | | | | |
| | Henderson Track 290 Roller | 3 | *included* | | | | | | | | | | | | |
| **Outside/ Inside doors** | Door lock | 10 | *included* | | | | | | | | | | | | |
| | Door handle | 10 | *included* | | | | | | | | | | | | |
| | Door | 10 | Innentüre, Holz | A | m2 | | 15 | 100 | 25 | 1.0 | 15 | 1440 | 2.17 | 46872 | |
| | Door frame | 10 | *included* | | | | | | | | | | | | |
| | Door hinges, set of 2 | 10 | *included* | | | | | | | | | | | | |
| | Enviro-Touch wood treatment, 5 lt | 3 | Envirotouch | E | kg | 1000 | 15 | 15 | 5 | 5.0 | 75 | 20 | 1.00 | 1500 | |

# Table 6.4: Calculation of the embodied energy of the building materials, part 3

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Interior walls** | | | | | | | | | | | | | | | **51641** |
| **Posts** | non treated beam 50mm x 76mm, 3m | 75 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 462 | 462 | 25 | 1.0 | 462 | 2.21 | 2.17 | 2216 | |
| | 75mm cut screws x 125 | 4 | *negligible* | | | | | | | | | | | | |
| **Boards** | NuTec Dry walling 3.0m x 1.2m x 4mm | 26 | Faserzementplatte gross | A | kg | 1800 | 674 | 674 | 25 | 1.0 | 674 | 11.2 | 2.17 | 16381 | |
| | NuTec Dry walling 2.4m x 1.2m x 4mm | 20 | Faserzementplatte gross | A | kg | 1801 | 415 | 415 | 25 | 1.0 | 415 | 11.2 | 2.17 | 10086 | |
| | Paint, 5lt | 6 | Acryl-Dispersion, wasserverdünnbar | A | kg | 1200 | 40 | 40 | 5 | 5.0 | 200 | 52.9 | 2.17 | 22959 | |
| **Electricity** | | | | | | | | | | | | | | | **14498** |
| **Conduiting** | Conduiting, pipe, 4m | 15 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 75 | 75 | 25 | 1.0 | 75 | 78.6 | 2.17 | 12792 | |
| | Conduiting T's | 14 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| | Conduiting Elbows | 14 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| | Light sockets | 22 | *negligible* | | | | | | | | | | | | |
| | Osram light bulbs | 22 | *negligible* | | | | | | | | | | | | |
| | Light wall switches | 11 | *negligible* | | | | | | | | | | | | |
| | Light hanging switches | 4 | *negligible* | | | | | | | | | | | | |
| | Electric cord, meters | 80 | *negligible* | | | | | | | | | | | | |
| **Supply** | Photovoltaic | 1 | *included in use-calculation* | | | | | | | | | | | | |
| | Wind generator | 1 | *included in use-calculation* | | | | | | | | | | | | |
| **Water supply** | | | | | | | | | | | | | | | **88651** |
| **Pipes** | 50mm pipe, 100m | 4 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 120 | 120 | 25 | 1.0 | 120 | 78.6 | 2.17 | 20467 | |
| | 50mm connectors | 10 | *negligible* | | | | | | | | | | | | |
| | 50mm to 15mm polycarp reducer | 2 | *negligible* | | | | | | | | | | | | |
| | 15mm polycarp piping, 50m | 3 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 150 | 150 | 25 | 1.0 | 150 | 78.6 | 2.17 | 25584 | |
| | Plumbing fittings T's | 50 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| | Plumbing fittiings Elbows | 70 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| **Tanks** | Water tanks, 5000lt | 4 | Water tank, plastic, 5000lt | D | each | | 4 | 400 | 25 | 1.0 | 4 | 8050 | 1.27 | 40894 | |
| **Warm water** | Solar water heater | 1 | *included in use-calculation* | | | | | | | | | | | | |
| **Sewage/ Sanitary** | | | | | | | | | | | | | | | **64396** |
| **Sanitary fittings** | wash hand basin | 9 | Sanitary fittings (wash hand basin) | B | each | | 9 | 0 | 25 | 1.0 | 9 | 2265 | 1.00 | 20385 | |
| | wc | 4 | Sanitary fittings (wc) | B | each | | 4 | 0 | 25 | 1.0 | 4 | 4169 | 1.00 | 16676 | |
| | shower | 4 | Sanitary fittings (shower), *half impact* | B | each | | 2 | 0 | 25 | 1.0 | 2 | 5992 | 1.00 | 11984 | |
| **Sewage** | 150mm pipe, 6m | 6 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 90 | 90 | 25 | 1.0 | 90 | 78.6 | 2.17 | 15351 | |
| | Connectors | 8 | *negligible* | | | | | | | | | | | | |
| | Soak-away | 1 | *reuse of old water tank* | | | | | | | | | | | | |
| **Drainage** | | | | | | | | | | | | | | | **13160** |
| **Trench** | Stone 4m3 | 1 | Kies gebrochen | A | kg | 2000 | 8000 | 8000 | 25 | 1.0 | 8000 | 0.319 | 2.17 | 5538 | |
| **Pipe** | Drainagepipe 110mm, 3m | 13 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 39 | 39 | 25 | 1.0 | 39 | 78.6 | 2.17 | 6652 | |
| | Bend, 45 ° | 2 | *negligible* | | | | | | | | | | | | |
| | Bitumen, pack | 4 | Bitumenbahn V60 | A | kg | 1160 | 10 | 10 | 25 | 1.0 | 10 | 44.7 | 2.17 | 970 | |
| **TOTAL** | | | | | | | | **172784** | | | | | **1.8653** | **658223** | |

### 6.1.2 Machine use

The following machines were used during the construction process. Their specific resource use is estimated.

Table 6.5: Machines and their resource use

| machine | energy | use per unit |
|---|---|---|
| chainsaw | petrol | 0.5 lt/hour |
| compactor | petrol | 0.5 lt/hour |
| concrete mixer | petrol | 1 lt/hour |
| digger | petrol | 3 lt/hour |
| drill | electricity | 2 kWh/day |
| generator | petrol | 1.5 lt/hour |
| hedgetrimmer | petrol | 0.5 lt/hour |
| roundsaw | petrol | 0.5 kWh/hour |
| tractor | petrol | 0.5 lt/hour |
| wacker | petrol | 0.5 lt/hour |

File: building process.ods

There is no electricity on the building site. All tools (except for the cordless drill) had therefore to run on petrol, or alternatively with a generator. The latter was thus often used. A day's use for the cordless drill is assumed to be 2 fully charged batteries.

Based on the chronicles of the construction process, resource use through machines was calculated. Details can be found in the spreadsheet “building process.ods”. To finish the buildings, more machines will be used. That resource use is projected linearly. It is assumed that the same amount of resources is used for the finishing phase as for the construction phase.

### 6.1.3 Utilisation stage: Volunteer Accommodation

The supply for the Straw Bale Volunteer Accommodation is designed according to the design principles for the development of Hawequas. The demand is based on assumptions on the consume of the volunteers. The envisaged demand is very low, following energy efficiency principles. It is only possible with behaviour striclty following the design outlines. Table 6.6 lists supply, demand and the resulting embodied energy.

