Implementing Value Engineering in Green Buildings for Energy Efficiency

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Declaration

I declare that: "Implementing Value Engineering in Green Buildings for Energy Efficiency" is my original work. It is submitted for the degree of Master of Science in Building at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination in any other university. All the sources I have quoted have been indicated and acknowledged by means of complete references.

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Signed

Martin.R.K.Shoniwa

Name

13th November 2008

Date

Acknowledgements

I am deeply indebted to Professor Alfred Talukhaba for patiently holding my hand and showing me how to produce quality and high standards in research in the difficult task of being my supervisor. Without his guidance and wisdom and motivation this research would not have been possible.

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My sincere gratitude also goes to the many seekers of knowledge who preceded my work and set out the path for my search for wisdom especially in the field of green buildings, energy efficiency and value engineering. The future belongs to us because of the foundations you set in our yesterdays.

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Abstract

This research primarily addresses problems in the implementation of green building principles for energy efficiency. The root of the problem lies in how green building principles are being implemented for energy efficiency. It is possible that only one green principle like insulation can be applied to only one building element like the roof and then the building is labelled a green building. The problem here is that in time the building might change ownership and the new owners can renovate and perform building alterations to that green building element and the building will not be as green nor as energy efficient as it was labelled. This could have been avoided if the building had been identified as green according to how well-spread across the building the green principles were.

In other instances, a green building can be designed with many green building techniques but which only cover one specific principle. For instance, a green building may be designed with massive radiant heating and cooling systems, lots of trombe walls, large atriums and sunspaces, and slabs fully covered with rock beds. But all these green building technologies are all really addressing a single green building principle in the form of thermal mass storage. The green technologies being used are not addressing other green building principles like lighting systems and cooling systems so the problem is that this green building is not maximizing on energy efficiency as it might have if the principles were implemented in a more well spread fashion across the building.

So the problem that is being researched is that there needs to be a more systematic method of ensuring that green building principles are well-spread in the way they are implemented in a building. This research will need to first identify which of the many green building principles have energy-efficiency potential and then systematically classify green building principles and listing the technologies aligned to each energy efficient green principle. This research will then root out the value of each green principle based on its definition and use that to measure its effectiveness in comparison with other green building rating systems. Then finally this value for use method will be used to measure how well spread the green building principles are used across building elements of prominent and rated green buildings to assess how well spread those green principles are implemented across building elements.

Keywords

Green Building Principles and Techniques, Building Elements, Green Building Rating Systems, Value Engineering.

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Chapter 1

Introduction

1.1. Topic Background

Which principles of green building have potential energy-efficiency benefits, what are the rating systems used to measure the effectiveness green building principles, and how can we use value engineering to systematically implement the principles of green building for energy efficiency?

"In the developed world, the built environment … consumes between 40% and 50% of a country's energy." (du Plessis 2002; foreword).

The Principles of Green Building as an alternative method of Energy Efficiency are rooted in Ecology. Roaf (2001; 11) defines Ecology as the study of the interactions of organisms and their physical and biological environment. Birkeland (2002; 1) observes that it is now possible to design products, buildings, and landscapes that purify the air and water, generate electricity, treat sewerage, and produce food. Just as people live in a building, a building lives on a site and can thus be designed to be ecologically friendly. The process of designing a building as part of the planet's ecology closely connected to the site, social and regional context is now collectively called "Green Building."

According to Wikipedia (2007; 1) Green Building is the practice of increasing the efficiency of buildings and their use of energy, water, and materials, and reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal — the complete building life cycle.

Roaf (2001; 1) states that the shift towards green building began in the 1970's as a response to higher oil prices and points to 2012 as being the when the oil shortages will really begin to bite hard and start changing the face of society. The US imports 53% of its energy and Australia imports 60% of its energy, when they could be energy self-sufficient by using appropriate technologies. (Birkeland 2002; 15). Buildings are the single most damaging polluters of the planet, consuming over half of all the energy used in developing countries and producing over half of all climate change gases. (Roaf 2001, 1) Although urban areas occupy only 2% of the world's land surface, they use 75% of the world's resources and release a similar percentage of global wastes. (Birkeland 2002; 57).

Ecological design can be cheaper, cleaner and more equitable because it works with, rather than against – natural systems. Some buildings have been designed to create a fraction of the energy demand of similar buildings at little or no extra cost (Mackenzie 1997). Well-designed buildings can generally retrieve any extra costs incurred for energy conservation measures within eight to ten years, in those cases were extra costs cannot be avoided altogether (Edwards 1998; 2), (Birkeland 2002; 14).

