Chapter 1 Introduction

Hypothesis

With regard to practitioners of energy efficient design, Holm (1996) suggests that "It seems to be part of our mental make-up that we keep on believing that there must be a single elixir (Medicine) that will be the answer to all problems." This report hopes to discover if such a remedy does or ever can exist.

1.1 The problem

Until 1970 energy was abundant and inexpensive. During this period building technology is said to have soared. Architects and developers embraced the artificial with regards to thermal comfort and lighting and thus, gradually moved away from the traditional, more energy efficient building.

Slessor (2000) states that "Since the Industrial Revolution, but more particularly in the present century, the twin phenomena of more widely diffused wealth and cheaper energy have resulted in a greater prevalence of energy usage."

Slessor (2000) continues; "Until the oil crisis of the 1970's shocked the developed world out of its apathy, it had seemed unnecessary and irrelevant to make connections between design and energy use, as the cost of making and maintaining buildings was relatively low."

The current crisis regarding global warming, resource depletion, energy availability and rising costs, now dictates an immediate reduction in energy consumption for providing thermal comfort and lighting.

Holm (1996) suggests that "It seems to be part of our mental make-up that we keep on believing that there must be a single elixir (Medicine) that will be the answer to all problems." As a result, after more than 30 years of experimentation and research, few 'successful' examples of energy efficient buildings exist. The danger is that designers and practitioners in the building industry will continue to look to these few examples of energy efficient building and apply the principles blindly with little consideration to context, resulting in inefficient buildings.

1.2 Research Objectives

The author's objective is to highlight the 'basic principles' of energy efficiency with regard to the built environment and to assist the reader in understanding the practical application of these traditional principles in building design. This is done in order to equip the reader with a fundamental understanding of energy efficient principles, so that these may be applied to the BOTEC case study.

The BOTEC building was selected as the case study for this report as it is well known as a 'successful' energy efficient building. Interestingly, the BOTEC building was built as an example and living exhibit for building practitioners to study with regard to alternate design.

Marland (2001), previously Principal Architect, (BOTEC), Gaborone, Botswana is quoted as saying, "From the outset, it was decided that the new headquarters (BOTEC) would be, technologically speaking, a landmark building for the Southern Africa region and would demonstrate a range of technologies beyond the current conventional passive solar design… Apart from being an energy efficient building, it will also serve as a practical demonstration for researchers, developers, designers, etcetera, of appropriate technologies for achieving thermal comfort in buildings in Botswana's hot-dry climate."

The objective, therefore, is to investigate whether the BOTEC building is performing to expectations and if indeed, the principles used at the BOTEC building do result in and can be used as the "elixir that will be the answer to all problems" with regards to energy efficient design.

1.3 Scope of Study

The author acknowledges that the subject of energy efficiency is vast and may include; life cycle costing of buildings and materials, embodied energy of buildings and materials, energy audits, labour, vertical transport, horizontal transport, recycling and much more.

As an example, the typical embodied energy of some building materials have been listed in the table below in order to demonstrate the remarkable differences in embodied energy and the possibility of saving energy when specifying recycled materials.

Table 1 Energy content of building material

Material		**KJ/kG or MJ/ton**
Metal	Steel	20
	Steel, recycled	3,6-55 (82,5% Saving)
	Aluminium by hydro electricity	75
	Aluminium by coal fired power	167
	Aluminium, recycled	4,7 (97,2% saving)
	Lead	31
	Copper	40
	Zinc	46-52
Plastics	Polythene	137,5
	Polypropylene	144,5
	Polyvinyl chloride (PVC)	102,6
	Polystyrene	45,2
Other	Cement	13,1
	Glass, sheet, bottles	14-18
	Glass, technical ware	54
	Glass, hand made	80
	Porcelain	80
	Glazed earthenware	40
	Tiles	4
	Clay brick	1-6 say 3,5

A more detailed list has been compiled and can be found in the appendix.

The table above allows the reader to see easily the importance of embodied energy audits and life cycle costing.

However, due to time constraints, the scope of this analysis has been confined to the principles of energy efficient design which affect heat gain and heat loss in a building. If these principles are understood and implemented correctly, energy wastage will be drastically reduced. Therefore, the principles dealt with include; building orientation, building envelope design, insulation, lighting and HVAC.

1.4 Resource Depletion

"A detailed timetable of destruction and distress that global warming is likely to cause the world was unveiled …and Southern Africa is going to be hit hard unless urgent action is taken to reverse the effects of a worldwide disaster that scientists have been warning about for decades" (Hooper-Box, 2005).

"The Kruger National Park alone is projected to lose two-thirds of its animals 65 years from now. Global warming will also stir outbreaks of infectious disease, wipe out animal and plant species, deplete water and food stores and by 2050, generate an army of 150 million 'environmental refugees' fleeing the increasingly uninhabitable regions of the world" (Hooper-Box, 2005).

Rosenthal (2005) adds that "the biggest study yet carried out from Oxford University, reported that climate change could prove to be twice as catastrophic as the worst predictions of the intergovernmental panel on climate change…we could reach the point of no return in 10 years."

Rosenthal (2005) explains that the world would have to reduce CO2 emissions by 50% by 2050. Rich countries would have to cut theirs by 30% by 2020. ..The good news is it can be done with established technology, by cutting energy waste, and expanding the use of renewable sources..."

"Despite differences in definitions, perspectives and priorities, sustainability remains a critical challenge. For the developed world, the predicament is how to maintain reasonable consumption and living standards while reducing greenhouse gas emissions. For emerging nations, the problem is how to meet basic need, transcend conditions of marginality, and improve levels of economic sustenance without generating the damaging pollution prevalent in industrial societies. The consequences of complacency will fuel the future degradation of our ecosystem and an environmental apocalypse capable of matching the direst medieval imaginings"(Slessor, 2000).

The 1992 Earth Summit in Rio de Janeiro, reiterated that we are using the planet's resources in such a fashion that we are beginning to exceed the earth's long-term capacity to sustain itself, thus rendering 'life' unsustainable.

According to the 'Perspectives for Germany' document published for the World Summit on Sustainability 2002, held in South Africa, crude oil shows a low level of reserves, expected to last only 42 years, natural gas only 65 years and coal reserves only 170 years. Even supplies of uranium are expected to last for just 50 years.

Interestingly, during the 1992 Earth Summit in Rio de Janeiro, the building industry was highlighted as 'the major contributor' to resource depletion due to massive amounts of water and energy required in common building technology and building climate control.

According to Holm (1996), "buildings constitute at least 20 percent of South Africa's national energy consumption"

It can thus be deduced that buildings "currently constitute the single largest energy-consuming human creation, with the simple consequence that the sustainability of the built environment has a major impact on the global ecosystem" (Slessor, 2000).

The CIB Report Publication 237, Agenda 21 on sustainable construction concurs; "Although the figure differs from country to country, buildings use about 30% of total energy directly…if indirect use is included the proportion is closer to 50% "

1.5 Sustainability

Addressing the goal of sustainability means developing more responsive ways of 'managing shelter, infrastructure and built spaces'. The model for this development i.e., sustainable development, became known in 1987 when the World Commission on Environment and Development (The Brundtland Commission) presented its report titled, 'Our Common Future'.

Sustainable development became defined as, "a form of development which meets the needs of the generation of today without jeopardising the chance for future generations to meet their own needs" (Brundtland Commission, 1987).

The basic premise of the model for sustainable development is to provide a link between the needs of today's generations with the unforeseen needs of future generations and, via a form of contract between the generations, long-term development must be designed in a manner which is fair to both parties.

Further, at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, the international community of states announced the ‘model of sustainable development’ and ‘a global program of action for the 21st Century’ under Agenda 21. These called upon signatory states to create strategies targeted at development that are ‘economically competitive’, ‘socially fair’ and ‘ecologically sustainable’.

1.6 Energy Efficient Design

“Looking at the global economy today, one has to be increasingly aware of energy as a scarce resource; the need for architects to design for a sustainable future becomes a self-evident imperative” (Yeang, 2004).

According to Yeang (2004), “design is only part of a greater gestalt in environmental design. Regarded independently, there are essentially three routes to low energy consumption in architecture: through material and component selection; through supplier economics (i.e. a life-cycle approach from 'source' to 'sink'); or through basic design.”

“Many environmental problems result directly or indirectly from inefficient use of resources, particularly energy (bio-climatic principles). Careful design of the building envelope, lighting systems, and heating, ventilation, and air-conditioning (HVAC) systems are important, as all of these elements affect the energy use of the building” (Rocky mountain institute 1998).

The most effective building designs with respect to energy efficiency emerge through careful attention to the following elements; (Green Development, 1998).

1. Design to fit the site. (Orientation)
2. Design for resource efficiency. (Control heat gain and heat loss)
3. Design for a healthy indoor (and outdoor) environment.
4. Design for adaptability.
5. Design for durability and easy maintenance.

Chapter 2.0 Literature Analysis of Energy Efficient Building Principles

2.1. Historical Overview of Climatic Building Design.

"Until a few hundred years ago the relationship between human beings and their environment was characterized by their willingness to adapt to the environment and to live in harmony with it" (Daniels, 1997).

Most researchers are in agreement with Daniels (1997) with regard to the extent and complexity of skills, measures and elements used to obtain energy efficiency. "The measures employed in ecological building are complex and derive from several specialised disciplines – from urban planning, architecture, construction, and façade design to active technical building services and their applications. Planted surfaces, indoor and outdoor, fresh air, soil, water, and rainwater all contribute to an integrated design, as does the management of building services and utilities that use the abundant resource of the environment"

Holm (1996), however, suggests that many of the aforementioned applications and elements are used carelessly and therefore often have the adverse effect of rendering a building unsustainable or inefficient.

Population growth through the years has played the major role in rendering the earth and its resources unsustainable. "Small populations (in the past) and modest requirements for energy utilization meant low emissions, mainly related to combustion processes (open fires). The waste products of past centuries were readily recyclable and bio-degradable and posed no threat to the environment. All waste could be returned to the natural cycle." (Daniels, 1997).

2.1.1 Building Envelope

Small windows characterised buildings in the past, demonstrating “building masses with high storage capacities, and low standards for heating and sanitary systems…The small window units allowed little daylight to penetrate into rooms…Small windows also resulted in minimal heat gains from the outside to the inside and therefore also in minimal cooling loads….Compensating for thermal loads never presented itself” (Daniels, 1997).

Daniels (1997) explains that in winter, the small window did not allow for significant heat losses “and the heating requirements for rooms in these buildings were generally no higher than they are in modern, well-insulated buildings.”

The ‘thermal storage masses’ of older buildings were large in proportion to the square meterage – (high storage capacity is the current term) and were usually constructed of unfinished thick, natural stone walls, so that thermal energy coming from the outside or released in the room was almost completely absorbed by the building mass.

Figure 1 Thermal massing Author: 2004

“ Due to the minimal loads and the high storage capacity such buildings remained cool even on hot summer days and tended to be uncomfortably cold in winter…unacceptable to modern comfort requirements” (Daniels, 1997).

Holm (1996) agrees and explains that lots of mass reduces the temperature range towards the average temperature which may be either too high or to low for comfort. The designer should therefore be aware that thermal massing is not always desirable. Thermal mass may be useful in hot dry climates such as Botswana, but not in hot humid areas. Therefore mass must be considered together with night cooling or solar heating.

"As the use of building materials continued to evolve together with demands for comfort and better hygiene, the form of buildings changed; they became more open" (Daniels, 1997).

2.1.2 Temperature control, Lighting and Ventilation

The Glucksberg, a castle with a moat, displays a much larger window, allowing more daylight to penetrate the room, improving lighting conditions and ventilation. At the same time, thermal gains from the outside increased in summer as did heat losses in winter. Nonetheless, high storage buildings were still constructed of massed local stone thus the "greater heat gains in summer did not create over-heated rooms but merely improved the comfort level" (Daniels, 1997).

Figure 2 The Glucksberg Castle Daniels: 1997

Replacing open fires, heating shafts were introduced in order to heat individual rooms more efficiently in multistorey buildings during the cold winter months. Thus the first forms of climate control occurred. "Tile stoves came into use between the 15th and 18th centuries; they could heat not only one, but several rooms through shafts. This system improved comfort overall and satisfied the increased heat requirements created by the larger windows" (Daniels, 1997).

The moat around the castle Glucksburg was created for safety reasons. However, the moat held secondary benefits to the inhabitants of the building. Light conditions within the building were improved as the water reflected additional light towards the windows. Most Practitioners agree that water is also a powerful thermal control element. Thus general comfort was improved. Through evaporation occurring at the waters surface, the surrounding air is cooled in summer, and "at night, the water mass cools less slowly than the surrounding air, improving the climate near the building" (Daniels, 1997).

Holm disagrees with Daniels with regard to water as a cooling device. Holm (1996) suggests that context must be taken into account as solar reflection from nearby buildings, roads and water sources can have a serious effect on the heating of a building.

A fundamental mistake with regard to the practical application of energy efficient design principles is, according to Holm (1996), the fact that most designers dismiss diffuse solar radiation with regards to heat gain. Holm (1996) explains that a significant amount of solar radiation is diffuse. Commonly, designers assume that solar radiation consists of direct rays only. Holm (1996) suggests that "For example, the average diffuse radiation is near half the total solar radiation (46%) in Durban."

Holm (1996) continues; "If the radiation reflected from the ground, (water) and neighboring buildings is added to the average diffuse radiation, the total diffuse radiation easily surpasses the direct component during a period of maximum negative impact.

In hot desert climates, the tendency was to locate living spaces beneath ground level to take advantage of the insulating properties of sand and stone as well as to "utilize the coolness of the earth and to create ventilation through buoyancy, thus improving thermal comfort" (Daniels, 1997).

At the beginning of the 19th century, the dawn of the Industrial age, rapid advances in technology increased the demands for energy created at this time through the burning of coals and natural gas. "The sharp increase in emissions was generally ignored and no effort undertaken to act against the environmental threat posed by dust soot and other polluting materials" (Daniels, 1997).

In addition, with an increase in industrial activity, the dumping of untreated waste water on a larger scale, into rivers and lakes, created devastating effects on the natural environment. This phenomenon has not slowed. On the contrary, rivers and lakes are still used as industrial dumping grounds and only recently with the introduction of Agenda 21 and similar models, governments around the world are keeping a close eye on global industry and multinationals.