Table 6.6: Utilisation stage: matter and energy Volunteer Accommodation facilities

**Future development**

**Supply**

| | | |
|---|---|---|
| Energy supply | photovoltaic cells on roof | main power system |
| | wind generator | backup |
| | | demonstration object for camps |
| | natural gas | cooking |
| | natural gas | fridge |
| Water supply | drinkwater supply from stream | only treatment: filtration |
| | rainwater collection from roof | for all other uses |
| Hot water | solar water heater | |

**Demand**

Volunteers 8 volunteers in Straw bale accommodation

| | | | | |
|---|---|---|---|---|
| Electricity | Light | 7W * 8 * 8 hours | 448 | Wh/day |
| | Music | 20W * 8 hours | 160 | Wh/day |
| | Laptop | 1 user | 210 | Wh/day |
| | Unknown | Cell phone a.o. | 150 | Wh/day |
| | | total | 968 | Wh/day |
| | | = | 1 | kWh/day |
| | | **total** | **365** | **kWh/year** |

Source: Discussion with Dave from Bulungula, www.bulungula.com

| | | | | |
|---|---|---|---|---|
| Hot water | daily usage | | 20 | gallons/volunteer/day |
| | | 1 gallon = 3.785 lt | 75 | lt/volunteer/day |
| | | 8 volunteers | 300 | lt/day |
| | tank temperature | assumption | 60 | ℃ |
| | temperature inlet water | assumption | 15 | ℃ |
| | heating energy | | 4.19 | J/lt/℃ |
| | | (60°-15°) * 300lt * 1cal | 56522 | J/day |
| | | | 20630 | kJ/year |
| | | **total** | **21** | **MJ/year** |

Source: www.greenbuilder.com/sourcebook/HeatCool.html

| | | | |
|---|---|---|---|
| Gas | Cooking | 15 | kg/capita/year |
| | | **120** | **kg/year** |
| | Fridge | **180** | **kg/year** |

Source: http://timesofindia.indiatimes.com/articleshow/950402.cms
Source: www.rpc.com.au/products/appliances/fridges/fridge_spec.html

**Future development, condensed**

| Energy | amount | unit | EE per unit [MJ-Eq per unit] | Source | Correction factor | EE [MJ-Eq] |
|---|---|---|---|---|---|---|
| Electricity | 365 | kWh | 1.5 | A | 2.17 | 1188 |
| Hot water | 21 | MJ | 0.06 | A | 2.17 | 3 |
| Gas | 300 | kg | 29 | B | 1.00 | 8700 |
| | | | | | **total** | **10000** |

File: matter and energy volunteers.ods

### 6.1.4 Utilisation stage: matter and energy flows at Hawequas

The data for the matter and energy flows at Hawequas were sampled from accounts of 2006 at SASA-WC Headquarters. One reliable source was the electricity bills from Eskom (South African electricity supplier). A second source was the account for Petty Cash for Hawequas, including detailed information about what had been purchased at what time. The third source was the receipts for the checks issued at the Headquarter for Hawequas. This led to reliable information about the expenses. A condensed list (without monetary values) is accessible in the spreadsheet “matter and energy hawequas.ods”.

To extract information about embodied energy proved more difficult. Following categories could be identified: electricity, gas and petrol. The latter was both used for machines and transport. In January 2007, an old truck (light duty vehicle) called Dennis was donored to the farm. This increased petrol use considerably (+ 200 %) and will keep it high. Data from January to March 2007 was thus extrapolated for the use of petrol. 30 % was assumed to be used for machinery, therefore counted for everyday activities on the farm; 70 % was assumed to be used for transport. An average petrol price of ZAR 5-89 per litre was assumed[6]. Unquantifiable matters in terms of embodied energy was included by adding 20 % to the total amount of embodied energy.

6 www.aa.co.za/Advice+and+Information/Fuel+Price+Fluctuations/

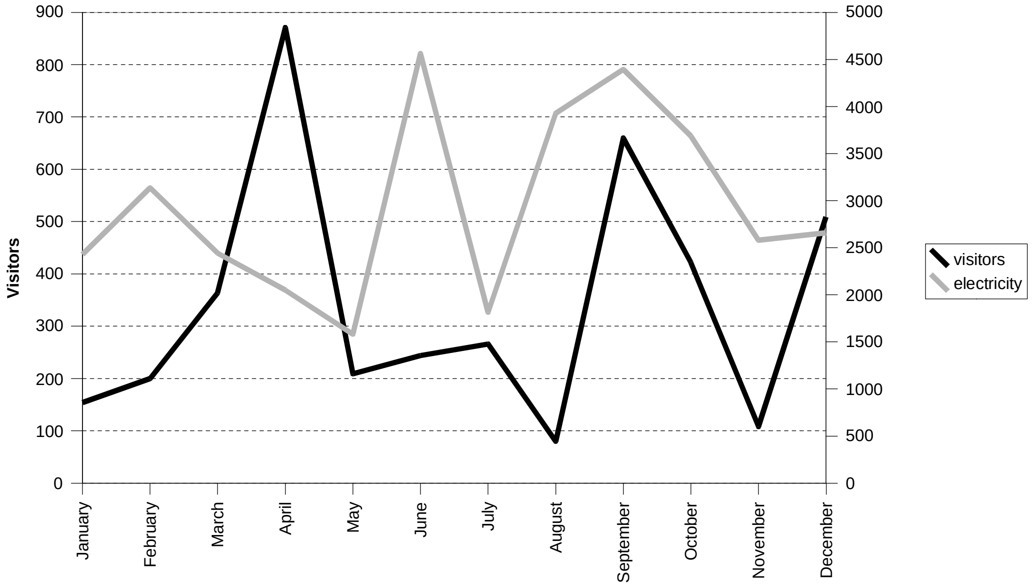
Table 6.7: Utilisation stage: matter and energy Hawequas 2006

| Matter and energy | amount | unit | EE per unit [MJ/unit] | Source | Correction factor | EE [MJ] |
|---|---|---|---|---|---|---|
| Electricity | 35265 | kWh | 10.13 | B | 1.00 | 357234 |
| Gas | 720 | kg | 29 | B | 1.00 | 20880 |
| Petrol machines | 811 | lt | 127.47 | B | 1.00 | 103413 |
| +20 % to include unquantifiable matters | | | | | | 96305 |
| | | | | **total** | | **578000** |

File: matter and energy hawequas.ods

Assumptions must be made to estimate the future environmental impact. Figure 6.1 shows a correlation between the number of visitors and the electricity use. The peak of visitors in April is due to PLTU, the premier leadership training course of the Scouts. This means that many people stay on the farm (camping!) but use only little resources as the activities are set mainly in nature. The peak in June is probably due to the cold winter season, resulting in extensive use of electric heaters. It is considered a correlation good enough to linearly extrapolate future increase of visitors with corresponding increase of energy use.

Figure 6.1: Comparison Visitors - Electricity use




Source: SASA-WC Headquarters

The farm occupancy will increase by 82 %. Matter and energy fluxes will thus increase by the same amount:

Table 6.8: Utilisation stage: matter and energy Hawequas in future

| Matters and energy | increase | amount | unit | EE per unit [MJ/unit] | Source | Corr. factor |
|---|---|---|---|---|---|---|
| Electricity | 82% | 28917 | kWh | 10.13 | B | 1.00 |
| Gas | 82% | 590 | kg | 29 | B | 1.00 |
| Petrol | 82% | 665 | lt | 127.47 | B | 1.00 |
| +20 % for unquantifiables | 82% | | | | | |
| | | | | | **total** | |

File: matter and energy hawequas.ods

## 6.2 Transport

### 6.2.1 Construction process

Base for the calculations is again the building materials list. The supplier for the building materials is identified and the distance to the building site estimated, using the online-tool www.brabys.com. The transport mode is specified and the resulting number of trips. Taking the same value for the Life Cycle (LC) coefficient as for the building material itself, the LC distance is calculated, taking always the trips forth and back. The total embodied energy is then calculated using the specific values from Table 5.5 with the unit MJ/VehKm.

Normally, when dealing with material transport, one would calculate with tonnes-kilometres, assuming a certain average load. However, in this building process, the transporting vehicle was hardly ever fully loaded. Firstly, an ancient bridge restricts heavy loads, making every crossing with a heavy duty vehicle a game of Russian roulette. And secondly, most materials were transported in small quantities, resulting in a atypical load structure. The load could often be less than 50 kg, transported on a light duty vehicle of several tons. To calculate with vehicle-kilometres as unit was therefore concluded most accurate.

Tables 6.9 to 6.11 show the spreadsheet “building material.ods” with the calculations for the transport for the building materials.

The trips not related to a specific building material are all listed in “building process.ods”. They are based on the author's chronicles. Trips in a passenger car are listed and calculated as pkm.

The builders' trips are all listed in “building process.ods”. A reduction factor is included where the purpose of the travel was not for the construction process. Distances are again calculated using the online-tool on www.brabys.com. The trips are divided into following transport modes: plane, car, bus (meaning mini-bus) and train.