Some buildings have only implemented very few green principles across only a few building elements then labelled their properties as green buildings. This research sets out to investigate if the green principles are well spread across the building elements. The danger of this is that if only one principle was implemented on one building element and that building was rated green, then if, say, a new tenant were to buy that building and then demolish that particular building element to make the building better suit his needs, then the building is not a green building as it was previously labelled. Green principles need to be consistently and equally spread across building elements to be sustainable and effective throughout the life cycle of a building.

1.2. Problem Statement.

This research primarily addresses problems in the implementation of green building principles for energy efficiency. The root of the problem lies in how green building principles are being implemented for energy-efficiency. It is possible that only one green principle like insulation can be applied to only one building element like the roof and then the building is labelled a green building. The problem here is that in time the building might change ownership and the new owners can renovate and perform building alterations to that green building element and the building will not be as green nor as energy efficient as it was labelled. This could have been avoided if the building had been identified as green according to how well-spread across the building the green principles were.

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1.3 Importance of this Research

1. The very act of classifying both green building principles and techniques and relating them to building elements as suggested by value engineering introduces a systematic, structural and holistic approach to implementing Green Buildings for energy-efficiency which guarantees that buildings implement more energy-efficient techniques and become more effective in saving energy.

2. The functional and fitness-for-use approach of spreading Green Building Principles and Techniques across Building Elements also allows better individual assessment of each green principle for its performance and in relation to how it's used on a specific building element. When this advantage is enhanced with further investigation on how much energy is actually saved by specific green principles on specific building elements, then the building's energy-efficiency performance can actually be dictated and upgraded by using value engineering which all gives the designer more control in green building design.

3. By measuring how well spread building elements are used across building elements, then green building principles and techniques are exposed to more physical material and spaces on which to implement their energy saving techniques and this means the same green building principles and techniques will save more energy from that building than before.

4. Another critical importance is that currently, the implementation methods for Green Building Principles have focussed on the 80/20 rule where all green building principles are collectively considered as a whole and those that are cheapest or easiest to implement for the best result are applied. Now with this research comes the opportunity to further classify Green Building Principles and hence apply the 80/20 rule at a micro scale for the same benefits but with an effective and boosted value!

1.4 Research Objectives

1. To identify the principles of Green Building that potentially beneficial to energy-efficiency.

2. To critically review the rating systems used to assess the implementation of green building principles.

3. To introduce value engineering as a method to measure the implementation of green building principles for energy efficiency and as a tool to manage and control quality in implementing green building principles.

4. To carry out a field investigation on how the principles of green buildings are being implemented for energy efficiency.

5. To conduct a field investigation of how well-spread the principles of green buildings are across building elements.

1.5. Research Questions

1. Which of the green building principles have energy efficiency potential among other uses of green building principles and can they be classified by use including listing the techniques aligned to each principle?

2. How effective are the current rating systems that organisations use to assess the implementation of green building principles?

3. Is it possible to formulate an assessment system more suitable for the specific and unique purpose of rating the implementation of green building principles for energy efficiency?

4. How practical it is to implement each of the green building principles for energy efficiency and which are the most implemented and least implemented principles?

5. How well spread are green building principles and techniques applied across building elements?

1.6. Hypothesis

1. Some of the green building principles implemented by design professionals are not energy efficient. There is a clear definitive list of types of green building principles that have energy efficiency benefit based on understanding the mechanics of how each green building principle works so as to extract the maximum value and a list of techniques aligned to each principle.

2. The rating systems used to assess green buildings are not effective because their methodology does not extract the most value that can be extracted from each energy efficient green building principle. Value Engineering is a better quality than the rating systems currently being used to assess green buildings for energy efficiency.

3. The Principles of Green Buildings for Energy Efficiency are not being implemented effectively in buildings by design professionals and therefore the property and construction industry is not benefiting from maximum value out of their implementation.

4. There is a minimum number of green principles that must be implemented on a building for that building to be labelled a green building and there is a minimum number of green principles that must be applied to each building element for green principles to be consistently spread across the building.

1.7. Scope

While ecology broadly covers living organisms and how they relate to their environment including factors like sunlight, climate and geology (Wikipedia 2007; 1), it can narrowed down to focus on Green Building which also is a broad subject and can further be broken down into concepts like conserving energy, conserving water, improving occupants health and reducing environmental impact (Wikipedia 2007; 1). There is need for research that singles out which Green Building principles have energy efficiency benefits so that they can be more efficiently applied in isolation with the specific benefit of energy efficiency.