2.1.3 High rise and air conditioning

The 20th Century saw continued advancement in technology and industry as well as continued concentration of labour migrating to the cities. Maximisation of available space inevitably became the order of the day. However, to do this, Daniels (1997) explains, "architects abandoned the previous standards of natural ventilation and building services switched to fully automated climate control…Skyscrapers built in Manhattan approximately 30 years ago (late 1960's) have hermetically sealed facades, incapable of responding to environmental influences such as wind, smog, external temperatures, and humidity. "

Daniels suggests that 'with all the competition to build as high as possible and the preoccupation with 'up', architects and developers neglected the 'around'; and ignored context and climate.'

Some researchers are of the opinion that it was not so much that practitioners ignored the context, but rather that they did not know how to deal with it. According to Yeang, (2004) the greater the height of the building the greater the wind velocities, creating substantial pressure and suction forces on the facades of tall buildings. The problem of ventilating the building became an issue with the problems caused due to wind pressures.

The occurrence of air conditioning systems solved the problem of ventilating tall buildings. Air conditioners advanced to include a refrigeration cycle that cooled and dehumidified the air without even opening a window. The beginning of all year round, fully automated climate control caused the use of energy to increase dramatically, resulting in an energy crisis.

According to Daniels (1997), the 'energy crisis', beginning in 1973, brought with it a search for simpler solutions with regard to climate control…, giving rise to a new wave of thought focused on ecological building design". (Daniels, 1997)

Some of these systems were;

1. the opening up of facades for natural ventilation, (openable windows)
2. the creation of climate buffer zones (halls, atria and balconies)
3. improved heat insulation and protection (shading and massing),
4. the implementation of energy recovery systems

"In architectural terms, this has engendered a re-opening of the inside-outside relationships in buildings, with both physical and experiential consequences. Devices such as solar shading, screens, balconies, brise-soleil, and shutters add layering and complexity to the external envelope. Many buildings now display different degrees of enclosure, which may be inhabited more flexibly, with potential to respond to changes in the external environment" (Slessor, 2000).

2.1.4 Common Oversights

Holm (1996) warns against using the aforementioned systems blindly and suggests some common oversights in response to Daniels, suggested, ecological building design systems.

1. Ventilation is commonly understood as a cooling device. This is not always the case. According to Holm (1996), the fact is that radiation is not influenced by ventilation. Radiation is absorbed by an object; its temperature rises and it emits radiation and warms the adjacent air. The warmed air can be removed by ventilation and even the objects can be cooled off.

   Ventilation has a cooling effect only if the air is cooler than the heated body temperature. Ventilation will have a heating effect if the air temperature is higher than the body temperature. Therefore, designing large windows for the purpose of being opened up on a hot summer afternoon for the sake of the 'cooling effect' of the (hot) wind clearly defeats the purpose.

   "Vancouver Engineer Geoff McDonnell of Omicron Consulting states that natural ventilation can be a good thing or a bad thing depending on where you're applying the natural ventilation. I find a lot of people tend to use natural ventilation as a panacea (magic potion) without looking at the building in context. You don't do natural ventilation in a downtown. It can be dirty and smelly with high CO2 levels. I think it's worth looking at but it's not a panacea" (Betterbricks, 2005).

The suggestion that north windows should always be large is also not always true. Large north windows do provide desirable winter day time heating, but they are also sources of massive heat loss during winter nights if they are not double glazed. During hot summer days they cause overheating if not shaded correctly. If these windows are double glazed the heat build up in summer will be excessive if insufficient ventilation is provided.

2 In high rise buildings, designers may be easily tempted to communicate their energy conscious buildings with the use of solar features like conservatories, glazed multi storey atrium spaces and photo voltaic panels. According to Holm (1996), “Conservatories (if designed in isolation) generally lose heat, and are therefore energy losers. Glazed multi storey atriums are spectacular but of very doubtful merit in hot climates”.

3. In a west facing room with inadequate ventilation, the addition of roof insulation will actually worsen the interior climate in summer. According to Holm (1996), the addition of insulation without attention to thermal mass and ventilation will worsen indoor conditions and result in additional expense. Also, insulation placed on the interior face of walls ceilings or floors destroys the mass effect and should thus be avoided.

One must be aware of relying on previous assumptions especially when dealing with orientation. As a general rule, architects would argue that the south elevation requires no sun shading at all. According to Holm (1996) the south elevation of a building in Pretoria receives more radiation during a typical summer day than the north elevation. A large percentage of radiation is diffuse, rendering window overhangs almost ineffective, if they have been introduced at all.

For example, “a shading device placed at window head level will render the top portion of the window an energy loser in winter because it is shaded during the period of maximum winter shine. A better strategy is place the shading device outside the maximum winter noon angle” (Holm, 1996).

It is therefore important to consider the combined effects caused by orientation, shading, internal mass, insulation and ventilation on a structure. In addition, a designer must, as a point of rule, check the solar angles of each specific site and record the changing angles throughout the day.

4. According to Holm (1996), “the use of PV (photovoltaic) panels orientated in all directions for façade cladding may make a solar statement, but this represents a sub-optimal design. On the other hand the proper integration of PV Panels with due care to detailing can reduce the total cost by up to 30%.”

2.2 Contemporary Design for Energy Efficiency Buildings

“The climate…presents a challenge to the Architect not satisfied with substituting mechanical equipment for good design” Cowan (Architectural Science Review).

Biederman (1974) states that “The crisis or shortage has served to make the buying public as well as the builder acutely aware that we can no longer afford two ton automobiles that achieve eight miles to the gallon or houses that disregard heat gain and loss…With today’s technology utilizing proven methods, we have the capability of reducing fuel usage in a house by as much as 40%”

The following table was compiled by the U.S Department of Commerce and indicates how energy is consumed in residential and commercial buildings 'by type of use'; (Centre for Building Technology ,1973)

Table 2 Energy Consumption

Space heating	53%
Water heating	12%
Air Conditioning	8%
Refrigeration	7%
Lighting	5%
Other electrical	5%
Cooking	4%
Clothes drying	1%
Miscellaneous	5%
TOTAL	**100%**

This table clearly demonstrates that the greatest proportion of energy consumed in buildings is in heating and cooling the climate. The U.S. Centre for building technology estimates that" on a national scale 30-50% of this is wasted because known 'energy saving' technology is not applied" (Centre for Building Technology ,1973).

The above suggests that over 60% of the total energy utilized in a building is for climate control. It is thus easy to see the importance of designing for maximum energy efficiency in this respect. Passive means must be used in place of mechanical systems.

2.2.1 Economics of energy efficient design

Acceptable indoor climatic conditions within the building can be achieved in one of two ways. Firstly, the building is constructed without any consideration for energy conservation; later mechanical and electrical engineers are appointed to fit air conditioning and lighting systems into the building. Secondly, the design professionals can unite and design, from inception, a building that takes maximum advantage of natural surroundings and climate, thereby drastically reducing the need for substantial artificial climate control and lighting systems.

By bringing together as many elements as possible of environmental design from the onset of a project, a more holistic and systemic result will form, incorporating environment, comfort and economy. “Using energy, water and materials efficiently is one of the most important strategies for creating an environmentally responsible building. It also makes the building more affordable to own and operate”(Green Development, 1998).

Despite overwhelming proof that energy efficient design is more economical, developers tend to struggle with the notion that by spending a little more on energy efficient systems upfront, one can save dramatically over the life cycle of the building, outweighing any additional investment.

At the AIA / Vermont Roundtable on Building Energy Alternatives discussion (2001), it was concluded that the key impediments to including energy efficient building design and alternate energy sources are;

- The perceived or actual upfront cost of designing buildings with other than traditional systems. (High initial cost premiums)

- It is often difficult to obtain finance for the additional upfront capital required for new energy efficient building projects.
- Most developers are looking for a Rate of ROI over 36months. It is difficult to show a return on the energy saved in such a short period of time.
- Engineers and Architects are reluctant to propose these systems knowing that their fees will not cover the costs of the additional work and detailing required for the inclusion of these systems.
- Engineers and Architects are reluctant to propose these systems knowing that if the project comes in over budget, the alternate systems are usually the first to go.
- Engineers and Architects are reluctant to propose these systems due to the possibility that new or alternate systems may not work as planned resulting in a legal claim, thus increasing their risk. (Perceived risk)
- Lack of current technology understanding by developers, owners, architects, engineers and contractors. (Limited pool of experienced practitioners)

Outweighing the aforementioned impediments, it has been shown that “If heating and cooling loads are kept low through careful envelope design, glazing selection, and lighting design, heating and cooling equipment can be significantly downsized or, in some cases, even eliminated. This can make the building cheaper to build or, at a minimum, offset any price increases that the additional energy-saving equipment may impose”(Green Development, 1998).

Holm (1996) provides an example of a life cycle costing reflecting this kind of saving as demonstrated in the table below.

Table 3 – Cost comparison of home with/without insulated ceiling.

	House without insulated ceiling	**House with insulated ceiling**
Period of analysis	20 & 60 Years	20 & 60 years
Initial cost	0	R2 500
Salvage value	Not separated from house after insulation	
Maintenance cost	0	0
Replacement	Not Necessary	
Base year energy	R1 120	R1 000
Present value of all Future energy costs (20 years)	R36 900	R32 950
Life cycle costs (20 years)	R36 900	R35 450
Life cycle costs (60 years)	R345 100	R310 600
If a conventional house without a ceiling is compared with an insulated ceiling, it may cost R2 500 to save R37 000 over 60 years.		

It was suggested by most of the participants at the AIAVT roundtable discussion (2001) that possibly the best way of promoting initiative with respect to energy efficient design is to raise the price of energy.

Developer Harold Kalke believes that energy prices are already headed for significant further increases, and he plans for that possibility through careful designs. Kalke, states; "Anything we can do to make our commercial tenants and residential buyers more equipped to deal with that increase in the future, we should do it.'" Kalke rightly adds that in addition to the economic benefits of careful design, reductions in energy use significantly benefit the environment by reducing pollution generation (Green Development, 1998).

Dimsky (2005) of 'Home Work' suggests that the additional upfront costs of alternate energy is not an issue. Dimsky suggests " The most important reason for energy efficient building is because more than ever before it can be done for nearly the same cost as the homes now being constructed."

Indeed, with crude oil prices increasing from R46.00 per barrel to over R60.00 per barrel this year, (2005) in the space of only 3 months, it seems as though the economy is creating the required incentive needed for energy efficient design to flourish.

2.2.2 Building Envelope Design.

A building is a climate moderator with the fundamental role of modifying the external environment through its building envelope, and creating a hospitable climate for human dwelling. The measure of degree of control of the indoor thermal climate is known as the thermal performance of the building.

The building envelope is often described as the skin of the building as it is this layer that is in direct contact with the environment. As skin protects and regulates the temperature of a living being, the building envelope needs to perform a similar function.

Many designers support the opinion that energy efficient systems can easily be added to a building after construction, similarly to how air-conditioning is added.

On the contrary, it has been proven that it is substantially more expensive to add alternate energy systems to buildings after construction. So much so that it becomes prohibitive in most cases (AIAVT Roundtable discussion 2001).

Envelope design needs to be well thought out from the inception of the building design. “Getting the building envelope right the first time is particularly important, because future modifications will be difficult, expensive and environmentally costly”(Green Development, 1998).

It therefore becomes important to consider building envelope design systematically and holistically, in conjunction with all the other elements of energy efficient design and resource management.

In cool climates, indoor temperatures are maintained significantly higher than outdoor temperatures. Here, heat gains and losses through the building envelope elements can be determined by the general resistance to the flow of heat through these elements. As an example, the colour and texture of a wall surface can affect the wall’s thermal resistance as well as its insulation and heat storage capacities.

In areas of large diurnal temperature ranges and intense solar radiation, thermal massing is required. Thus materials with good heat storage capacity are desirable.

Cooler climates or even warm humid climates with low diurnal temperature ranges may require light weight materials with a high resistance to heat transfer.

Yeang (2004) suggests that “external walls should be regarded as permeable, ‘environmentally interactive membranes’ with adjustable openings (rather than as a sealed skin). In temperate climates the external wall has to serve very cold winters and hot summers. In this case, the external wall should be filter-like, with variable parts that provide good insulation but are openable in warm periods. In the tropics the external wall should have moveable parts that control and enable good cross-ventilation for internal comfort, provide solar protection, regulate wind-driven rain, besides facilitating rapid discharge of heavy rainfall"

If the building membrane does not serve the aforementioned functions effectively, active energy intensive systems have to be introduced to moderate the interior climate.

It therefore stands to reason that the "envelope decisions will likely determine the energy consumption of the building for decades to come…"(Green Development, 1998).