# Table 6.9: Calculation of the embodied energy of the transport of building materials, part 1

| Building element | Building material | Qty | Where purchased | distance [km] | transport mode [car, light or heavy duty vehicle] | number of trips | Life cycle | Life cycle coefficient | total distance [km] | EE per unit [MJ-Eq] | EE total [MJ-Eq] | EE systems |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building Materials** | | | | | **TRANSPORTATION** | | | | | | **126796 MJ-Eq** | |
| **Foundation** | | | | | | | | | | | | **21506** |
| **Trench** | Rubble/ half-bricks, 4m3 | 4 | Paarl | 18 | heavy | 4 | 25 | 1.0 | 144 | 43.9 | 6322 | |
| **Concrete** | Sand, m3 | 10 | Paarl | 18 | heavy | 2 | 25 | 1.0 | 72 | 43.9 | 3161 | |
| | Gravel, m3 | 20 | Paarl | 18 | heavy | 4 | 25 | 1.0 | 144 | 43.9 | 6322 | |
| | Cement, 50kg | 70 | Wellington | 9 | light | 4 | 25 | 1.0 | 72 | 17.6 | 1267 | |
| | Iron poles | 1 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Rebars 10mm, 6m | 10 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Rebars 10mm, 6m | 20 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Brickforce, 25m-roll | 4 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| **Framework** | shutterboards, 21mm x 1.2m x 2.4m | 3 | Paarl | 18 | light | 1 | 25 | 1.0 | 36 | 17.6 | 634 | |
| | shutterboards, 21mm x 1.2m x 2.4m | 3 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | shutterboards, 21mm x 1.2m x 2.4m | 8 | Somerset West | 45 | light | 1 | 25 | 1.0 | 90 | 17.6 | 1584 | |
| | Pine beams, 22 x 44mm x 3m | 10 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Cut screws, 4.0x50 | 1 | Wellington | 9 | car | 0 | 25 | 1.0 | 0 | 12.8 | 0 | |
| **Pipe for tensioning** | Wood Drill 22mm | 1 | Wellington | 9 | car | 0 | 25 | 1.0 | 0 | 12.8 | 0 | |
| | Pipe 20mm x 5m | 10 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| **Other** | Post brackets | | Paarl | 18 | car | 0 | 25 | 1.0 | 0 | 12.8 | 0 | |
| | Wire and tools | | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| **Straw bale walls** | | | | | | | | | | | | **18773** |
| **Straw bale structure** | Straw bales | 750 | Watervlei | 20 | heavy | 2 | 25 | 1.0 | 80 | 43.9 | 3512 | |
| | Blue gum stakes | 600 | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| | Baling twine, 500m | 1 | Wellington | 9 | car | 1 | 25 | 1.0 | 18 | 12.8 | 230 | |
| **Base plate/ wall plate** | treated beam 50mm x 76mm, 3m | 140 | Cape Town | 83 | light | 1 | 25 | 1.0 | 166 | 17.6 | 2922 | |
| | Dowels 19mm, 1.8m | 55 | Paarl | 18 | light | 1 | 25 | 1.0 | 36 | 17.6 | 634 | |
| | Damp proof course 2.0 x 30m | 1 | Paarl | 18 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Wood glue | 1 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Silicone | 3 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Pine beams, 32 x 44mm x 3m | 4 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Cut screws, 6.0 x 120mm, 60 pieces | 2 | Wellington | 9 | car | 0 | 25 | 1.0 | 0 | 12.8 | 0 | |
| | Cut screws, 6.0 x 100mm, 500 pieces | 1 | Wellington | 9 | car | 0 | 25 | 1.0 | 0 | 12.8 | 0 | |
| | Wood drill 19mm | 1 | Wellington | 9 | car | 0 | | 0.0 | 0 | 12.8 | 0 | |
| | Nail in Nylon 8 x 100mm, 50 pieces | 3 | Wellington | 9 | car | 0 | | 0.0 | 0 | 12.8 | 0 | |
| | Nail in Nylon 8 x 100mm, single pieces | 20 | Wellington | 9 | car | 0 | | 0.0 | 0 | 12.8 | 0 | |
| **Tensioning** | Fencing wire, 50kg, 3mm | 1 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | wire strainer | | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Polyester strapping, 500m | 1 | Cape Town | 83 | car | 1 | 25 | 1.0 | 166 | 12.8 | 2125 | |
| **Plastering** | Clay, m3 | | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| | Lime, 25kg | 30 | Robertson | 126 | light | 1 | 15 | 1.7 | 252 | 17.6 | 7392 | |
| **Other** | baling tools | | Wellington | 9 | car | 2 | 25 | 1.0 | 36 | 12.8 | 461 | |
| | Drill set | 8 | Wellington | 9 | car | 0 | | 0.0 | 0 | 12.8 | 0 | |
| | Gewindestangen, 16mm x 1m | 4 | Wellington | 9 | car | 1 | 25 | 1.0 | 18 | 12.8 | 230 | |
| | Gewindestangen, 12mm x 1m | 4 | Wellington | 9 | car | 0 | 25 | 1.0 | 0 | 12.8 | 0 | |
| | Wood drill | 3 | Wellington | 9 | car | 0 | | 0.0 | 0 | 12.8 | 0 | |
| | Chicken wire, 1.2m widel, per m | 20 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |

# Table 6.10: Calculation of the embodied energy of the transport of building materials, part 2

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Floor** | | | | | | | | | | | | **18719** |
| **Drainage/ ground** | Stone 4m3 | 4 | Paarl | 18 | heavy | 4 | 25 | 1.0 | 144 | 43.9 | 6322 | |
| | Sand 4m3 | 1 | Paarl | 18 | heavy | 1 | 25 | 1.0 | 36 | 43.9 | 1580 | |
| | Cardboard, 5mm | | Paarl | 18 | light | 2 | 25 | 1.0 | 72 | 17.6 | 1267 | |
| **Cob-floor acc.** | Clay | | Hawequas | | | | | 0.0 | 0 | 0 | 0 | |
| | Lime, 25kg | 8 | Robertson | 126 | light | 0 | 15 | 1.7 | 0 | 17.6 | 0 | |
| | Beeswax | | Wellington | 9 | light | 1 | 2 | 12.5 | 18 | 17.6 | 3960 | |
| **Tile-floor abl.** | Sand 4m3 | 1 | Paarl | 18 | heavy | 1 | 25 | 1.0 | 36 | 43.9 | 1580 | |
| | Stone 4m3 | 1 | Paarl | 18 | heavy | 1 | 25 | 1.0 | 36 | 43.9 | 1580 | |
| | Cement, 50 kg | 20 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Tiles, m2 | 30 | Paarl | 18 | light | 2 | 15 | 1.7 | 72 | 17.6 | 2112 | |
| **Roof** | | | | | | | | | | | | **12478** |
| **Post and beams** | Blue gum posts, 3m | 12 | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| | Blue gum beams, 6m | 7 | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| | Blue gum beams, 8m | 24 | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| | Blue gum beams, 12m | 4 | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| | Wood treatment, 5lt | 4 | Wellington | 9 | light | 1 | 10 | 2.5 | 18 | 17.6 | 792 | |
| | Hoop Iron, 10m | 9 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| **Ceiling** | Shutterboard, 1.2 x 2.4m, 21mm | 65 | Paarl | 18 | light | 1 | 25 | 1.0 | 36 | 17.6 | 634 | |
| **Perlins** | SABS 38x76mm x 3m | 25 | Somerset West | 71 | light | 1 | 25 | 1.0 | 142 | 17.6 | 2499 | |
| | SABS 38x152mm x 3m | 60 | Somerset West | 71 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | SABS 38x76mm x 2.7m | 35 | Somerset West | 71 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| **Insulation** | Thermguard, recycled paper, 25kg | 40 | Somerset West | 71 | light | 2 | 25 | 1.0 | 284 | 17.6 | 4998 | |
| **Roof sheeting** | IBR roof sheeting, 1m2 | 270 | Cape Town | 83 | light | 1 | 25 | 1.0 | 166 | 17.6 | 2922 | |
| | Transparent roof sheeting, 1m2 | 10 | Cape Town | 83 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Roofing nails, 90mm, 50 pieces | 12 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| **Guttering** | PVC Guttering, 6m | 7 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Gutter brackets | 30 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Stop end | 4 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Outlet | 2 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| **Other** | 75mm cut screws x 125 | 10 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Scorch screws, 90x8mm x 125 | 6 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Washers | 400 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| **Windows and doors** | | | | | | | | | | | | **15664** |
| **windows** | Winsters Window frame WC2, 1200x1145 | 4 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Winsters Window frame WB1, 1200x595 | 4 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Glazing | 1 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Pine-shelves (for windows and doors) | | Wellington | 9 | light | 2 | 10 | 2.5 | 36 | 17.6 | 1584 | |
| | Enviro-Touch wood treatment, 5lt | 1 | Somerset West | 71 | light | 0 | 5 | 5.0 | 0 | 17.6 | 0 | |
| | Silicone | 2 | Wellington | 9 | light | 0 | 5 | 5.0 | 0 | 17.6 | 0 | |
| **Outside sliding door** | Henderson Track 290, 3m | 1 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Henderson Track 290 Brackets | 6 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Henderson Track 290 Roller | 3 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| **Outside/ Inside doors** | Door lock | 10 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Door handle | 10 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Door | 10 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Door frame | 10 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Door hinges, set of 2 | 10 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Enviro-Touch wood treatment, 5 lt | 3 | Somerset West | 71 | light | 1 | 5 | 5.0 | 142 | 17.6 | 12496 | |