2.3 Factors Determining Thermal Response

For that reason, the main factors determining the thermal response of a building regarding envelope design are; according to Welsh, (1986);

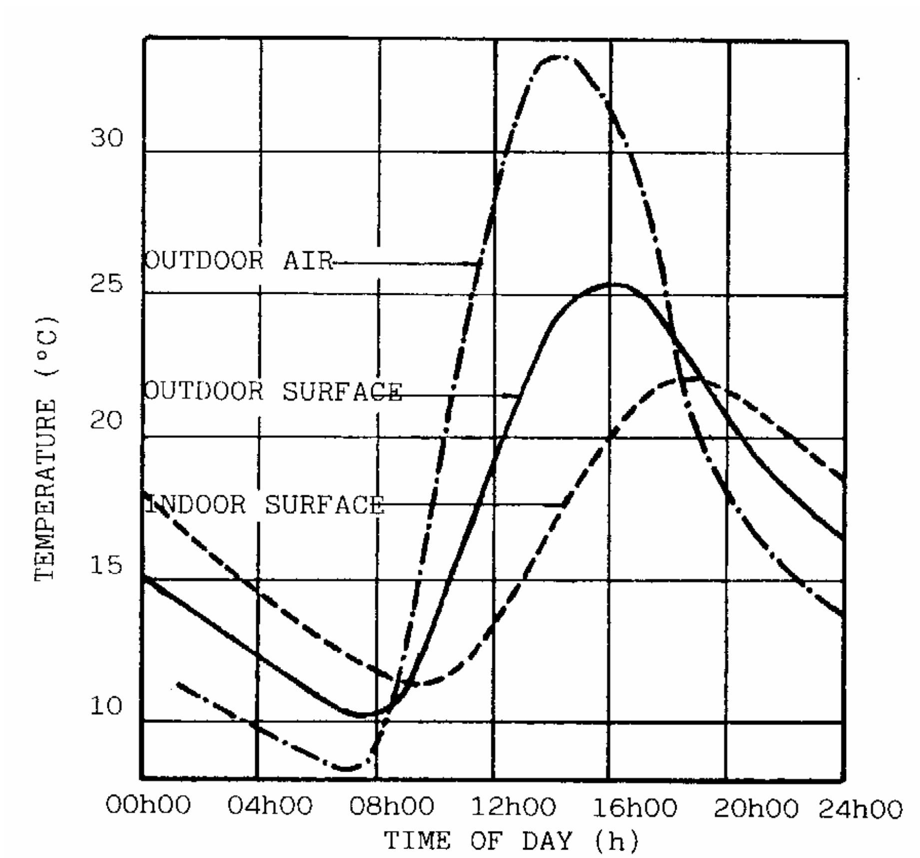
1. "the heat storing capacity or mass of the structure as a whole;
2. the thermal insulating properties of the shell, viz façade and roof;
3. solar heat gains, both direct and indirect; (orientation)
4. The ventilation rate
5. Heat gains from internal sources. (lights, people, computers…)"

2.3.1 Heat Storage and Insulation

Mass determines the ability of a material to store heat energy. The greater the mass of a building façade, the more heat will be required to warm up the entire element. As a result, the greater the mass, the less heat will be transferred to the air on the other side of the material.

In areas with high diurnal temperature ranges, during the day time, heat energy can be stored in the structural mass for a period long enough to raise the temperature of the indoor air at night. As a result, the interior temperature range can be moderated to some extent. 'During the hot day, internal spaces are kept cool by the mass which acts as an effective insulator.

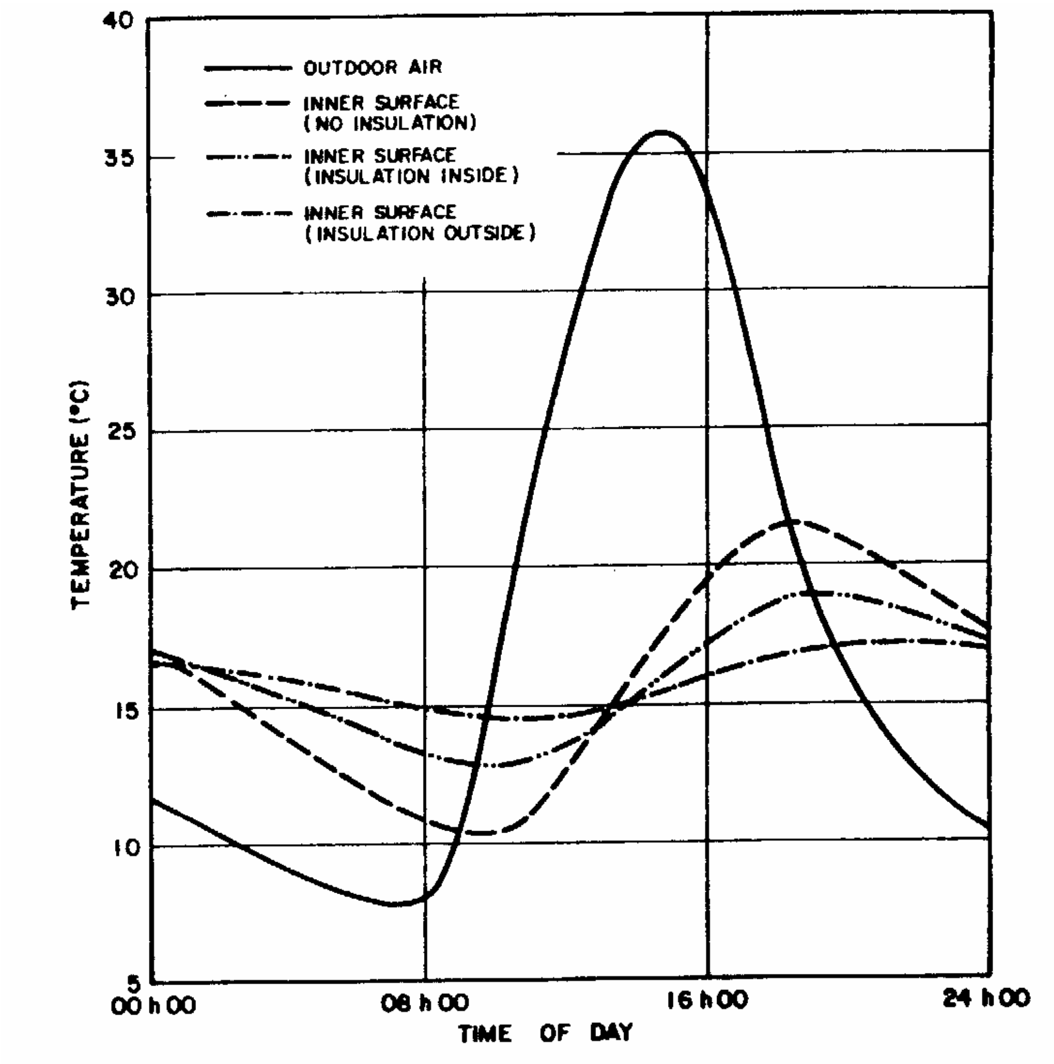
Welsh (1986) insists that "attention should be paid to the absorption and emission properties of surfaces; these properties are determined by colour and texture. A black painted steel surface absorbs about 90% of normally incident solar radiation, while the same material painted white absorbs only 30%. (approximately 26°C hotter)"



Graph A

Source: (Welsh, 1986)

"In an insulated wall of high mass, the position of the insulation relative to the mass, has a marked influence on the heating and cooling of the building interior…When additional insulation of massive structures is considered necessary for improving thermal performance, the insulation should be applied to the exterior or in such a position that the mass is not insulated from the interior" (Welsh 1986).



Graph B Source: (Welsh, 1986)

Yeang (2004) suggests that "a water-spray system on hot facades promotes evaporation and therefore cooling. In temperate climates, solar windows or a 'solar-collector wall' can be located on the outer face of the building to collect the sun's heat"

Opportunities exist to use solar-collector walls as energy generators with the aid of photovoltaic panels.

Clearly, the thermal insulating properties of the entire envelope need to be considered including the roof. Any thermal advantage gained by the heavy exterior walls can quickly be counterbalanced by the heat gain or loss radiating through the roof.

2.3.2. Heat Gain and Orientation

Solar heat gains can occur either directly or indirectly and can have a significant influence on the thermal performance of a building. In cold climates, solar heating can be advantageous. In warm climates direct sun penetration should be kept to a minimum.

“During summer the north wall should be protected by shading devices and it is an advantage in orientating the major facades of the building to the north, or at least within 20° of north” (Welsh 1986).

Yeang (2004) concurs, stating that; “the overall building orientation has an important bearing on energy conservation. In general, arranging the building with its main and broader openings facing north and south gives the greatest advantages in reducing insolation.”

Therefore, window openings should generally face the direction of least insolation (north and south in the tropics), leaving the east and west facades exposed to direct radiation. For this reason, window openings or apertures on the east and west façades should be kept to a minimum. Where windows occur on these facades some form of solar shading is required. In temperate zones, transitional spaces can have adjustable glazing at the outer face so that balconies or recesses can act as 'sun spaces', collecting solar heat, like a greenhouse.

Corners of the building must not be ignored and may need to be treated with ‘corner-shading adjustments’.

“Solar shading is absolutely essential for all glazed facades, orientated towards the sun (east and west). Numerous configurations and systems of passive devices can be used such as; fins, spandrels, egg-crates, etc. The angle and type of device depends on facade orientation and solar path angle” (Yeang, 2004).

2.3.3 Ventilation

‘Cross ventilation’ is essential for the process of air exhaustion. Cross ventilation promotes the suctioning of fresh air into the building and the exhausting of hot air.

For buildings to function passively, without mechanical air conditioning systems, sufficient ventilation must be provided for the removal of heat gains within the building. This must be achieved with the least possible rise in indoor air temperature.

In contrast, at night, where outdoor temperatures drop well below the indoor air temperature, the cooler exterior air flow can be used to cool the thermal mass structure, which in turn, warms the air entering the building, thereby regulating the interior air temperature.

In winter, ventilation should generally be kept to a minimum. Even air filtering into a building through cracks and under doors can affect the level of comfort in the building and thus influence the heating requirements. Most text recommends that all openings be weather stripped and sealed and that the building is only ventilated during the warmer mid afternoon.

Transitional spaces (atria and passageways) can be compared to the verandah spaces (stoeps) of old, which clung to the exterior walls of houses. These spaces were covered open spaces which allowed air to move through the space, cooling the air while simultaneously shading the walls of the structure below.

In tropical and temperate areas, the ground floor should preferably be open to the outside and naturally ventilated. Cooler air can thus be suctioned into the building at the ground level, used throughout the building for cooling, and expelled higher up.

2.3.4 Heat gain due to lighting

"Twenty-five percent of the electricity consumed in the United States is for lighting. The air–conditioning required to take away the heat produced by inefficient electric lighting can amount to 3 to 5 percent of the total energy use. In homes, incandescent lighting prevails, despite the fact that roughly 90 percent of energy used in the bulb is directly converted into heat and only 10 percent into light" (Green Development, 1998).

Therefore not only is incandescent lighting an inefficient form of lighting but also generates a massive amount of heat gain that requires other energy intensive systems, such as air conditioning, to remove it. "Mechanical engineer, Toon Herman's survey of Johannesburg buildings, indicates that an alarming 43% of total energy used in a building can be attributed to lighting alone."

Table 4 Lighting analysis Source: (Welsh, 1986)

Building Name	**Lights in lettable area kwh/m² pa**	**Lights in service area kwh/m² pa**	**Total energy consumption Kwh/m² pa**	**%**
Life Centre JHB	97.6	54	242.4	**42.5 %**
Killarney JHB	152.5	21.7	410.8	**42.2 %**
Total House JHB	118.7	13	304.6	**43.2 %**

Heat gain caused by lighting can be varied by using more efficient lighting systems, as well as by implementing 'task lighting' instead of the typical uniform lighting. Task lighting is essentially placing the light where you need it such as above a desk. This light can be turned on and off manually when required.

By designing with energy efficiency in mind, natural day-lighting can be utilised to provide most of the required ambient lighting, along with most of the light required for office use.

Passive elements such as light shelves, reflective ceilings and walls help direct daylight deep into a building. "By coupling day-lighting with dimmable fluorescent lighting controlled by photocells, the lighting controls can be automated." (Green Development, 1998)

All text concurs that the reduction in lighting levels drastically reduces the internal heat gain, as well as saves electricity.

2.3.5 Air Conditioning

"Optimum comfort control can be achieved in two ways. The first is by using a properly designed building envelope to eliminate high heat gains and losses, hot and cold radiation, rapid temperature changes, draughts and infiltration. In a number of modern buildings the air conditioning system has to perform a corrective function because, for various reasons, the architect has ignored the functions of the building envelope. Secondly, control can be achieved by using the air conditioning system to deal with the function of final comfort trimming only. " (Building design for energy economy, 2001)

Therefore, if the architect is able to reduce heat gain in the building, the cooling load is reduced, allowing for a smaller air conditioning system, which accordingly decreases maintenance, installation, capital and energy costs.

“If the building envelope is not completely resolved and maximally efficient, any comfort control element added to the system cannot be used efficiently and may even be rendered ineffectual”. (Building design for energy economy, 2001)

Use of excess air conditioning units has an additional drawback. Typically air conditioners release Co2 into the environment. A reduction in the use of air conditioning translates to a direct reduction of Co2 emissions.

In an assignment carried out by the author at Wits University in 1999, communications were held with management at the Mega Watt Park Building complex. Management stated that the Mega Watt Park Buildings, underwent upgrades which consisted of upgrades to air-conditioning systems as well as lighting systems, building management systems and systems relating to sulphur dioxide, nitric oxide and carbon dioxide emissions. ‘The air-conditioning system was upgraded by installing variable speed drives (VSD) to all the supply fans of the air handling units. The reduction of Carbon dioxide emissions related to the upgrade was said to be equivalent to the ‘removal of 7000 vehicles from South Africa’s Vehicle stock’. ‘

In order to assist in reducing heat gain, and thus cooling load, windows should be protected from the sun and their size reduced. In cool climates heating loss can be reduced by double glazing the windows.

Where possible, walls should be insulated externally, exposing the internal mass which acts as a moderator of diurnal temperature. If insulation is not used, the fluctuations in internal temperature will demand rapid artificial heating and cooling which will result in a large HVAC plant.

2.3.6 Energy Efficient Design Elements

The design elements of energy efficient buildings can therefore be listed as follows;

1. **Heat gain reductions (summer)**

- Orientation
- External screening and shading
- Reflective glass and cladding
- Internal shading devices
- Heavy external walls / roof (Thermal Mass)
- Internal mass
- Material colours (reflective/absorptive)
- Insulation
- Ventilation

2. **Heat loss reduction (winter)**

- Orientation
- Heavy walls / roof (Thermal Mass)
- Double glazing
- Material colours (reflective/absorptive)
- Insulation
- Weather stripping

3. **Ventilation**

- Orientation
- Buoyancy
- Window size
- Openable windows
- Wind scoops
- Internal atria

4. **Lighting**

- Natural lighting
- Shading
- Light shelves
- Task lighting
- Reflective materials and colours
- Low voltage

5. **Air Conditioning**

- The air conditioning requirements are affected by all of the aforementioned elements as air conditioning is a corrective measure used when these elements have not been.

2.4 Literature Model

The table below lists the energy efficient design principles as stipulated in the mainstream literature on the subject. The principles have been extracted from the literature research undertaken and have been compiled into a table in order to facilitate the testing of these principles against the principles used in the case study which follows.