# Table 6.11: Calculation of the embodied energy of the transport of building materials, part 3

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Interior walls** | | | | | | | | | | | | **2534** |
| **Posts** | non treated beam 50mm x 76mm, 3m | 75 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | 75mm cut screws x 125 | 4 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| **Boards** | NuTec Dry walling 3.0m x 1.2m x 4mm | 26 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | NuTec Dry walling 2.4m x 1.2m x 4mm | 20 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Paint, 5lt | 6 | Wellington | 9 | light | 1 | 5 | 5.0 | 18 | 17.6 | 1584 | |
| **Electricity** | | | | | | | | | | | | **12531** |
| **Conduiting** | Conduiting, pipe, 4m | 15 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Conduiting T's | 14 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Conduiting Elbows | 14 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Light sockets | 22 | Wellington | 9 | light | 1 | 15 | 1.7 | 18 | 17.6 | 528 | |
| | Osram light bulbs | 22 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Light wall switches | 11 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Light hanging switches | 4 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Electric cord, meters | 80 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| **Supply** | Photovoltaic | 1 | Cape Town | 83 | light | 2 | 25 | 1.0 | 332 | 17.6 | 5843 | |
| | Wind generator | 1 | Cape Town | 83 | light | 2 | 25 | 1.0 | 332 | 17.6 | 5843 | |
| **Water supply** | | | | | | | | | | | | **21196** |
| **Pipes** | 50mm pipe, 100m | 4 | Wellington | 9 | car | 1 | 25 | 1.0 | 18 | 12.8 | 230 | |
| | 50mm connectors | 10 | Wellington | 9 | car | 1 | 25 | 1.0 | 18 | 12.8 | 230 | |
| | 50mm to 15mm polycarp reducer | 2 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | 15mm polycarp piping, 50m | 3 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Plumbing fittings T's | 50 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| | Plumbing fittiings Elbows | 70 | Wellington | 9 | light | 0 | 25 | 1.0 | 0 | 17.6 | 0 | |
| **Tanks** | Water tanks, 5000lt | 4 | Cape Town | 83 | heavy | 2 | 25 | 1.0 | 332 | 43.9 | 14575 | |
| **Warm water** | Solar water heater | 1 | Cape Town | 83 | light | 2 | 25 | 1.0 | 332 | 17.6 | 5843 | |
| **Sewage/ Sanitary** | | | | | | | | | | | | **1267** |
| **Sanitary fittings** | wash hand basin | 9 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | wc | 4 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | shower | 4 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| **Sewage** | 150mm pipe, 6m | 6 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Connectors | 8 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Soak-away | 1 | Hawequas | 0 | | 0 | | 0.0 | 0 | 0 | 0 | |
| **Drainage** | | | | | | | | | | | | **2128** |
| **Trench** | Stone 4m3 | 1 | Paarl | 18 | heavy | 1 | 25 | 1.0 | 36 | 43.9 | 1580 | |
| **Pipe** | Drainagepipe 110mm, 3m | 13 | Wellington | 9 | light | 1 | 25 | 1.0 | 18 | 17.6 | 317 | |
| | Bend, 45 ° | 2 | Wellington | 9 | light | 0 | | 0.0 | 0 | 17.6 | 0 | |
| | Bitumen, pack | 4 | | 9 | car | 1 | 25 | 1.0 | 18 | 12.8 | 230 | |
| **TOTAL** | | | | | | | | | | | **126796** | |

## 6.2.2 Utilisation stage: mobility of staff and volunteers

The assumptions for the mobility of staff and volunteers is listed in the table below:

Table 6.12: Mobility staff and volunteers

| **Staff** | when | where | distance [km] | purpose | transport mode | exceptions | distance [pkm/year] | EE per pkm [MJ] | EE [MJ] |
|---|---|---|---|---|---|---|---|---|---|
| **Tess** | 2/week | Wellington | 9 | shopping | light duty truck | | 1872 | 17.60 | 32947 |
| | 1/week | Paarl | 20 | shopping | car | | 2080 | 7.36 | 15309 |
| | 3/week | gate | 2 | opening gate | car | | 624 | 7.36 | 4593 |
| | 2/day | inside farm | 1 | working | light duty truck | weekdays | 520 | 17.60 | 9152 |
| | 1/week | Paarl | 18 | scout meeting | car | | 1872 | 7.36 | 13778 |
| | 5/week | Wellington | 9 | pick up kids | car | holidays, 14 weeks | 3420 | 7.36 | 25171 |
| | 1/week | Paarl | 18 | pick up Bronwyn | light duty truck | holidays, 6 weeks | 1872 | 17.60 | 32947 |
| **Alwyn** | 6/week | Paarl | 18 | work | car | holidays, 3 weeks | 10584 | 7.36 | 77898 |
| | 1/week | Paarl | 18 | scout meeting | car | | 1872 | 7.36 | 13778 |
| | 2/week | Paarl | 18 | pick up Bronwyn | car | holidays, 6 weeks | 3744 | 7.36 | 27556 |
| **Bronwyn** | 5/week | Wellington | 9 | school | car | holidays, 14 weeks | 3420 | 7.36 | 25171 |
| | 2/week | Paarl | 18 | work | car | holidays, 6 weeks | 8280 | 7.36 | 60941 |
| | 1/week | Paarl | 18 | scout meeting | car | | 1872 | 7.36 | 13778 |
| **Samantha** | 5/week | Wellington | 9 | school | car | holidays, 14 weeks | 3420 | 7.36 | 25171 |
| | 1/week | Paarl | 18 | scout meeting | car | | 1872 | 7.36 | 13778 |
| | | | | | | ***total, fam Pettiquin*** | ***47000*** | | ***392000*** |
| **Andrew** | 4/week | Blovlei | 4 | work | car | holidays, 6 weeks | 1472 | 7.36 | 10834 |
| | 3/week | Paarl | 18 | work | car | holidays, 6 weeks | 4968 | 7.36 | 36564 |
| | 2/week | Cape Town | 83 | work | car | holidays, 6 weeks | 15272 | 7.36 | 112402 |
| | | | | | | ***total, andrew*** | ***22000*** | | ***160000*** |
| **Volunteers** | | | | | | | | | |
| **Type 1 international busy** | 1/6 month | overseas | 9000 | home | plane | | 36000 | 6.05 | 217800 |
| | 3/week | Wellington | 9 | work | car | travel break, 1 month | 2376 | 7.36 | 17487 |
| | 2/week | Wellington | 9 | shopping | car | travel break, 1 month | 1584 | 7.36 | 11658 |
| | 2/month | Cape Town | 83 | leisure | car | travel break, 1 month | 3984 | 7.36 | 29322 |
| | 1 month | Southern Africa | 4000 | travel | car | | 4000 | 7.36 | 29440 |
| | | | | | | ***total*** | ***48000*** | | ***306000*** |
| **Type 2 international calm** | 1/6 month | overseas | 9000 | home | plane | | 36000 | 6.05 | 217800 |
| | 1/week | Wellington | 9 | shopping | car | travel break, 2 weeks | 1728 | 7.36 | 12718 |
| | 1/month | Cape Town | 83 | leisure | train | travel break, 2 weeks | 1826 | 1.39 | 2538 |
| | 1/month | Wellington station | 9 | home | car | travel break, 2 weeks | 198 | 7.36 | 1457 |
| | 2 weeks | South Africa | 2000 | travel | car | | 2000 | 7.36 | 14720 |
| | | | | | | ***total*** | ***42000*** | | ***249000*** |
| **Type 3 local coordinator** | 3/month | Cape Town | 83 | home | train | | 5976 | 1.39 | 8307 |
| | 3/month | Wellington station | 9 | home | car | | 648 | 7.36 | 4769 |
| | 1/week | Wellington | 9 | work | car | | 936 | 7.36 | 6889 |
| | 1/week | Wellington | 9 | shopping | car | | 936 | 7.36 | 6889 |
| | | | | | | ***total*** | ***8000*** | | ***27000*** |
| **Type 4, local local** | 1/month | Cape Town | 83 | home | train | | 1992 | 1.39 | 2769 |
| | 1/month | Wellington station | 9 | home | car | | 216 | 7.36 | 1590 |
| | 1/week | Wellington | 9 | shopping | car | | 936 | 7.36 | 6889 |
| | | | | | | ***total*** | ***3000*** | | ***38000*** |