Table 5 Literature Model

Heat gain reductions (summer)	
Orientation	
Building must face North - South (within 20º of North)	Openings on East & west facades must be minimised
	Solar shading and massing is required on the East and West façade
Solar path angle must be considered	Building must be designed to specific solar path
Building Envelope	
External shading of walls (Solar shading, balconies,)	Assists thermal mass in cooling function (insulation)
	North wall and windows to be protected with shading devices
External Screening of windows	Less direct solar radiation
(brise-soleil, shutters, fins, spandrels, egg-crates)	
Planting	Interior and Exterior Shading device & improves environment
Smaller window openings on exposed facades	Less direct solar radiation
Walls: Building Mass	Stores Heat and acts as insulator
Underground: (Earth Mass)	Sand and stone are good insulators
Insulation of walls	Insulation on exterior of walls
Insulation of roof	
Water	Effective thermal modulator (interior and exterior)
Climate buffer zones (Halls and atria)	Climate modulator / should have adjustable glazing
Internal shading of windows	
Glazing selection	Reflective or tinted glass reflect or retard direct solar radiation
Wall surface colouring and texture (Cladding)	Reflective or light coloured materials such as aluminium are good
	Thermal resistors. Dark colours absorb and store heat.
Ventilation	
Underground: (Earth Mass)	Increased ventilation through buoyancy
Adjustable openings	Increased / controlled ventilation
Climate buffer zones (Balconies, halls and atria)	Increased ventilation to interior of building
Larger opening windows on North and South facades	Increased ventilation
Recesses cut into façade exposed to solar radiation	Allow for windows on facades exposed to direct solar radiation which assist with ventilation
Cross Ventilation	Promotes suction of fresh air into building and the exhaustion of hot air out.
External Screening of windows	Allow for increased window surface on facades with direct solar radiation
Wind Scoops (side vents)	Channel fresh air into ceiling plenums and interior open spaces.

Ground floor to be naturally ventilated	Cool, fresh air is suctioned in to building at ground level.
Lighting system	
Smaller window openings on exposed facades	Allows less direct and more diffused light in to building
Larger window openings on North and South facades	Allows for more natural light to penetrate building (must be diffused)
Water	Allows for reflected, diffused, natural light to penetrate building
External shading of glassed facades	Allows for diffused, natural light to penetrate the building
External Screening of windows	Allows for diffused, natural light to penetrate the building
Climate buffer zones (Halls and atria)	Allows for more natural light to penetrate further into building
Glazing selection	Allows for more natural light on more exposed facades
Dimmable fluorescent lighting	Reduced heat gain
Task Lighting	Reduced heat gain
Light shelves	Allows for reflected, diffused, natural light to penetrate building
Reflective ceilings	Allows for reflected, diffused, natural light to penetrate building
Heat loss reduction (winter)	
Orientation	
Solar path angle must be considered	Building must be designed to specific solar path to allow for direct solar infiltration during winter.
Building Envelope	
Smaller window openings	Allow for less heat transfer, thereby reducing heat loss
Walls and roof: Building Mass	Stores heat and acts as insulator, reducing heat loss
Underground: (Earth Mass)	Sand and stone stores heat and act as insulators, reducing heat loss
Insulation of walls	Insulation allows for less heat transfer, thereby reducing heat loss
Insulation of roof	Insulation allows for less heat transfer, thereby reducing heat loss
Water	Effective thermal modulator (interior and exterior)
Climate buffer zones (Halls and atria)	Climate modulator / should have adjustable double glazing
Glazing selection (double glassing)	Double glassing retards heat transfer, thereby reducing heat loss
Wall surface colouring and texture (Cladding)	Dark surfaces, heat up, store and radiate heat efficiently, reducing heat loss
Service core positioning (Double core east & West)	Mass stores heat and acts as insulator, reducing heat loss.
Ventilation	
Ventilation to be kept to a minimum in winter	Manual ventilation to occur only during warm afternoon periods.
Weather stripping	All openings to be weather stripped to stop any cold air infiltration
Sealing of all openings	All openings to be sealed to stop any cold air infiltration

Chapter 3 Case study: Botswana Technology Centre (BOTEC)

Architects: BOTEC, Ken Stucke & Anderson & Anderson Architects.

3.1 Case Study Methodology

According to Tellis (1997), case studies can be either exploratory, explanatory or descriptive.

The *exploratory* case study as used in the BOTEC analysis makes use of fieldwork and data collection which is according to Tellis (1997) often undertaken prior to definition of the research questions and hypotheses. However, the framework of the study must be created ahead of time. Pilot projects are very useful in determining the final protocols that will be used. Survey questions may be dropped or added based on the outcome of the pilot study. A pilot study was accordingly undertaken which involved interviews with selected architects and building practitioners.

As cited in Tellis (1997), Feagin, Orum, & Sjoberg suggest that “the quintessential characteristic of case studies is that they strive towards a holistic understanding of cultural systems of action

Case studies go beyond the quantitative statistical results and explain the conditions through the perspective of the "actors." Therefore, “case study evaluations can cover both process and outcomes, because they can include both quantitative and qualitative data” (Tellis 1997).

The unit of analysis makes up a vital part of the case study. According to Tellis (1997), it is typically a system of action rather than an individual or group of individuals. Case studies therefore, tend to be selective, focusing on one or two issues that are fundamental to understanding the system being examined.

Tellis (1997) shows that when designing a case study, Yin identifies five components of research design that are important:

- A study's questions
- Its propositions, if any
- Its unit(s) of analysis
- The logic linking the data to the propositions
- The criteria for interpreting the findings

The following image taken from Tellis (1997) depicts how a study's questions are subdivided into propositions, which are in turn linked to the Data compiled. The units of analysis are linked back to study propositions through the data, resulting in findings and the interpretation there off.

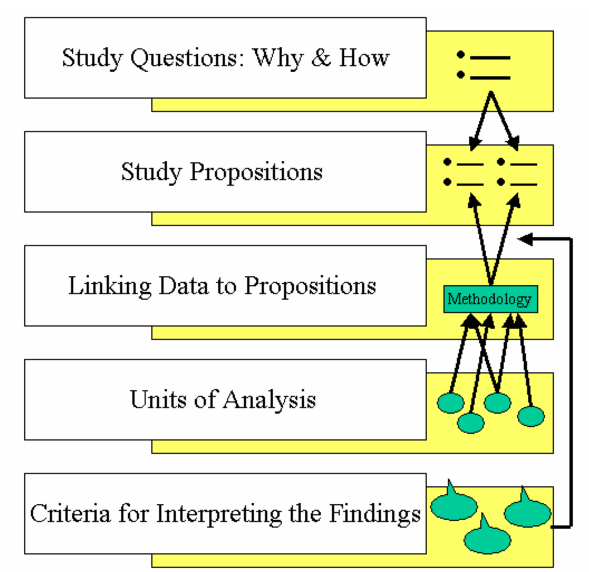


Figure 3. Case Study Design Components

The study's questions are most likely to be "how" and "why" questions, and their definition is the first task of the researcher. The study's propositions sometimes derive from the "how" and "why" questions, and are helpful in focusing the study's goals. Not all studies need to have propositions. An exploratory study, rather than having propositions, would have a stated purpose or criteria on which the success will be judged. The unit of analysis defines what the case is. This could be groups, organizations or countries, but it is the primary unit of analysis.

Case studies can be either single or multiple-case designs. According to Tellis (1997), “single cases are used to confirm or challenge a theory, or to represent a unique or extreme case. Single-case studies are also ideal for revelatory cases where an observer may have access to a phenomenon that was previously inaccessible.”

A case study consists of data which is gathered from various sources so that conclusions can be drawn on those facts from a holistic perspective.

Tellis (1997) highlights Yin’s suggested sources of evidence, found in case studies. Each source serves to support the data extracted from another;

- Documents
- Archival records
- Interviews
- Direct observation
- Participant-observation
- Physical artifacts

Documents could be letters, drawings, memoranda, leaflets, agendas, or any document that pertains to the investigation. These formed an essential part of the case study analysis.

According to Tellis (1997), interviews are one of the most important sources of case study information. There are several forms of interviews that are possible: Open-ended, Focused, and Structured or survey. In an open-ended interview, key respondents are asked to comment about certain events. They may propose solutions or provide insight into events. They may also corroborate evidence obtained from other sources.

The focused interview is used in a situation where the respondent is interviewed for a short period of time, usually answering set questions. This technique is often used to confirm data collected from another source.

The structured interview is similar to a survey, and is used to gather data in cases such as neighborhood studies. The questions are detailed and developed in advance, much as they are in a survey. The BOTEC case study analysis makes use of all three forms of interviews.

Direct observation occurs when a field or site visit is conducted during the case study. This technique is useful for providing additional information about the topic being studied. Direct observation is also a critical component of the BOTEC case study analysis.

As cited in Tellis (1997) Yin states, “it is important to keep in mind that not all sources are relevant for all case studies.”

According to Tellis (1997) the aspect of analyzing case study data, is not very well developed. As cited in Tellis (1997) Miles and Huberman suggest analytic techniques such as placing the evidence in a matrix of categories, creating flowcharts or data displays, tabulating the frequency of different events, using means, variances and cross tabulations to examine the relationships between variables, and other such techniques to facilitate analysis. Many of the aforementioned techniques have been used to analyse data from BOTEC case study.

The main principles according to Yin for creating a high quality analysis are presented below: (Tellis, 1997)

- Show that the analysis relied on all the relevant evidence

- Include all major rival interpretations in the analysis
- Address the most significant aspect of the case study
- Use the researcher's prior, expert knowledge to further the analysis

According to Tellis (1997), case study is a valuable method of research, with distinctive characteristics that make it ideal for many types of investigations. It can also be used in combination with other methods as it has been in this research report.

3.2 Documents and Direct Observation

The author selected the Botswana Technology Centre (BTC) for the following reasons;
Apart from being an energy efficient building, the building is also said to "serve as a practical demonstration for researchers, developers and designers of appropriate technologies for achieving thermal comfort in buildings in Botswana's hot-dry climate" (South African Association of science and technology centres: www.saastec.co.za/centres/centres.html).
In addition, Botswana's temperate climate is also characterised by cold nights and thus high diurnal temperature ranges; a challenge for any climate control system.

The objective, therefore, is to investigate whether the BOTEC building is performing to expectations and if indeed, the principles used at the BOTEC building do result in and can be used as the "elixir that will be the answer to all problems" with regards to energy efficient design.

3.2.1 General description

Botswana is a landlocked country that lies between the latitudes 17ºS and 27ºS and longitudes 20ºE and 30ºE. The climate in Botswana is semi-arid to dry, with extremely hot summers and cold winters, when the diurnal swing can reach 20ºC or more. The BOTEC headquarters is located in the capital, Gaborone (24.45ºS and 25.55ºE).

Mainly passive cooling systems are to be used throughout this building. This is a remarkable achievement, as air temperatures in Botswana reach as high as 40º Celsius and as low as freezing point.

The Architecture and Civil Engineering Units at BOTEC work closely together on aspects such as water conservation, development of appropriate construction materials, passive and active solar and low energy building environment systems.

Anderson + Anderson International, together with Ken Stucke, were appointed to design and supervise the construction of the BOTEC headquarters. BOTEC Architecture Units provided input to the design, centered on the technologies to be employed and ensuring that the design achieved a sufficiently high profile.

According to Ken Stucke, the air temperature inside the Botswana Technology centre never exceeds 23º Celsius (20 to 24 º Celsius).This temperature falls well within the comfort zone specified for workplaces in Botswana. There was, however, no mention of how low the temperature drops and if this temperature is within the comfort zone specified for workplaces in Botswana.

The building is said to have been designed as a living temperature moderator, combining all elements of passive design to create a successful, healthy and efficient working environment. “The moderated air temperature can only be attributed to the devotion to energy efficient design, from the inception of the project.” (South African Association of science and technology centres: www.saastec.co.za/centres/centres.html)

According to Marland, former Principal Architect, Architecture Unit, Botswana Technology Centre (BOTEC), Gaborone, Botswana, “From the outset, it was decided that the new headquarters would be, technologically speaking, a landmark building for the Southern Africa region and would demonstrate a range of technologies beyond the current conventional passive solar design.

The design brief stipulated that wherever appropriate, technologies should be expressed in the form of the building. Also, as far as possible, all technologies and construction techniques should be replicable with the object that developers should be able to understand and make use of the technologies.

The nature of the technology required a close working partnership between the M & E, civil and structural engineering consultants. “

(http://www.erc.uct.ac.za/Energy%20Managment%20News/emn%20march%202000.htm)

Marland continues, “The two-storey building is located on site with its long façades facing north and south. The East elevation is protected from the low angle sun by existing mature trees on a small hill, which has been integrated into the landscaping of the building. The roof takes the form of a concrete ceiling protected by a highly reflective steel parasol roof. Internally, circulation takes place either by movement through the open plan offices or via the 'internal street', which runs between the office/workshop/laboratory building and the library/public area on the north side.

There are 4 courtyards, which open off the internal street; each is capped with 4 rotating ventilators. These, and the permanently open louvres over the street, ensure effective stack effect ventilation.

The hot summer time conditions are the determining factors for producing a strategy to maintain internal comfort conditions (interestingly, still no mention is made of the cold temperatures experienced during the winter nights). Pumping evaporative cooled air through the hollow core ground and first floor slabs cools the structure. Evaporative cooling takes place in the basement, with the air being fed into the ground floor slabs via basement ducts and into the first floor slabs via exposed insulated ducting. This continues throughout the working day and at night for nighttime purging. Rainwater is harvested in the wet season from the roofs to supply the evaporative cooling system.

Shading, day lighting and low energy electric lighting play an important role in the design. Heat absorbing glass is extensively used on the north façade, with horizontal shading devices to limit solar radiation on the glass. On the south façade, there is a relatively stable source of daylight from the clear sky vault. This means that a system of photocell controlled permanent supplementary artificial lighting can effectively be used in the ground and first floor offices/ laboratories/ workshops. Low energy lamps are specified throughout the building."
(http://www.erc.uct.ac.za/Energy%20Managment%20News/emn%20march%202000.htm)

3.2.2 Orientation

The building is orientated facing north, with its main axis running east to west. An intense study was undertaken in order to visualise the solar path angle. Interestingly, a solar window has even been incorporated as a tribute to this investigation.

Figure 4 Solar Window Author: 2005

Figure 5 Wind scoops Author: 2005

Roof sheets cantilever, forming ‘wind scoops’ which take advantage of the prevailing winds which blow from the south-east. The air is guided by the scoops into a central shaded court, with atriums, which runs east to west throughout the building. Curved screen walls also act as wind scoops, bringing wind in to the building at ground level, assisting in ventilating the building. These are ‘text book ‘design elements as defined in main stream literature.

Once the warm air enters the ‘central shaded court’, it immediately begins to cool and sink. The lower the air sinks, the cooler it becomes. The air moves past the first floor level and down to the ground floor.

3.2.3 Water

At the ground floor level there is a water feature which runs along most of the length of the court. As suggested in some text, water is a good temperature moderator as it has a low diurnal temperature range in comparison with air. By having the water feature run the full length of the open court area, it is able to assist in regulating the temperature throughout the court yard.

Figure 6 Covered Central Court with Water Feature Author: 2005

What is important, and does not reflect in main stream text on the subject of water cooling, is the fact that in order for water to cool air effectively, it should be turbulent. At the BTC, (Botswana Technology Centre) during the day, the water aids in cooling the sinking air further via evaporative cooling. This has been achieved successfully by splitting the level of the water, creating turbulence in the waters flow and thus evaporation at the waters surface.

At night however, air entering the courtyard becomes colder than the water and it is at this point that the water's role switches to a heating rather than cooling mechanism.

3.2.4 Building Envelope

Continuing to work with the changing levels of the building, and the fact that air decreases in temperature as it descends, the architect successfully creates an 'air sump'. At the lowest point on the ground floor purposefully situated under the staircases, a metal grating is used as a floor covering which allows the cool air to sink through the ground level slab even further into an underground basement bellow.

Figure 7 Image showing metal grating beneath staircase Author: 2005

Due to the thermal mass of the earth and the added shading of the roof structure above the courtyard, the basement is kept well below 20°C. The sinking air is cooled down drastically by the time it enters the basement where it is still cooled down further.

3.2.5 Ventilation

The elaborate system of sinking and cooling air, water and basement, together create a giant passive air conditioning system. From the basement, the air is pumped up through large ducts which penetrate the offices situated on both the north and south sides of the courtyard. Each office has numerous ventilation outlets whereby the occupants of the office can manually control the amount of air entering the office through the ducts.

Figure 8 & 9 Images showing Exhaust system Author: 2005

Air that is warmed by body heat, lighting systems or machinery is efficiently but passively expelled from the building.

The Botswana Technology Centre includes a series of small courtyards situated between the offices, on the northern side of the building. Therefore, the northern side of the building is characterised by an alternating series of office areas and small courtyards. These small court yards are not open to the sky. However, above each courtyard a tall tower- like structure hovers, with four passive air extractors. According to Stucke, these towers are known as 'solar chimneys'.

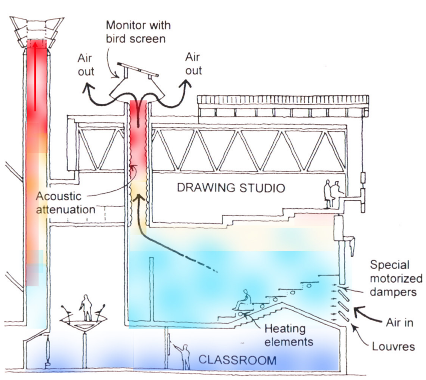


Figure 10 Drawing showing typical solar chimney Author: 2005 **Figure 11** Solar Chimney Author: 2005

Solar chimneys act as exhausts, expelling warm air, which is sucked up into and out of the tower. In order to work, solar chimneys rely on a heat build up at the apex of the tower, which causes the required temperature inversion. Therefore, the air temperature at the apex needs to be acutely the hottest area of the building and also needs to exceed the air temperature outside of the building.

This heat gain is achieved by glazing the northern face of the tower, which allows direct sunlight to penetrate the tower. In order to exploit the heat gained in the solar chimney for as long as possible; the south, interior face of the tower has been constructed of masonry and clad in black tiles. The dark colour absorbs 90% of the solar radiation, which is efficiently transferred and stored in the brick mass.

Ducts also carry warm air from each office and expel the air into the solar chimneys. Additional elements which radiate heat such as geysers have also been placed high up into the shaft of the chimney. At the apex of each chimney, four wind powered extractor’s aid in the expulsion of the hot air.

Figure 12 Cross section showing Solar Chimney and exhaust system Author: 2005 **Figure 13** Exhaust Vents

3.2.6 External Screening and Shading

A mix of shading devices has been incorporated into the design of the Botswana Technology Centre. On the east and west façades, vertical and horizontal, 'egg grate' screens and shading overhangs are required. In addition, dark reflective, double glazed glass has been used, to reflect and retard any flow of heat in or out of the building.

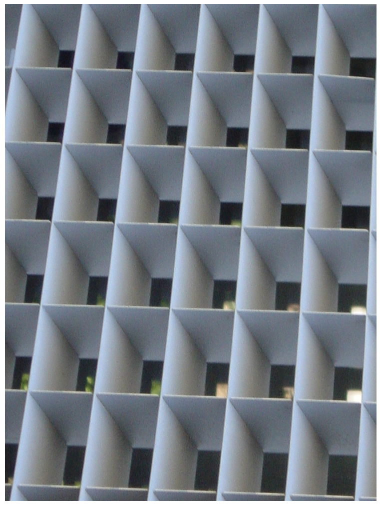




Figure 14, 15, & 16 Shading screens at BOTEC Headquarters Author: 2005

According to the architect, all shading devices have been set away from the wall and placed outside the maximum winter noon angle but inside the maximum summer noon angle. This is due to the fact that practically, if a shading device was placed at window head level, it would retard any solar gain at the top part of the window during the period of maximum winter solar radiation (noon).

The building's west façade is characterised with few windows and large thermal mass blocks, seemingly stacked above each other, clad in black tiles. The entrance on the west façade is situated deep into the face of the building, completely shaded from the sun by the blocks above.


Figure 17 Thermal Massing at BOTEC Author: 2005 **Figure 18** Entrance Foyer at BOTEC

Minimal planting has been used as a shading device, other than the trees situated in front of the west facade. There are, however, trees placed in the central covered court yard, which assist in creating a healthier and more harmonious working environment.

On the northern façade, windows are set deep into the wall mass, characterised by concrete frames that protrude well from the wall face. Other than the one deep overhanging, horizontal element on the north façade, no other external shading device has been used. Because of the particular sun angle in Botswana, the deep overhang shades the entire north wall during mid summer afternoons. In winter, however, it would seem that the function of both the north and west walls are to store heat energy and to release it into the building.

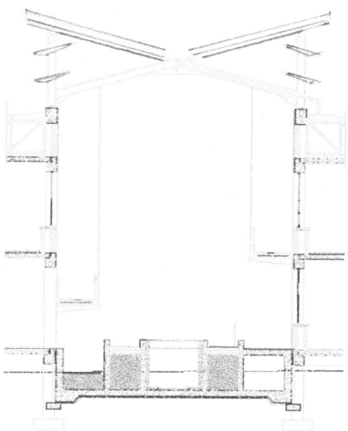
Figure 19 North Façade BOTEC Author: 2005

Figure 20 South Façade, BOTEC Author: 2005

The southern façade is made up of a mix of reflective aluminium cladding, dark tinted double glassing and horizontal shading elements. The south wall is where most of the direct light will enter the building and it is for this particular reason that a curtain wall has been used.

3.2.7 Interior Shading

The central open court is shaded by a steel structure characterised by a butterfly steel roof and finned screens. The corners and sides of the court, which are not closed to the outside, are shaded by manually controlled horizontal aluminium louvres that begin on the ground level and stretch almost up to the corrugated iron roof of the courtyard. The 'exterior walls' within the courtyard are therefore completely shaded.



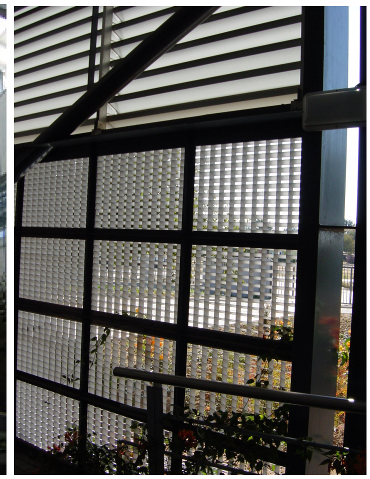


Figure 21 & **22** Cross section at BOTEC Showing Central Court Author: 2005

Figure 23 Internal Shading Author: 2005

3.2.8 Lighting

Natural light has been exploited to its fullest. Throughout the entire building, reflective, aluminium light trays have been used to reflect direct sunlight and allow only defused light to penetrate building. Where task lighting is required, such as in the offices, low voltage lights have been used.

Figure 24 Light Trays, BOTEC Author: 2005

3.3 Summation

Having applied the literature model to the Botswana Technology Centre's design principles, we see a strict adherence to basic theory of energy efficient design, which, on the surface, results in a successful and healthy energy efficient building.

However, we do note the use of some adapted and additional 'practical principles', which are as follows;

- Orientation: Use of prevailing winds for cooling and ventilation with the aid of screen walls.
- Orientation: Strict design adherence to specific context, solar angles and prevailing winds to foster a comfortable and efficient building.
- Building membrane: Use of a controllable, screened open courtyard which controls the environment directly in contact with the offices (3 of the 4 walls are within the controlled environment).
- Building membrane: Layered corrugated roof system for increased cooling via shading. The top layer provides a shaded area for the layer below. The space between the layers allows wind to move through, cooling the roof surface and the air in direct contact with it.
- Building membrane: Screen walls used to shade transitional spaces.
- Ventilation: Use of solar chimney provides for the expelling of hot air and the suction of fresh cooler air into the building. Without the solar chimneys, the building would not function passively.

Despite the successful use of the literature principles in this particular building, one must be aware of the numerous examples where the principles had to be altered substantially in order to suite this site and its unique constraints. This is an important finding as the most important design factor with respect to energy efficient design is context.

Elements such as site, wind exposure, wind direction, sun exposure, sun angles, summer and winter temperatures, and moisture levels are but a few that will define what energy efficient design principles will be used and which will be more effective. The building therefore adapts and makes use of additional elements that do not occur widely in text on the subject of energy efficient design.

The BOTEC building correctly utilises ‘standard’ principles of energy design and adapts them to suit its own climate, context and topography. One would therefore expect the BOTEC building to perform to expectation.

To complete the BOTEC case study, a questionnaire was sent out to selected users of the building. This was done in order to gain consensus that the building does indeed perform to expectation.

Chapter 4.0 Case Study: Interviews and questionnaire

4.1 Objective of Questionnaire

The objective of the questionnaire was to establish whether the users of the BOTEC building consider the building to facilitate a comfortable working environment, even though the building is based primarily on energy efficient design principles.

4.2 Methodology

In conjunction with the scope of this report, the questionnaire probes into the likes and dislikes of the user with respect to the following;

1. Heating (thermal comfort)
2, Cooling (thermal comfort)
3. Lighting
4. Noise
5. Ventilation
6. Window use

The questionnaire therefore was categorised in order to promote active thought when answering the questions. These categories are;

1. Employee particulars (type of job, age, experience)
2. General performance of building
3. Temperature (comfort)
4. Lighting
5. Noise
6. Ventilation
7. Windows

In addition, users were encouraged to suggest possible improvements they would make and/or shortcomings they considered to be present (if any) in the design of the building and its energy efficient systems.

The questionnaire had to be constructed in such a way so as to facilitate brief and concise answering. Most of the questions were in the form of ‘closed probes’; limiting the user to the suggested answers on the questionnaire. The most appropriate answer need only be ticked off. Where ‘open probes’ were included, adequate space was allowed for the recipient to answer.

The BOTEC building is well known among many in the building industry to “demonstrate appropriate technologies such as passive solar design, environmental design, innovative building systems, materials, and natural day lighting”. In addition the building is intended to “act as a demonstration facility and show how such technologies can be applied in commercial and institutional buildings and lead to considerable energy savings.” (http://www.erc.uct.ac.za/Energy%20Managment%20News/emn%20march%202000.htm)

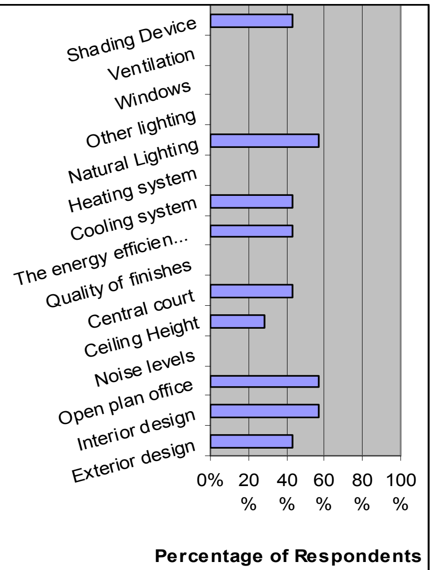
It therefore seems obvious that the renowned BOTEC building would be the perfect test to see weather energy efficient systems do indeed work practically and to the approval and expected comfort levels of the users of the building.

4.3 Survey Sample

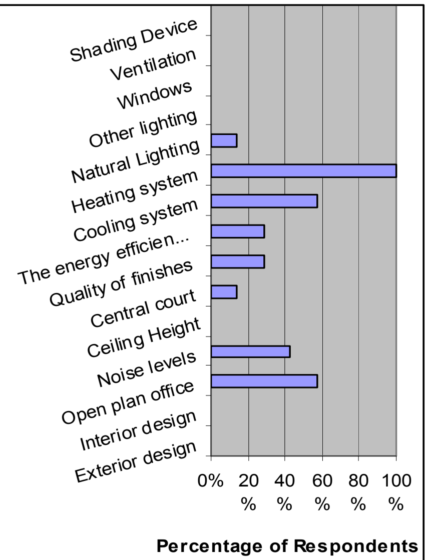
The recipients of the questionnaire are all staff members working in the BOTEC building. Each recipient was selected by management of the BOTEC building according to age, gender, and hierarchy ensuring that a diverse sample of staff opinions was achieved.