File: mobility hawequas.ods

### 6.2.3 Utilisation stage: transport related to farm use

To calculate the embodied energy of the transport for matter and energy at Hawequas, the account for Petty Cash for Hawequas was the main source. It includes detailed information about what had been purchased at what time. Following assumptions were made:

- One return trip per item on the list to collect
- Assumed destination: Wellington, distance = 9 km
- Reduction factor due to coordination of several purposes for one return trip
- Increase factor due to further distances than Wellington
- Mode of transport: light duty truck Dennis

This assumptions were applied to the Petty Cash account, distinguishing the categories Repair & Maintenance, Stationery and Cleaning. An additional category considers petrol. As assumed in appendix 6.1.4, 70 % of the petrol is used for transport.

Table 6.13: Utilisation stage: transport of matter and energy at Hawequas

| **Material** | **No. Of trips** | **Distance** | **Reduction** | **Increase** | **Distance** | **EE per unit** | **EE** |
|---|---|---|---|---|---|---|---|
| | | | | | [km] | [MJ/unit] | [MJ] |
| Repair & Maintenance | 26 | 9 | 5% | 30% | 585 | 17.60 | 10296 |
| Stationery | 11 | 9 | 20% | 0% | 158 | 17.60 | 2788 |
| Cleaning | 29 | 9 | 20% | 10% | 470 | 17.60 | 8268 |
| **Petrol** | **amount** | **unit** | | | | **EE per unit** | **EE** |
| | | | | | | [MJ/unit] | [MJ] |
| Petrol transport | 1893 | lt | | | | 127.47 | 241297 |
| | | | | | | **total** | **263000** |

File: matter and energy hawequas.ods

### 6.2.4 Utilisation stage: transport of visitors

Four visitor groups with different detailing can be identified out of the information from the reservation registry from SASA-WC Headquarters:

1. “Known” Scout groups, number, date and duration, identified origin
2. “Unknown” Scout groups, number, date and duration, origin not known as a variety of different Scout groups participated (training courses)
3. Non-Scout groups, number, date and duration, origin not known
4. Land Care camps, number, date and duration, origin assumed

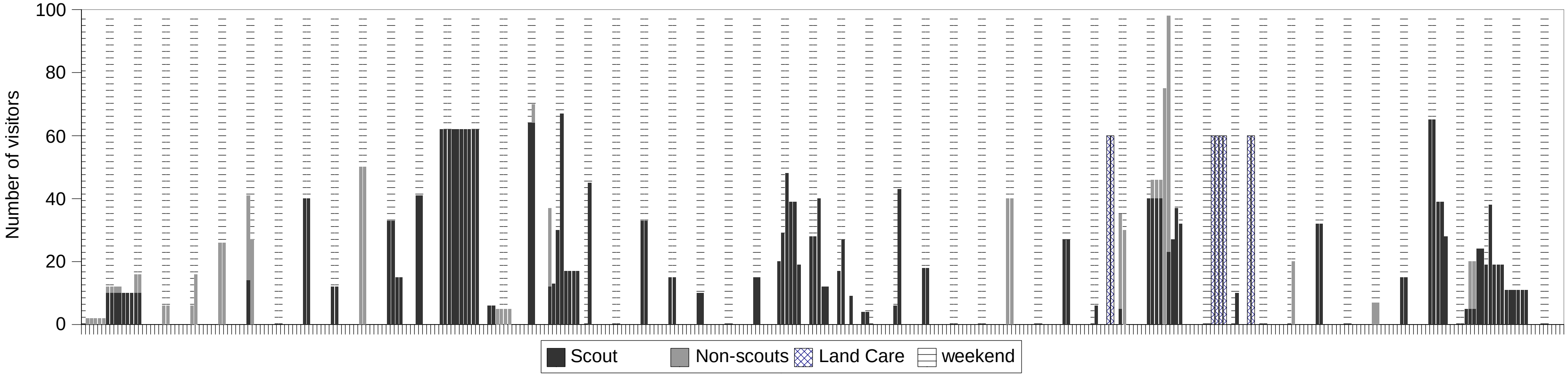
Examination of the first group showed consistent pattern concerning their origins. Most of the groups are located in Cape Town's suburbs. The distance of their corresponding group headquarters is calculated using the online-tool www.brabys.com. The average distance is 77.6 km with a standard deviation of 11.4 km. Due to this small variation, the same average travel distance is assumed for groups 2 and 3. For the fourth group, 30 km travel distance is assumed as local groups from surrounding communities are anticipated. For the calculations, two visitor groups are distinguished: General visitors (all Scouts and non-Scouts) and Land Care camps. See Figure 6.2 for their distribution over the year 2006. A concentration of visitors can be noticed on weekends.

Table 6.14: Statistics visitors 2006

| | | | | |
|---|---|---|---|---|
| total people | 1687 | people | 4198 | nights |
| known scouts | 722 | people | 1784 | nights |
| unknown scouts | 327 | people | 1092 | nights |
| non-scouts | 362 | people | 662 | nights |
| land care | 276 | people | 660 | nights |
| total general visitors | 1411 | people | | |
| total land care | 276 | people | | |
| average stay | 2.5 | nights | | |
| average distance | 77.6 | km | | |
| median | 76.0 | km | | |
| standard deviation | 11.4 | km | | |

Source: SASA-WC Headquarters, file: transportation visitors.ods

Figure 6.2: Distributions visitors 2006




Source: SASA-WC Headquarters, file: transportation visitors.ods

The warden's diary for January to March 2007 is consulted to estimate the modal split of the two visitor groups. As it is not complete, corrections have to be applied. Following procedure is applied for general visitors:

1. Determine the modal split for known groups (11 out of 20 groups). It results an occupancy of 3.3 people per car and 5.8 people per bus (mini-bus).
2. + 50 % visitors, as groups with unknown modal split are mainly small groups, assumed transport mode: private car!
3. Calculate the corrected modal split

Table 6.15: Calculation modal split general visitors

**General Visitors**

| | | | |
|---|---|---|---|
| Number of people | | | |
| 327 | 100 cars | | 3.3 people/car |
| 93 | 16 buses | | 5.8 people/bus |
| 0 | 0 trainpassengers | #VALUE! | |
| 420 in total | | | |

**Modal Split**

| | |
|---|---|
| 77.9% | private cars |
| 22.1% | buses |
| 0.0% | train |

**Correction**

| | |
|---|---|
| 11 | groups transportation analysed |
| 9 | groups transportation unknown, assumed cars! |
| 45% | of transportation unknown |
| +50% | visitors, in cars (mainly small groups unknown) |
| 630 | visitors in total |

**Corrected Modal Split General Visitors**

| Number of people | transportation | | |
|---|---|---|---|
| 537 | cars | **private car** | **85.2%** |
| 93 | buses | **bus** | **14.8%** |
| 0 | trainpassengers | **train** | **0.0%** |
| **630** | **in total** | | |

File: transportation visitors.ods

A similar procedure is applied for the Land Care camps:

1. Determine the modal split. It results an occupancy of 30.8 people per bus. This is plausible as the 60 children per camp are transported in two coaches.
2. Correction: 4 people per camp as supervisors, or 1 person driving forth and pack 4 times per camp, assumed in a car.
3. Calculate the corrected modal split

Table 6.16: Calculation modal split Land Care camps

**Land Care**

Number of people

| | | | |
|---|---|---|---|
| 0 | 0 cars | #VALUE! | people/car |
| 370 | 12 buses | 30.8 | people/bus |
| 48 | 36 trainpassengers | 1.3 | |
| 418 in total | | | |

**Modal Split**

| | |
|---|---|
| 0.0% | private cars |
| 88.5% | buses |
| 11.5% | train |

**Correction**

| | |
|---|---|
| 4 | people/camp as supervisor |
| 24 | people transported, assumed cars |
| 442 | visitors in total |

**Corrected Modal Split Land Care**

| Number of people | transportation | | |
|---|---|---|---|
| 24 | cars | **private car** | **5.4%** |
| 370 | buses | **bus** | **83.7%** |
| 48 | trainpassengers | **train** | **10.9%** |
| **442** | **in total** | | |

File: transportation visitors.ods

With the information about the number of future visitors, their origins and their transport mode, it is then possible to deduct the impact on embodied energy. See Table 6.17 for details.

Table 6.17: Calculation of the embodied energy due to additional visitors

| | | | | |
|---|---|---|---|---|
| **General visitors, additional** | | | | |
| | 20% increase | | | |
| | 282 people | | | |
| Travel distances, additional | 43770 pkm | | = 282 * 77.6 * 2 | |
| | | | | |
| **General visitors** | **modal split** | **distance** | **EE per unit** | **EE** |
| | [%] | [pkm] | [MJ/pkm] | [MJ] |
| private cars | 85.2% | 37309 | 7.36 | 274591 |
| buses | 14.8% | 6461 | 1.64 | 10596 |
| train | 0.0% | 0 | 1.39 | 0 |
| | | | **subtotal** | **285000** |
| | | | | |
| **Land Care camps, additional** | | | | |
| | 16 camps | | | |
| | 1104 people | | | |
| Travel distances, additional | 66240 pkm | | = 1104 * 30 * 2 | |
| | | | | |
| **Land Care camps** | **modal split** | **distance** | **EE per unit** | **EE** |
| | [%] | [pkm] | [MJ/pkm] | [MJ] |
| private cars | 5.4% | 3597 | 7.36 | 26472 |
| buses | 83.7% | 55450 | 1.64 | 90938 |
| train | 10.9% | 7193 | 1.39 | 9999 |
| | | | **subtotal** | **127000** |
| | | | **total** | **412000** |

File: transportation visitors.ods

## 6.3 Alternative design: conventional brick building

The alterations in comparison to the Straw Bale design are listed in chapter 3.3.4. Comments on a selected building materials:

Table 6.18: Comments on building materials

| | |
|---|---|
| Fired clay bricks | dimensions: 290 x 140 x 150 mm |
| Mortar | 10 mm layer between bricks, results in 10 % of wall surface |
| Fixing mortar | necessary for mineral wool to stick on bricks, 3 mm thin layer |
| Life cycles | most materials endure at least the entire life cycle of the building set as 25 years, materials with lower life cycles are paints, wood treatment, lime plaster and window sill |

# Table 6.19: Calculation of the embodied energy of the conventional construction, part 1

| Building element | Building material | Qty | Name or *Comment* | Source | Unit | Density [kg/m3] | Qty unit | Mass kg | Life cycle | Life cycle coefficient | Life cycle Qty | EE per unit [MJ-Eq] | Correction factor | EE total [MJ-Eq] | EE systems |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building Materials** | | | | | | **BUILDING PROCESS** | | | | | | | | **1764479** | **MJ-Eq** |
| **Foundation** | | | | | | | | | | | | | | | **140379** |
| **Concrete trench** | concrete, m3 | 25 | Beton C 25/30 speziell für Fundamente/ Bodenplatten | A | kg | 2385 | 59760 | 59760 | 50 | 1.0 | 59760 | 0.72 | 2.17 | 93499 | |
| | steel, 20 kg/m3, per kg | 500 | Armierungsstahl | A | kg | 7850 | 500 | 500 | 50 | 1.0 | 500 | 24.1 | 2.17 | 26149 | |
| **Framework** | shutterboards, 21mm x 1.2m x 2.4m | 3 | Sperrholz/ Multiplex | A | kg | 780 | 142 | 142 | 50 | 1.0 | 142 | 14.4 | 2.17 | 4437 | |
| | shutterboards, 21mm x 1.2m x 2.4m | 3 | Sperrholz/ Multiplex | A | kg | 780 | 142 | 142 | 50 | 1.0 | 142 | 14.4 | 2.17 | 4437 | |
| | shutterboards, 21mm x 1.2m x 2.4m | 8 | Sperrholz/ Multiplex | A | kg | 780 | 377 | 377 | 50 | 1.0 | 377 | 14.4 | 2.17 | 11780 | |
| | Pine beams, 22 x 44mm x 3m | 10 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 16 | 16 | 50 | 1.0 | 16 | 2.21 | 2.17 | 77 | |
| | Cut screws, 4.0x50 | 1 | *negligible* | | | | | | | | | | | | |
| **Walls** | | | | | | | | | | | | | | | 572896.28 |
| **Brickwall** | fired clay bricks, 15cm thick, per m2 | 196 | Backstein | A | kg | 1000 | 29400 | 29400 | 50 | 1 | 29400 | 2.82 | 2.17 | 179910.36 | |
| | mortar, 10% of wall sufrace, per m2 | 20 | Zementmörtel | A | kg | 1700 | 5100 | 5100 | 50 | 1 | 5100 | 1.6 | 2.17 | 17707.2 | |
| **Insulation** | mineral wool, 20cm thick, per m2 | 120 | Steinwolle | A | kg | 100 | 2400 | 2400 | 25 | 2 | 4800 | 22.2 | 2.17 | 231235.2 | |
| | fixing mortar, 3mm thick, per m2 | 120 | Klebemörtel, Kunststoffbasis | A | kg | 1600 | 576 | 576 | 25 | 2 | 1152 | 25 | 2.17 | 62496 | |
| **Plastering** | mineral plaster outside, 15mm thick, per m2 | 196 | Mineralischer Deckputz | A | kg | 1500 | 4410 | 4410 | 20 | 2.5 | 11025 | 1.73 | 2.17 | 41388.95 | |
| | mineral plaster inside, 15mm thick, per m2 | 175 | Mineralischer Deckputz | A | kg | 1500 | 3937.5 | 3937.5 | 30 | 1.67 | 6562.5 | 2.82 | 2.17 | 40158.56 | |
| **Floor** | | | | | | | | | | | | | | | 146340.79 |
| **Drainage/ ground** | Stone 4m3 | 4 | Kies gebrochen | A | kg | 2000 | 32000 | 32000 | 25 | 1 | 32000 | 0.32 | 2.17 | 22151.36 | |
| | concrete, 20cm thick, per m2 | 96 | Beton C 25/30 speziell für Fundamente/ Bodenplatten | A | kg | 2385 | 45792 | 45792 | 50 | 1 | 45792 | 0.72 | 2.17 | 71644.79 | |
| | steel, 20 kg/m3, per kg | 384 | Armierungsstahl | A | kg | 7850 | 384 | 384 | 50 | 1 | 384 | 24.1 | 2.17 | 20082.05 | |
| | cement mortar, 7cm thick, per m2 | 96 | Zementunterlagsboden | A | kg | 1700 | 11424 | 11424 | 50 | 1 | 11424 | 1.28 | 2.17 | 31731.3 | |
| **Tile-floor ablution** | Tiles, m2 | 30 | Keramikplatten | A | kg | 1900 | 285 | 285 | 20 | 2.5 | 712.5 | 14.8 | 2.17 | 22882.65 | |
| **Roof** | | | | | | | | | | | | | | | 101703 |
| **Beams** | timber beams, 20x10cm, 8m long | 20 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 1728 | 1728 | 50 | 1.0 | 1728 | 2.21 | 2.17 | 8287 | |
| **Ceiling** | Shutterboard, 1.2 x 2.4m, 21mm | 65 | OSB Platte | A | kg | 473 | 1860 | 1860 | 30 | 1.7 | 3100 | 18.1 | 2.17 | 121759 | |
| **Perlins** | SABS 38x76mm x 3m | 25 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 117 | 117 | 30 | 1.7 | 195 | 2.21 | 2.17 | 935 | |
| | SABS 38x152mm x 3m | 60 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 561 | 561 | 30 | 1.7 | 935 | 2.21 | 2.17 | 4484 | |
| | SABS 38x76mm x 2.7m | 35 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 147 | 147 | 30 | 1.7 | 245 | 2.21 | 2.17 | 1175 | |
| **Insulation** | mineral wool, 12cm thick, per m2 | 87 | Steinwolle | A | kg | 100 | 1044 | 1044 | 25 | 2.0 | 2088 | 22.2 | 2.17 | 100587 | |
| **Roof sheeting** | IBR roof sheeting, 1m2 | 270 | Iron sheets, galvanised and corrugated | B | kg | 7850 | 981 | 981 | 25 | 2.0 | 1962 | 26.6 | 1.00 | 52189 | |
| | Transparent roof sheeting, 1m2 | 10 | *no information* | | | | | | | | | | | | |
| | Roofing nails, 90mm, 50 pieces | 12 | Nails and wires | B | kg | 7850 | 24 | 24 | 25 | 2.0 | 48 | 20.13 | 1.00 | 966 | |
| **Guttering** | PVC Guttering, 6m | 7 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 35 | 35 | 25 | 2.0 | 70 | 78.6 | 2.17 | 11939 | |
| | Gutter brackets | 30 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 2.0 | 10 | 78.6 | 2.17 | 1706 | |
| | Stop end | 4 | *negligible* | | | | | | | | | | | | |
| | Outlet | 2 | *negligible* | | | | | | | | | | | | |
| **Other** | 75mm cut screws x 125 | 10 | Nails and wires | B | kg | 7850 | 20 | 20 | 30 | 1.7 | 33 | 20.13 | 1.00 | 671 | |
| | Scorch screws, 90x8mm x 125 | 6 | Nails and wires | B | kg | 7850 | 10 | 10 | 30 | 1.7 | 17 | 20.13 | 1.00 | 336 | |
| | Washers | 400 | Nails and wires | B | kg | 7850 | 5 | 5 | 30 | 1.7 | 8 | 20.13 | 1.00 | 168 | |