4.4 Results

4.4.1 General Performance



Graph 1
Genral Likes



Graph 2
Genral Dislikes

The first two questions deal with the general performance of the building, as well as likes and dislikes the users may have of the BOTEC building.

Graph 1 shows that the most liked features of the BOTEC building in order of their preference are; the interior design (57,14%) the open plan offices (57,14%) and the use of natural lighting (57,14%). The exterior design (42,86%), central court (42,86%), energy efficient cooling system (42,86%), and shading devices (42,86%) following with the ceiling height (28,57%)

4.4.2 Most Disliked Features

Graph 2 demonstrates the most disliked features in order of rank which are; energy efficient heating system (100%), open plan offices (57,14%), energy efficient cooling systems (57,14), noise levels (42,86%),quality of finishes (14,29%), and central court (14,29%). An interesting comment was made by one recipient who stated that the energy efficient systems in place at the BOTEC building are “very theoretical and do not work practically”.

Other comments also refer to the poor performance of the energy efficient heating system, the fact that open plan offices facilitate a noisy environment and that the open, central court should be minimised as to control the inflow of dust and birds. A comment was made by a recipient in the architectural department who suggested a ‘reverse mechanical system’ for winter heating.

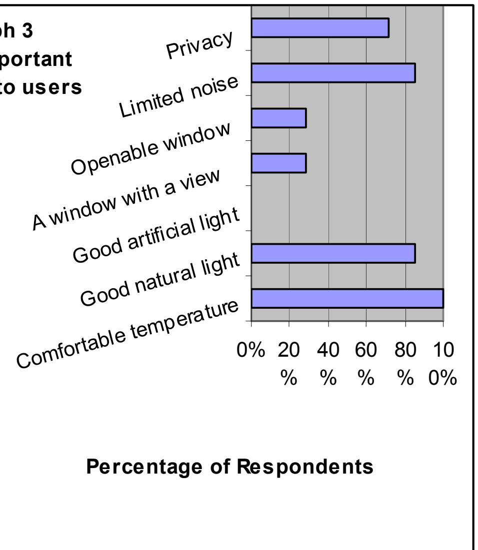
What is alarming and worthy of further investigation is that 100% of the recipients seem to be completely dissatisfied with the energy efficient heating system in the BOTEC building.

Interestingly, the features that that the users deemed most important, were also the features that, according to the users, performed the worst.

4.4.3 Most Important Features

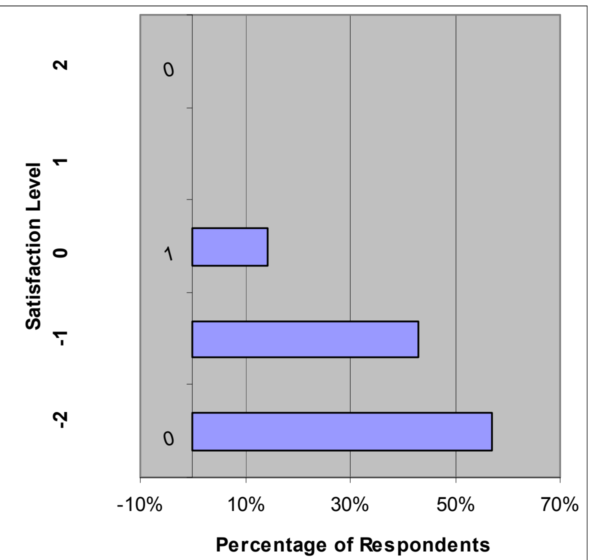
In order of preference, according to the users of the BOTEC building, the most important features that should be present in any building is, a comfortable temperature (100%), good natural light (86%), limited noise (86%), privacy (71%), openable windows (29%), and a window with a view (29%). These figures are a represented in the following graph 3.

Graph 3
Most important features to users



In comparison to graph 3, the satisfaction levels of the users of the BOTEC building are represented by the following graphs. The graphs depict 'satisfaction ratings' from -2 to 2; 2 being completely dissatisfied and 2 being completely satisfied.

4.4.4 Heating System



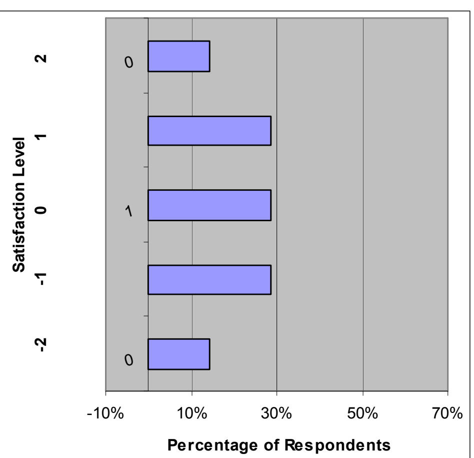
Graph 4
Satisfaction of Heating system in BOTEC building

Graph 4 demonstrates the high level of dissatisfaction with the performance of the energy efficient heating system at the BOTEC building. This is in line with graph 2 which depicts the heating system as a feature which is unanimously disliked. The performance of the heating system was therefore found to be poor.

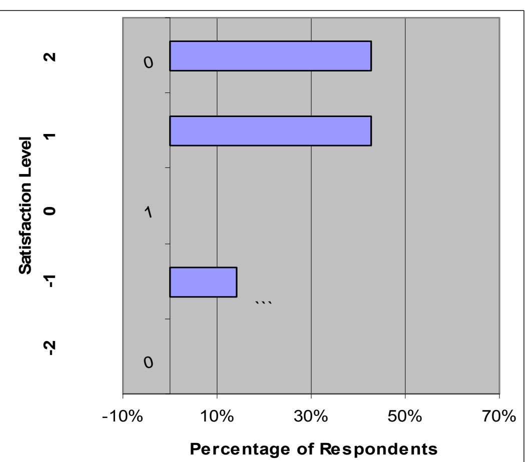
4.4.5 Cooling System

The respondents were generally indifferent about the energy efficient cooling system of the building. It must be said, however, that exterior temperatures climb to well beyond 40º Celsius in this area of Botswana. Therefore, the mere fact that the recipients aren't concerned about the performance of the cooling system in the BOTEC building, suggests that the system is functioning well and to the design expectations. This is demonstrated in graph 5 below.

It must also be noted that according to the recipients, no allowance has been made to control the temperature of their environment individually, i.e. the systems cannot be individually shut of or turned on.



Graph 5
Satisfaction of Cooling system in BOTEC building

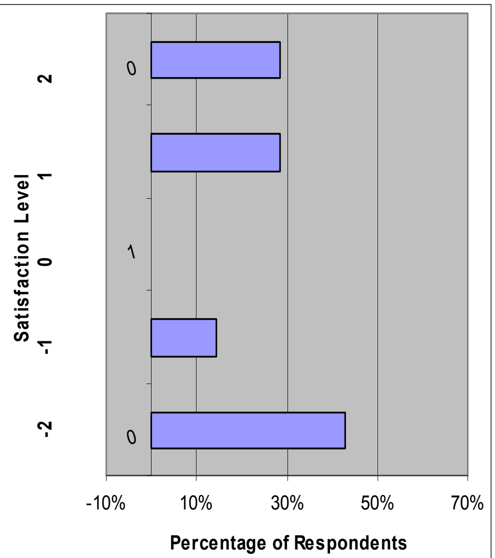


Graph 6
Satisfaction of lighting in BOTEC building

4.4.6 Lighting

With regards to lighting, 85% of recipients were satisfied with the level of lighting in the building with 100% of the recipients preferring a combination of natural and artificial lighting.

4.4.7 Noise



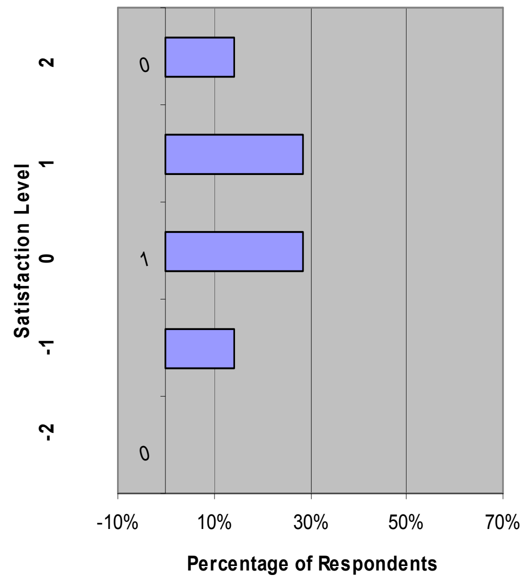
Graph 7

Satisfaction of Noise level in BOTEC building

The level of satisfaction for the reduction of noise is mixed. Generally the staff members working in an open plan environment complained that their environment was too noisy. The staff members in cellular offices were less affected by noise made by other staff members, telephones etc.

4.4.8 Ventilation

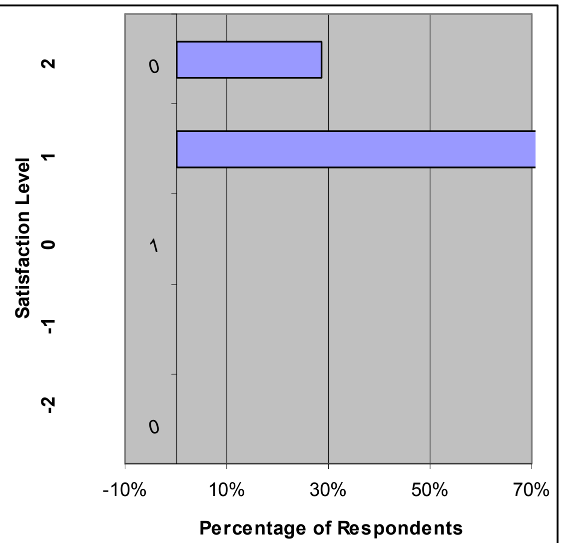
By large the recipients seem to be satisfied with ventilation in the building, with over 70% of the recipients being relatively satisfied. Again taking into consideration the extreme heat of the Botswana climate, one can ascertain by the level of satisfaction, that the users are generally comfortable with the rate of ventilation allowed for in the design of the BOTEC building.



Graph 8

Satisfaction of Ventilation in BOTEC building

4.4.9 Windows



Graph 9

Satisfaction of use of Windows at the BOTEC building

The vast amount of windows, shaded and insulated, is well received by the recipients with 100% of the recipients being satisfied and 28,57% being absolutely satisfied as depicted in graph 9 above.

47% of the recipients regard the most important feature of a window as letting sunshine in to warm the room, 44% think it is to let fresh air in, and 25% of the recipients think the most important feature of a window is to keep you in contact with the outside, letting you know how the weather is or to allow for a view to break the work monotony. Only 19% thought that a window is useful to make a room feel more spacious.

4.4.10 Finding

In summation, the BOTEC building seems to be performing well and to design expectations with the one surprising exception; the energy efficient heating system. According to the answers to the questionnaire, an alarming 63% of the recipients said that the building becomes so cold, it makes them feel uncomfortable 'every day' in winter, with the remaining 37% stating that the building often becomes so cold that it makes them feel uncomfortable. (100% of recipients feel uncomfortable).

Clearly there is a serious problem with the heating component of the BOTEC building. Such a 'failure' must be investigated to determine where the design is flawed.

According to the recipients, portable heaters have to be brought in to assist with the heating of the working spaces during winter. The use of highly energy intensive heaters throughout the winter months is counterproductive in terms of the other energy efficient systems in place in the BOTEC building, not to mention a bad example to people hoping to learn from this particular building.

The author was unfortunately unable to acquire electricity accounts from BOTEC management in order to compare output during the summer (Building Performs well) and winter months (building performs poorly). One can assume, however, that the electricity output increases substantially during the winter months due to additional heating required.

4.5 Further Investigation

A meeting was set with Ken Stucke- one of the principle architects involved with the design and construction of the BOTEC building. Through some investigation into the design of the energy efficient heating and cooling system at the BOTEC building, the following was discovered;

In summer, the cooling system seems to perform to expectation, functioning with two fundamental components.

1. The air is scooped into the building, cooled passively and pumped into the building. (Cooling process)
2. The cool air that has been warmed either through radiation from humans, machines or solar is expelled from the building through solar chimneys equipped with rotating extractors which are powered passively by the rising warm air. (Extraction of warm air)

In winter, however, the heating system does not seem to be performing at all or badly at most. According to text, for a building such as the BOTEC building to perform well in winter, in its particular context, the heating system should involve the following;

1. The design is to allow for heat radiation to penetrate the building, which according to the recipients of the questionnaire, it does.
2. The heat radiation is to be stored by the building through massing. It is clear by the design of the buildings envelope that this is occurring.

However, the heat radiating from the walls and floors of the building seems to be efficiently vacuumed into the solar chimneys and expelled from the building ultimately cooling the building and defeating the heating process. This, according to Stucke ,seems to be the crux of the heating problem experienced by the users of the BOTEC building.

Stucke continues to suggest that a simple ‘shut off’ device to the passive extractors would allow the building to control the rate at which warm air was expelled from the building, especially during the winter months.

4.6 Summation

Having analysed a known energy efficient building which makes use and adapts these principles to specific climate, context and topography we find what is seemingly a successful energy efficient building.

However, due to what appears to be a major oversight, this particular building is not performing to expectation. It can easily be seen that even if the design team does not use principles of energy efficient building blindly and manages to adapt almost every aspect of these principles to suite a specific building, a solitary element that is overlooked will undo any advantage generated by all of the other elements in place.

Therefore, and in concurrence with Holms thinking, not all of the design principles are applicable to any situation. It is therefore important not to apply a once successful solution time and time again, but to consider each condition in accordance with its specific context and, where possible, to test the performance of these systems as soon as possible to minimise discomfort and inefficiency.

Chapter 5.0 Conclusion

The objective of this investigation was to prove that there is not one solution (elixir) or one set of solutions for solving our problems with regard to resource depletion and energy efficient design.

In proving this, a number of questions had to be asked.

1. Is the building industry an important component in combating resource depletion?
2. Can one justify including energy efficient design and alternate systems into our buildings with regards to the perceived increased financial burden, and risk?
3. Does the economy allow for the inclusion of energy efficient design and alternate systems? (Will it save money?)
4. Finally, if one follows basic principles of energy efficient design and alternate systems, is one guaranteed of a successful, comfortable building?