# Table 6.20: Calculation of the embodied energy of the conventional construction, part 2

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Windows and doors** | | | | | | | | | | | | | | | **136877** |
| **windows** | Winsters Window frame WC2, 1200x1145 | 4 | Holzfensterrahmen U 1.5 W/m²K (Rahmenfläche) | A | m2 | | 6 | 20 | 50 | 1.0 | 6 | 2670 | 2.17 | 34763 | |
| | Winsters Window frame WB1, 1200x595 | 4 | Holzfensterrahmen U 1.5 W/m²K (Rahmenfläche) | A | m2 | | 3 | 16 | 50 | 1.0 | 3 | 2670 | 2.17 | 17382 | |
| | Glazing | 1 | Glas (Flach-) unbeschichtet | A | kg | 2500 | 104 | 104 | 50 | 1.0 | 104 | 15.1 | 2.17 | 3408 | |
| | Pine-shelves (for windows and doors) | | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 194 | 194 | 10 | 5.0 | 970 | 2.21 | 2.17 | 4652 | |
| | Enviro-Touch wood treatment, 5lt | 1 | Envirotouch | E | kg | 1000 | 5 | 5 | 5 | 10.0 | 50 | 20 | 1.00 | 1000 | |
| | Silicone | 2 | Silicon-Fugenmasse | A | kg | 1700 | 1 | 0.6 | 5 | 10.0 | 6 | 61.6 | 2.17 | 802 | |
| **Outside sliding door** | Henderson Track 290, 3m | 1 | Innentüre, Holz | A | m2 | | 4 | 20 | 25 | 2.0 | 8 | 1440 | 2.17 | 24998 | |
| | Henderson Track 290 Brackets | 6 | *included* | | | | | | | | | | | | |
| | Henderson Track 290 Roller | 3 | *included* | | | | | | | | | | | | |
| **Outside/ Inside doors** | Door lock | 10 | *included* | | | | | | | | | | | | |
| | Door handle | 10 | *included* | | | | | | | | | | | | |
| | Door | 10 | Innentüre, Holz | A | m2 | | 15 | 100 | 50 | 1.0 | 15 | 1440 | 2.17 | 46872 | |
| | Door frame | 10 | *included* | | | | | | | | | | | | |
| | Door hinges, set of 2 | 10 | *included* | | | | | | | | | | | | |
| | Enviro-Touch wood treatment, 5 lt | 3 | Envirotouch | E | kg | 1000 | 15 | 15 | 5 | 10.0 | 150 | 20 | 1.00 | 3000 | |
| **Interior walls** | | | | | | | | | | | | | | | **93722** |
| **Posts** | non treated beam 50mm x 76mm, 3m | 75 | Massivholz Fichte / Tanne / Lärche, luftgetrocknet, rauh | A | kg | 540 | 462 | 462 | 30 | 1.7 | 770 | 2.21 | 2.17 | 3693 | |
| | 75mm cut screws x 125 | 4 | *negligible* | | | | | | | | | | | | |
| **Boards** | NuTec Dry walling 3.0m x 1.2m x 4mm | 26 | Faserzementplatte gross | A | kg | 1800 | 674 | 674 | 30 | 1.7 | 1123 | 11.2 | 2.17 | 27301 | |
| | NuTec Dry walling 2.4m x 1.2m x 4mm | 20 | Faserzementplatte gross | A | kg | 1801 | 415 | 415 | 30 | 1.7 | 692 | 11.2 | 2.17 | 16810 | |
| | Paint, 5lt | 6 | Acryl-Dispersion, wasserverdünnbar | A | kg | 1200 | 40 | 40 | 5 | 10.0 | 400 | 52.9 | 2.17 | 45917 | |
| **Electricity** | | | | | | | | | | | | | | | **14498** |
| **Conduiting** | Conduiting, pipe, 4m | 15 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 75 | 75 | 50 | 1.0 | 75 | 78.6 | 2.17 | 12792 | |
| | Conduiting T's | 14 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 50 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| | Conduiting Elbows | 14 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 50 | 1.0 | 5 | 78.6 | 2.17 | 853 | |
| | Light sockets | 22 | *negligible* | | | | | | | | | | | | |
| | Osram light bulbs | 22 | *negligible* | | | | | | | | | | | | |
| | Light wall switches | 11 | *negligible* | | | | | | | | | | | | |
| | Light hanging switches | 4 | *negligible* | | | | | | | | | | | | |
| | Electric cord, meters | 80 | *negligible* | | | | | | | | | | | | |
| **Supply** | Photovoltaic | 1 | *included in use-calculation* | | | | | | | | | | | | |
| | Wind generator | 1 | *included in use-calculation* | | | | | | | | | | | | |
| **Water supply** | | | | | | | | | | | | | | | **177303** |
| **Pipes** | 50mm pipe, 100m | 4 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 120 | 120 | 25 | 2.0 | 240 | 78.6 | 2.17 | 40935 | |
| | 50mm connectors | 10 | *negligible* | | | | | | | | | | | | |
| | 50mm to 15mm polycarp reducer | 2 | *negligible* | | | | | | | | | | | | |
| | 15mm polycarp piping, 50m | 3 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 150 | 150 | 25 | 2.0 | 300 | 78.6 | 2.17 | 51169 | |
| | Plumbing fittings T's | 50 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 2.0 | 10 | 78.6 | 2.17 | 1706 | |
| | Plumbing fittiings Elbows | 70 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 5 | 5 | 25 | 2.0 | 10 | 78.6 | 2.17 | 1706 | |
| **Tanks** | Water tanks, 5000lt | 4 | Water tank, plastic, 5000lt | D | each | | 4 | 400 | 25 | 2.0 | 8 | 8050 | 1.27 | 81788 | |
| **Warm water** | Solar water heater | 1 | *included in use-calculation* | | | | | | | | | | | | |
| **Sewage/ Sanitary** | | | | | | | | | | | | | | | **128791** |
| **Sanitary fittings** | wash hand basin | 9 | Sanitary fittings (wash hand basin) | B | each | | 9 | 0 | 25 | 2.0 | 18 | 2265 | 1.00 | 40770 | |
| | wc | 4 | Sanitary fittings (wc) | B | each | | 4 | 0 | 25 | 2.0 | 8 | 4169 | 1.00 | 33352 | |
| | shower | 4 | Sanitary fittings (shower), *half impact* | B | each | | 2 | 0 | 25 | 2.0 | 4 | 5992 | 1.00 | 23968 | |
| **Sewage** | 150mm pipe, 6m | 6 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 90 | 90 | 25 | 2.0 | 180 | 78.6 | 2.17 | 30701 | |
| | Connectors | 8 | *negligible* | | | | | | | | | | | | |
| | Soak-away | 1 | *reuse of old water tank* | | | | | | | | | | | | |
| **Drainage** | | | | | | | | | | | | | | | **26319** |
| **Trench** | Stone 4m3 | 1 | Kies gebrochen | A | kg | 2000 | 8000 | 8000 | 25 | 2.0 | 16000 | 0.319 | 2.17 | 11076 | |
| **Pipe** | Drainagepipe 110mm, 3m | 13 | Polyvinylchlorid (PVC) Rohr | A | kg | 1380 | 39 | 39 | 25 | 2.0 | 78 | 78.6 | 2.17 | 13304 | |
| | Bend, 45 ° | 2 | *negligible* | | | | | | | | | | | | |
| | Bitumen, pack | 4 | Bitumenbahn V60 | A | kg | 1160 | 10 | 10 | 25 | 2.0 | 20 | 44.7 | 2.17 | 1940 | |
| **TOTAL** | | | | | | | | **214152** | | | | | | **1764479** | |