The answers to these questions were;

1. Yes, the building industry is most definitely an important component in combating resource depletion as it was shown to be the largest consumer of energy in most countries.

2. With the threat of global warming, resource depletion, one can most definitely justify the use of energy efficient design and alternate systems in our buildings. Not only was it shown that our fuel supplies have a mere 40 years till they are depleted and that energy prices are already on the increase, but in most cases, energy efficient design was shown not to cost more than traditional design. An element such as correct orientation does not cost more to design or to build, but has a massive impact on the thermal performance of a building.

Daniels (1997) states; “Ecological building means applying technical aids sparingly, and making the most of all passive means provided by the buildings fabric. Here developments in structural engineering and construction in urban areas, building form, and orientation play important roles.”

3. With rapidly increasing energy prices, incentives given by government and energy efficient design and alternate systems becoming more prominent in the building industry (Thus decreasing in cost), It was shown that there has never been a better time, financially, to implement energy efficient design and alternate systems.

4. The BOTEC case study, with respect to the questionnaire that was circulated, showed clearly that by following basic principles of energy efficient design and alternate systems, one is by no means guaranteed of a successful, comfortable building. It was shown that every element must adapt to the specific context of the building into which it has been incorporated. As a result of this finding, It can be shown that, in accordance with Holm (1996) there is no single elixir that will be the answer to all problems with regard to energy efficient design.

The BOTEC case study also highlighted the fact that if one uses the basic principles of alternate design blindly or does not fully understand the principles, the results will be counterproductive. Also highlighted was the need for energy efficient systems to be both flexible and completely controllable.

With regard to combating some of the impediments mentioned at the AIAVT Roundtable discussion on Building Energy Alternatives in Vermont in 2001, Haupt (1997) suggests that as a minimum, architects and other professionals should be educated in the design of energy efficient buildings, taking into account “alternative sources of building and renewable energy sources such as solar, geothermal and wind energy. The benefits of natural light should be maximized and the use of artificial light minimized. Furthermore, building insulation and the use of energy efficient heating and cooling efficient systems should be mandatory specifications. Finally the innovative use of recycled building materials must be appreciated."

Further suggestions made at the AIAVT Roundtable Discussion (2001) were to create strict building codes that enforced energy efficient design criteria. Some researchers suggest that by enforcing a building 'code', contractors and professionals may do just enough to comply.

Croxton (1998) however warns that, "many building professionals assume that if a building complies with code, then it must be energy efficient. Croxton (1998) however points out that "building to code means that if the building were designed any worse it would be against the law."

In conclusion, developers, architects and other professionals have a responsibility to their fellow man to dedicate time and resources to compiling sufficient information regarding energy efficient design, for all types of buildings. With increasing populations and migration of people towards city centers, complex buildings are inevitably going to become a more common phenomenon and seriously require additional attention with respect to energy efficient design practice and principles.

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Appendix A

Botswana Technology Centre Case Study Analysis

	Heat gain reductions (summer)	
-	**Orientation**	
Y	Building must face North - South (within 20º of North)	Building faces North South
		East west facades are protected against direct solar radiation.
Y	Solar path angle must be considered	Solar angle has been used in design
Y	**Prevailing wind (use of screen walls and wind scoops)**	Building has been orientated to take advantage of prevailing winds
-	**Building Envelope**	
Y	External shading of walls (Solar shading, balconies,)	Solar shading, screens and balconies
Y	Recesses cut into façade exposed to solar radiation	Entrance to building is recessed below mass above
Y	External Screening of windows	Fins on south, egg-crates on East and West.
Y	**Screened open court.**	Entire open court screened on east side and south East corner.
N	Planting	Plants used in central court and side atria but NOT as shading device
Y	Smaller window openings on exposed facades	Small windows on North and east façade. Few on West facade.
Y	Walls: Building Mass	North and West Façade
Y	Underground: (Earth Mass)	Cooling basement
N	Insulation of walls	
Y	Insulation of roof	Roof is well insulated
Y	**Layered roof system for insulation**	Roof is a system of layers, one shading the other to reduce heat gain
Y	Water	Central water feature running full length of covered court
Y	Climate buffer zones (Halls and atria)	Central shaded court
N	Internal shading of windows	
Y	Glazing selection	Tinted and reflective
Y	Wall surface colouring and texture (Cladding)	Walls are kept light. Aluminium is used on west façade.
Y	Corner shading	Each corner is either closed by wall or screened by fins
Y	**Screen walls**	Screen walls used to shade gathering spaces
-	**Ventilation**	
Y	Underground: (Earth Mass) Ventilation by buoyancy.	Cooling basement
Y	Adjustable openings	Fins shading open court yard
Y	Climate buffer zones (Balconies, halls and atria)	Central open court and side atria
Y	Larger opening windows on North and South facades	Larger opening windows on North and South facades
Y	**Recesses cut into façade exposed to solar radiation**	At entrance and exit, sucking in cool air
Y	Cross Ventilation	Central open court promotes cross ventilation
Y	External Screening of windows	On East and West facades
Y	Wind Scoops (side vents)	Wind scoops: Roof sheets and screen walls
Y	**Solar chimney**	Solar chimneys expel hot air from building replacing it with fresh air
	Lighting system	
Y	Smaller window openings on exposed facades	
Y	Larger window openings on North and South facades	
Y	Water	Water reflects diffused light into offices

Y	External shading of glassed facades	Shading on All facades
Y	External Screening of windows	On East and West facades
Y	Climate buffer zones (Halls and atria)	Central covered Court provides diffused light to interior of building
Y	Glazing selection	colours have been selected for maximum light and minimum infiltration
Y	Dimmable fluorescent lighting	
Y	Task Lighting	
Y	Light shelves	Aluminium light trays
Y	Reflective ceilings	
- -	- -	
	Heat loss reduction (winter)	
_	**Orientation**	
Y	Solar path angle must be considered	
_	**Building Envelope**	
Y	Smaller window openings	Smaller openings to offices
Y	Walls and roof: Building Mass	Mass acts as insulation, retarding heat loss
Y	Underground: (Earth Mass)	Basement regulates temperature
N	Insulation of walls	
Y	Insulation of roof	Layered roof system
Y	Water	Central water feature running full length of covered court
Y	Climate buffer zones (Halls and atria)	Allow solar radiation to penetrate interior (controlled by fins)
Y	Glazing selection (double glassing)	Dark, tinted, small, doubled glassed, shaded windows on West facade
Y	Wall surface colouring and texture (Cladding)	Black wall tiles on Western facade elements
Y	Service core positioning (Double core east & West)	Service core situated on West
	Ventilation	
N	Ventilation to be kept to a minimum in winter	
N	Weather stripping	
N	Sealing of all openings	

Appendix B

Energy efficient Buildings

Thank you for making time to fill in this questionnaire.
The fact that you have given up a few minutes of your precious time is greatly appreciated.

This questionnaire will not be used for any purposes other than for research to be included into a Masters thesis in Building Science undertaken at WITS university.

The questionnaire is designed to be read and answered easily and fast.
Please answer the questions by clicking on the specific block/s and highlighting it. (E.g.) [ ] …………

Kindly complete the questionnaire in this 'exel' format, 'save' the file and reply to the following email address;
blackstone@ easymail.co.za

1. What is your Name? (optional)

____

2. What is your position at BOTEC? (optional)…(Director, management, secretary etc)

____

3. How long have you worked at BOTEC? 2yrs

____

4. What age group are you in?

	17-25	x	36-50
	26-35		50 and over

5. What sex are you?

	Male
x	Female

6. Is there anything you particularly like about the BOTEC Building?

	Exterior design		Cooling system
	Interior design		Heating system
x	Open plan office		Natural Lighting
	Noise levels		Other lighting
	Ceiling Height		Windows
x	Central court		Ventilation
	Quality of finishes	x	Shading Device
	The energy efficient systems		

7. Is there anything you particularly dislike about the BOTEC Building?

	Exterior design		Cooling system	
	Interior design		Heating system	
	Open plan office	x	Natural Lighting	(no natural lighting)
	Noise levels		Other lighting	
	Ceiling Height		Windows	
	Central court		Ventilation	
x	Quality of finishes		Shading Device	

x	The energy efficient systems	(very theoretical - does not work practically.)

8. Is there anything you would have designed differently to make the BOTEC building better?

x	Yes
	No

If Yes, Please specify The cooling and heating system….. I hate the wall mounted heaters positioned above door height

9. How does your office or work area in this building compare with your last office?

a)	appearance	b)	Comfort	c)	Suitability to job
x	Better		Better		Better
	Same	x	Same	x	Same
	Worse		Worse		Worse

10. How many people share your current work area?

	Alone in the office		Ten to twenty people
	Less than four people		More than twenty
x	Five to ten people		(open plan)

11. Rank the four most important features that make a work environment pleasant for you? (i.e.1,2,3,4)

2	Comfortable temperature		A window that may be opened
1	Good natural light	3	Limited noise
	Good artificial light		Privacy
4	A window with a view		Other (Please specify below)

12. How satisfied are you with the following aspects of your work area?

	-2	-1	0	1	2
Lighting				x	
Noise level					x
Heating			x		
Cooling			x		
Ventilation				x	
Windows				x	
Windows					

13. Does it ever get cold enough to make you feel uncomfortable (i.e., early morning or at night)

x	Every day during winter		occasionally
	Often		Never
	Sometimes		

14. What do you do if your office gets too cold?

	Adjust central heating system		Leave work station
	Nothing		No comment
x	Dress warmly		Other (please specify below)
	Complain		

(use portable heaters)

15. Does it ever get warm enough to make you feel uncomfortable?

[ ]	Every day	[ ]	Sometimes
[ ]	Every day during summer	x	occasionally
[ ]	Often	[ ]	Never

16.What do you do if your office gets too warm?

[ ]	Adjust central cooling system	[ ]	Leave work station
x	Nothing	[ ]	No comment
[ ]	Dress warmly	[ ]	Other (please specify below)
[ ]	Complain		

17. Can you control the temperature in your office to suit your particular needs?

[ ] Yes
x No

If yes, how?

18. Does your office become so noisy that you find it difficult to work?

[ ] Yes
x No

If yes, what do you think the cause of the noise is?

19. What noises do you notice most as you work (tick as many as apply)

[ ]	None	x	Telephones
[ ]	Office machines	x	Voices
x	Outside noises ***(cars)***	x	People walking around
[ ]	Noises from central court	[ ]	Other (Please specify below)

20. Do you prefer working by natural light, artificial light or a combination of both?

x Prefer natural
[ ] Prefer artificial
[ ] Prefer combination

21. Is there sufficient lighting in your office?

x Not enough natural light
[ ] Not enough artificial light
[ ] Not enough light in general

22. Does the artificial light ever cause enough glare to bother you?

[ ]	Often	x	Occasionally
[ ]	Sometimes	[ ]	Never

23. How important is it for you to have a window in your office or immediate work area?

x Very important *NEED TO CONNECT TO THE OUTSITE*
[ ] Moderately important
[ ] Not important

24. Do you have a window in your office or work area?

- [X] Yes
- [ ] No

25. Are you able to see as much of the outside as you would like to from your desk?

- [x] Yes
- [ ] No

26. Which of the following best describes the view out of your window/s?

	Satisfying		Frustrating
	Limited		Complex
x	Pleasant		Bright
	Confined		Unpleasant
	Dim		Spacious
	Stimulating		

27. Does the light from the windows ever cause enough glare to bother you?

	Often	x	Occasionally
	Sometimes		Never

28. Does your office ever become too hot because of the sunshine coming in the windows?

	Often		Occasionally
x	Sometimes		Never

29. Do you think the noise level near the window is noticeably greater than in the rest of the room?

	Often		Occasionally
x	Sometimes		Never

30. Listed below are some advantages of windows. Pleas rank the four most important to you (i.e. 1,2,3,4)

	Allow you to tell the time of day
4	To let sunshine in
1	To keep you in contact with the outside world
	Let you know how the weather is
3	Provide fresh air
2	Allow for a view to break the monotony
	Make a room feel more spacious

31. Are the windows in your work area openable?

- [ ] Yes
- [ ] No some

32. Which of the following activities are a normal part of your job (tick as many as you do)

	Reading		Working with numbers
	Writing		Interviewing or holding small meetings
x	Computer		Supervising the work of others
	Filing		Serving customers

33. In general, how much time do you spend in your office or immediate work area?

x	All the time	(7-8 hours per day)
	Most of the time	(4-6 hours per day)
	Some of the time	(Less than 4 hours)
	Other (Please specify)	____________

If you have any comments about the performance and or comfort of the BOTEC building please them
the theory aspect of the building is ok but practically it seems not to perform to expected standard
one wonders if it is anything to do with the workmanship or it is the design .