# 7 Impact assessment

## 7.1 Dimensions buildings

Table 7.1: Dimensions of the buildings, including 2 fictive examples

| | | Accom-modation | Ablution | Total | Alternative 1-storey | Alternative 2-storey |
|---|---|---|---|---|---|---|
| **length** | m | 14.85 | 9.45 | | 21.39 | 10.70 |
| **width** | m | 5.85 | 4.05 | | 5.85 | 5.85 |
| **height** | m | 2.90 | 2.80 | | 2.90 | 5.70 |
| **floor space** | m2 | 86.9 | 38.3 | 125.1 | 125.1 | 125.1 |
| **surface** | m2 | 293.8 | 152.1 | 446.0 | 408.3 | 313.8 |
| **volume** | m3 | 251.9 | 107.2 | 359.1 | 362.9 | 356.7 |
| **surface/volume** | m-1 | 1.17 | 1.42 | 1.24 | 1.13 | 0.88 |
| **difference surface** | | | | | -8% | -30% |

File: dimensions buildings.ods

## 7.2 Comparison of different construction techniques

Three different construction techniques are compared: the Straw Bale building as being built, a conventional design using fired clay bricks and a green design, avoiding most industrial products.

Table 7.2: Alterations for green design

| | |
|---|---|
| No concrete-foundation | - 70'000 MJ |
| No OSB boards as ceiling | - 70'000 MJ |
| No corrugated iron roof sheets | - 25'000 MJ |

Table 7.3: Comparison of three different construction methods

| | **straw bale** | | **conventional** | | **green** | |
|---|---|---|---|---|---|---|
| | [MJ] | | [MJ] | | [MJ] | |
| Foundation | 88174 | | 140379 | | 18174 | |
| Walls | 24541 | | 572896 | | 24541 | |
| Floor | 55853 | | 146341 | | 55853 | |
| Roof | 137658 | | 305202 | | 42658 | |
| Windows and doors | 119651 | | 136877 | | 119651 | |
| Interior walls | 51641 | | 93722 | | 51641 | |
| Electricity | 14498 | | 14498 | | 14498 | |
| Water supply | 88651 | | 177303 | | 88651 | |
| Sewage/ Sanitary | 64396 | | 128791 | | 64396 | |
| Drainage | 13160 | | 26319 | | 13160 | |
| **TOTAL** | **658000** | | **1742000** | | **493000** | |
| | **straw bale** | | **conventional** | | **green** | |
| | [MJ/a] | | [MJ/a] | | [MJ/a] | |
| Foundation | 3527 | | 2808 | | 727 | |
| Walls | 982 | | 11458 | | 982 | |
| Floor | 2234 | | 2927 | | 2234 | |
| Roof | 5506 | | 6104 | | 1706 | |
| Windows and doors | 4786 | | 2738 | | 4786 | |
| Interior walls | 2066 | | 1874 | | 2066 | |
| Electricity | 580 | | 290 | | 580 | |
| Water supply | 3546 | | 3546 | | 3546 | |
| Sewage/ Sanitary | 2576 | | 2576 | | 2576 | |
| Drainage | 526 | | 526 | | 526 | |
| **total per year** | **26320** | | **34840** | | **19720** | |
| **relative difference** | **76%** | | **100%** | | **57%** | |
| | **straw bale** | | **conventional** | | **green** | |
| | [MJ/m2*a] | [%] | [MJ/m2*a] | [%] | [MJ/m2*a] | [%] |
| Foundation | 28 | 13% | 22 | 8% | 6 | 4% |
| Walls | 8 | 4% | 92 | 33% | 8 | 5% |
| Floor | 18 | 8% | 23 | 8% | 18 | 11% |
| Roof | 44 | 21% | 49 | 18% | 14 | 9% |
| Windows and doors | 38 | 18% | 22 | 8% | 38 | 24% |
| Interior walls | 16 | 8% | 15 | 5% | 16 | 10% |
| Electricity | 5 | 2% | 2 | 1% | 5 | 3% |
| Water supply | 28 | 13% | 28 | 10% | 28 | 18% |
| Sewage/ Sanitary | 21 | 10% | 21 | 7% | 21 | 13% |
| Drainage | 4 | 2% | 4 | 2% | 4 | 3% |
| **total per m2 floor space and year** | **210** | **100%** | **278** | **100%** | **158** | **100%** |

File: summary embodied energy.ods

## 7.3 Influence of the transport

Table 7.4: Comparison influence of transport

| | *per year [MJ/a]* | *comparison 1* | *comparison 2* | *comparison 3* |
|---|---|---|---|---|
| construction process, straw bale | 75'440 | 18.0% | | 7.1% |
| construction process, conventional | 83'960 | | 19.7% | |
| operation volunteer accommodation | 10'000 | 2.4% | 2.3% | 0.9% |
| mobility volunteers without plane | 332080 | 79.4% | 78.0% | |
| mobility volunteers including plane | 982'600 | | | 92.0% |
| *sum [MJ/a]* | | 418'000 | 426'000 | 1'068'000 |

File: summary embodied energy.ods