Many thanks!
Please don't forget to 'save' and email the completed questionnaire to
blackstone@easymail.co.za

Taken from Welsh, (1986)

Appendix C

Derivation of Energy intensities of building construction materials by physical units

Sector and Material or Component	Unit	Unit Cost (R)	Total – Embodiment Primary Energy (MJT/R)	(MJT/Unit)
Products of Coal And Petroleum				
Coke	Ton	213,67	107,7	23 029,74
Petrol	Litre (l)	1,51	109	164, 69
Diesel	Litre (l)	1,43	109	155,96
Bitumen (Road Surface)	Litre (l)	0,56	109	61,08
Wood and Wood Products				
South African Pine, Kiln dried, not impregnated				
76 x 228 mm	m³	1040,79	22,6	23 603,53
38 x 228 mm	m³	898,85	22,6	20 384,54
51 x 76 mm	m³	937,90	22,6	21 249,73
Floor boards, (SAP)	m²	51,14	22,6	1159,73
Particle Boards, 13 mm	m²	21,07	22,6	477,84
Hardwood (meranti)	m³	4181,42	22,6	94 828,21
Ceiling boards (SAP)	m²	30,04	22,6	689,43
Plywood, 4mm	m²	15,68	22,6	355,60
Floor blocks (76 x 228 mm)	m²	64,28	22,6	1457,77
Flush door panel (std)	Each	101,43	22,6	2 300,28
Door Frame(std)	Each	92,60	22,6	2 100,03
Hardboard (untampered)	m²	8,95	22,6	202,97
Shelving (305 x 25 mm)	m²	77,40	22,6	1 755,31
Rubber and Plastic				
Modified resin vinyl tiles (300 x 300 x 2mm)	m²	23,76	32,6	775,82
Semi-flexible vinyl tiles (300 x 300 x 2mm)	m²	49,28	32,6	1 609,11
Chemicals & Chemical Products				
Gloss general purpose paint	5 letres	55,23	21	1 165,25
Oil gloss general purpose paint	5 letres	41,75	21	880,85

Primer	5 letres	61,25	21	1 292,26
Aluminium general purpose paint	5 letres	56,90	21	1 200,49
Emulsion paint (interior)	5 letres	37,13	21	783,38
Emulsion paint (exterior)	5 letres	39,23	21	827,68
Polyacrylic Paint	5 letres	44,22	21	932,96
Red alkyd (roof)	5 letres	49,66	21	1 047,74
Varnish, gloss	5 letres	45,45	21	958,91
Liquid floor polish	500 ml	5,20	21	109,71
Metal polish	500ml	0,98	21	20,68
Dextrin paste adhesive	Kg	4,23	21	89,25
Starch paste adhesive	Kg	2,78	21	57,60
Bitumen adhesive (vinyl tiles)	Litre	2,9	21	61,18
Roofing felt paste	Litre	2,73	21	57,60
Neoprene adhesive (vinyl tiles)	Litre	5,94	21	125,32
Non-metallic mineral products				
Portland Cement (50 kg bags)	100 (No.)	1 195,50	39	46 770,14
Bricks, smooth semi-faced	1000 (No.)	479	29	14 115,31
Bricks, clinker	1000 (No.)	397	29	11 697,06
Bricks, stock	1000 (No.)	245	29	7 218,58
Crushed stone for concrete	m^3	22,16	26	592,78
Sand for concrete	m^3	30	26	807,31
Slaked lime	Ton	198	21	4 349,55
Unslaked lime	Ton	143	21	3 142,79
Reinforced concrete (305 mm Ø)	M	41,72	21	914,22
Asbestos-cement pipes (152 mm Ø)	M	27,66	21	606,12
Vitrified clay pipes (102 mm Ø)	M	7,63	21	167,20
Corrugated asbestos cement roofing (6mm)	m^2	17,50	21	383,48
Gypsum board ceiling (6mm)	m^2	5,85	21	128,19
Electricity, Gas and Water				
Electricity	kWh	0.1	144	14,47
Gas	GJ	0,3	144	43,40
Water	Kl	0.8	44	35,94
Structural Metal Products				
Flat mild steel bars (60 x12 mm)	ton	1 299	23	30 889,70
Reinforced steel (25mm)	ton	1 125	23	26 753,56
Rounds, mild steel	ton	1 597	23	37 965,52
Angles (50 x 50 x 8mm)	ton	1 246	23	29 626,92
Joists (203 x 152 x 52mm) (1kg/m)	ton	1 493	23	35 501,29

Rails (40 kg/m)	ton	1 721	23	40 922,55
Rails (15 kg/m)	ton	1 744	23	41 464,56
Non-ferrous metal products				
Copper, rods and rounds	ton	13 238	39	519 786,79
Copper, sheet	ton	14 246	39	559 385,47
Brass bars and rounds (70% copper)	ton	9 696	39	380 743,39
Lead, sheets and strips	ton	5 675	39	222 828,48
Lead, pipes (25 mm Ø)	ton	6 225	39	244 424,19
Fabricated Metal Products				
Iron Sheets, uncoated (0.6mm)	ton	2 123	29	62 278,51
Iron Sheets, galvanized (0.6mm)	ton	2 500	29	73 306,98
Iron sheets, galvanized and corrugated (0.6mm)	ton	2 901	29	85 088,63
Galvanized fencing wire, barbed	ton	2 998	29	87 937,41
Wire netting, 76mm wide mesh, 1,2m wide	50m	191	29	5 603,69
Down Pipes, Galvanised iron, (76mm Ø)	M	9,50	29	278,34
Water tank, Corrugated iron (1.8 x 1.2m)	Each	629	29	18 455,87
Door jab (2.0 x 0.2m, 108mm)	Each	90	29	2 639,95
Steel window frame, residential (1,2 x 1,0 m)	Each	131	29	3 850,67
Nails, wire, 75mm	Ton	2 193	29	64 327,18
Construction Plant				
Grader, 110kW, South African	Each	463 571	34	15 923 630,00
Crawler mounted excavator, (100 kW, 1mp)	Each	542 558	34	18 636 936,00
Vibratory compaction plant (10ton, 1mp)	Each	222 409	34	7 639 783,50
Concrete pan-mixer (South African)	Each	22 9964	34	7 899 126,00
Concrete weight batcher (South African)	Each	13 800	34	474 030,00
Concrete boom scraper (South African)	Each	57 371	34	1 970 659,50
Concrete mixer, truck mounted, (South African)	Each	56 889	34	1 954 171,50
Cranes, self erecting, traveling tower, 5 ton at 10m radius (1mp)	Each	640 000	34	21 984 000,00
Hole drilling, boom crawler mounted drill rig, 102mm Ø, (South African)	Each	174 525	34	5 995 105,50
Industrial tow tractor (South African)	Each	272 842	34	9 372 054,00
Air compressor, 8m³/min (South African)	Each	67 235	34	2 309 694,00
Gyrospheric crusher, 914 mm (South African)	Each	2 77 091	34	9 518 041,50
Tipper truck, 16 ton (South African)	Each	352 923	34	12 122 802,00
Light truck , 1 ton (South African)	Each	32 645	34	1 121 527,50

Taken from: (Irurah, An embodied- energy algorithm: Appendix 8.04 , 1997:183-197)

Single-step and total-embodiment energy intensities by trade units: Trades measured by: Number (each)

Trade or Subtrade & unit of measure	Material or Component	Energy Intensity as installed (MJTEach)	
NUMBER (EACH)		Partial (MJT Each)	Overall (MJTEach)
Carpenter and joiner:			
Doors:	**Hollow Flush Door**		
	Door	1556,42	
	Fixers	223,78	
	Fuel and power	282,72	
	Total		**2 062.92**
	Solid Core flush doors/paint		
	Door	2666,76	
	Fixers	383,34	
	Fuel and power	484,43	
	Total		**3 534,53**
	Semi-Solid core/ veneer		
	Door	2736,61	
	Fixers	393,31	
	Fuel and power	497,13	
	Total		**3 534,53**
	Framed, ledged batten door (soft wood)		
	Timber	3 702 03	
	Fixers	532,04	
	Fuel and power	672,51	
	Total		**4 906,58**
	Hard Wood		
	Timber	5 691,39	
	Fixers	817,71	
	Fuel and power	1 033,87	
	Total		**7 542.97**
Iron mongery	**Iron mongery**		
	Mortice lock	1 594,24	
	Fuel and power	139,78	
	Total		**1734,02**
Structural Steelwork:	**Primed and Painted**		
Steel Door Frames:	Steel frames	1 1117,45	
	Fixers	82,38	
	Primer and Paint	47,26	
	Fuel and power	540,08	
	Total		**1 787,17**
	Galvanised		
	Steel frames	1 809,63	
	Fixers	126,14	
	Fuel and power	826,03	
	Total		**2 761,80**
Plumber and drain layer:	**Wash hand Basin**		
Sanitary fittings:	Basin	5 773,51	
	Fuel and power	788,29	
	Total		**6 561,80**
	Bath tub		

	Tub	15 270,31	
	Fuel and power	2 084,89	
	Total		**17 355,20**
	Wc		
	Wc	10 625,32	
	Fuel and power	1 450,70	
	Total		**12 076,02**
LENGHT (m)		**Partial (MJ$_T$ Each)**	**Overall (MJ$_T$Each)**
Carpenter and joiner:	**Timber trusses**		
Roof trusses:	38 x 114mm SA pine	86,18	
	Fixers	17,89	
	Fuel and power	18,32	
	Total		**122,39**
Timber Skirting	19- 25 x 70 -75 mm Timber	111,12	
	Fixers	28,74	
	Fuel and Power	23,62	
	Total		**163,48**
Plumber and drainlayer:	**Galvanised sheeting**		
Gutters	Sheeting	540,54	
	Fixers	17,86	
	Fuel and power	62,35	
	Total		**620,73**
	Asbestos-cement		
	Asbestos-cement	605,24	
	Fixers	26,66	
	Fuel and power	93,44	
	Total		**725,34**
Plumber and drainlayer:	**Mild Steel**		
Sewage Pipes	Pipe	605,24	
	Fuel and power	26,66	
	Total	93,44	**568,54**
	Plastic		
	Pipe	565,21	
	Fuel and power	42,66	
	Total		**607,87**
	Cast iron		
	Pipe	1 582,41	
	Fuel and power	174,89	
	Total		**1 757,30**
Plumber and drainlayer:	**Vitrified clay**		
Drain Pipes	Pipe	437,76	
	Fuel and power	94,38	
	Total		**532,14**
	Plastic		
	Pipe	794,59	
	Fuel and power	94,71	
	Total		**889,30**
AREA (m²)		**Partial (MJ$_T$ Each)**	**Overall (MJ$_T$Each)**
Formwork	**Formwork**		
	Steel	225,84	
	Timber	215,45	
	Fuel and power	286,31	
	Total		**727,60**
Brick Layer	**Brick**	835,80	
	Cement	168,22	
	Sand	69,01	
	Metal	25,22	
	Fuel and power	622,43	
	Total		**1 720,68**

Carpenter and joiner: Timber board shelving	**18 – 25mm, Paint Ready**		
	Timber board	1 121,00	
	Fixers	161,02	
	Fuel and power	203,62	
	Total		**1 485,64**
	18 – 25mm, Decorative veneer		
	Timber board	1 606,32	
	Fixers	230,82	
	Fuel and power	291,80	
	Total		**2 128,94**
Carpenter and joiner: Ceilings:	**Gypsum plasterboard on timber brandering(38x38mm)**		
	Gypsum board	375,15	
	Timber	103,64	
	Fixers	33,44	
	Fuel and power	78,59	
	Total		**590,82**
	Acoustic boards on T- system		
	Boards	591,44	
	Fixers	339,34	
	Fuel and power	123,90	
	Total		**1 054,68**
Carpenter and joiner: Roof coverings:	**Troughed iron cover**		
	Troughed iron	769,61	
	Fixers	329,96	
	Fuel and power	120,45	
	Total		**1 220,02**
	Corrugated asbestos – cement		
	Asbestos-cement sheets	627,81	
	Fixers	44,29	
	Fuel and power	96,91	
	Total		**769,01**
	Terra-cotta, cement or concrete tiles		
	Tiles	436,73	
	Felt	326,25	
	Timber	69,62	
	Fixers	44,87	
	Fuel and power	105,56	
	Total		**983,03**
Waterproofing: Sheet water proofing on flat roofs	**Waterproofing felts**		
	Adhesives and sealants	1761,62	
	Fuel and power	99,73	
	Total		**1 861,35**
Fibre glass insulation	**Fibre glass**		
	38mm thick fibre glass	182,28	
	Fuel and power	22,20	
	Total		**204,48**
Floor coverings	**Vinyl Asbestos Tiles**		
	Tiles and adhesives	1 581,20	
	Fuel and power	89,51	
	Total		**1 670,71**
	Quarry tile		
	Tile	1 329,75	
	Cement	196,38	
	Sand	67,14	
	Fuel and power	242,08	
	Total		**1 835,35**
	Terrazzo tile		
	Tile	900,41	
	Cement	178,78	

	Sand Fuel and power total	60,99 220,06	**1 360,24**
Structural steelwork	**Steel window frame (residential)** Steel window frame Fixers Fuel and power Total	3 201,02 105,55 1 064,92	**4 371,49**
	Steel window frame (industrial) Steel window frame Fixers Fuel and power Total	4 735,24 156,30 1 575,24	**6 466,78**
Plastering	**Floor screeds** Cement Aggregate Fuel and power Total	189,34 14,44 92,54	**296,32**
	Granolithic Cement Aggregate Petro-chemical prod. Fuel and power Total	133,79 35,31 28,21 42,32	**239,63**
	Terrazzo Cement Aggregate Perto-chemical prod. Fuel and power Total	533,59 140,44 111,76 168,56	**954,35**
	Vertical plastering Cement lime Aggregate Fuel and power Total	121,27 15,56 25,41 38,27	**200,51**
Tiler	**White, glazed tiles to walls** Tiles Cement Aggregate Fuel and power Total	856,39 134,18 45,74 165,09	**1 201,40**
	Ceramic floor tiles Tiles Cement Aggregate Fuel and power Total	1 347,99 120,86 72,22 259,82	**1 800,89**
Painter	**PVA or acrylic (internal walls)** Paint Fuel and power Total	54,43 20,73	**75,16**
	Gloss/oil paint Paint Fuel and power Total	69,84 26,63	**96,47**
Glazier	**3-4mm clear glass** Glass Putty Metal	1 020,60 183,08 15,81	

	Fuel and Power	117,73	
	Total		**1 337,22**
	6 mm laminated		
	Glass	3 540,05	
	Putty	634,93	
	Metal	54,80	
	Fuel and Power	408,37	
	Total		**4 638,15**
VOLUME (m³)		**Partial (MJ$_T$ Each)**	**Overall (MJ$_T$Each)**
Excavation and filling	**Open face and basement excavations**		
	Timber	44,22	
	Fuel and power	234,98	
	Total		**279,20**
	Trenches and holes		
	Timber	48,99	
	Fuel and power	260,28	
	Total		**309,27**
	Filling		
	Gravel	81,32	
	Fuel and power	183,16	
	Total		**264,48**
Mass concrete	Cement	3 769,00	
	Aggregate	1 114,67	
	Non-metallic mineral products	285,31	
	Fuel and power	3 137,82	
	Total		**8 306,80**
Reinforced concrete	Cement	3 458,20	
	Aggregate	1 576,37	
	Steel	700,57	
	Fuel and power	3 551,14	
	Total		**9 286,28**

Taken from Irurah (1997)