When the Green Building principles which have energy efficiency potential have been singled out, they need a description as to how they work so as to identify the actual roots energy saving potential in the Green Building principle so as to investigate ways to boost how effectively it is implemented. Without a description of how each Green Building Principle actually works, it is impossible to understand the methodical application that makes the Green Building Principle to be used in a maximally productive way.

There is need to analyse the current systems of measurement and ratings of their implementation. While it is important to identify the Green Building Principles with energy efficiency potential and while it is also important to understand the inner working of each principle so as to use the principles more effectively. It is equally important to implement rating systems so as to measure how effectively Green Building Principles are being used for energy efficiency. Green Building Rating Systems are also important as a quality control tool. When Buildings are designed using Green Building Principles it is important to implement a measure of how “green” the buildings are so as to identify methods of making the building more energy efficient using green principles.

The US Green Building Council (2005; 5) states that [Green Building Rating Systems] can be an asset because [projects and building professionals] get recognised in their communities, organisations, and industries for their commitment to environmental issues. The World Green Building (WGBC 2007; 01) enhance this by stating that Green Building Rating Systems stimulate market demand for high-performance buildings, provide "branding" and transform the skills and knowledge of the industry as a whole. So, having understood the essential role of rating systems in implementing green buildings, it becomes critically important to assess whether these rating systems themselves are fit for their use of measuring how effective green building principles are.

A critical scope limit of this research is that it does not confront issues of embodied energy because while they are very valid, they do not address issues of sustainable living on a design and lifestyle level.

This research does not extend into the technical methods and processes of measuring and quantifying the effects of green building and formulating how to measure principles of green building. While the valuating and quantifying and formulating the measurement of green building is critically important, it is not in the scope of this research because this research primarily focuses on measuring the implementation of green building principles and not measuring the effects.

This research primarily focuses on describing the green building principles that are of benefit to energy-efficiency. There are many green building principles which focus on different aspects of resource management. Some green building principles are focused on health management of buildings and avoiding the sick building syndrome. Other systems are focused on water conservation. While these are valid and have an important role to play in resource management, this research is centrally focused on energy efficiency and the principles that can help in the conservation and better use of energy.

Regional context and ecosystems play a huge role in influencing the ecology of a site and the resulting implementation of Green Building Design Principles. However, it is also important to note that the more that green building design principles are implemented on a particular site, the more opportunity that project has to conserve energy. This attitude can be attributed to the fact that it is possible to implement green building principles to any site as a means of conserving energy. However, the principles that could be used in different regional contexts and ecosystems will obviously be varied to suit.

There is a lot of literature which has been written on ecologically sensitive buildings and on sustainable green building principles and on energy-efficiency, most of which are valid by authors like Roaf. The key aim in this research is outlining green building principles beneficial to energy-efficiency, understanding which ones work, and using value engineering to ensure these principles are implemented more effectively.

1.8. Limitations

The first limitation of this research is geographical. Different regions of the world experience different climates and as a result have to implement different methods of controlling their environment. While the design objective of a building in a desert climate could be reducing heat gain, the design objective of a building in the arctic could be reducing heat loss. As a result, the implementation of green building principles around the world varies and there are limitations to a consistent and principled method of implementing green building principles around the world.

Furthermore, within similar climatic regions, there is great variation in the characteristics of individual sites. Two sites may experience the same climate but one may be on the top of a hill with a lot of tree coverage while the other is on the bottom of a valley with a bare minimum number of trees. As a result, the different character and personality of each site leads to a varied and inconsistent implementation of green building principles even on different sites in the same climatic region.

Another limitation of this research is that, at the time of writing, the Green Building Council had only recently been implemented in South Africa and had yet to be fully established like the branches in the United States, Australia, Japan, the United Kingdom, and other developed countries around the world. As a result, South Africa lacks a base where the ecologically sensitive design professionals can share and exchange ideas in the development of green buildings as specifically sensitive to the South African Climate. This resulted in lack of adequate literature in the implementing green buildings in the South African context.

Another limitation was lack of a rating system for accrediting Green Building design professionals. One of the primary tasks of a National Green Building Council is to assess the competence of design professionals in their ability to design green buildings. For example, the United States Green Building Council (USGBC) has implemented a Leadership in Environmental and Energy Design (LEED) accreditation for design professionals. At the time of this research, a similar system still had to be implemented in South Africa and this made it difficult to identify which design professionals were green building experts.

Another limitation was lack of a rating system for green buildings in South Africa at the time of this research. Most Green Building Councils around the world have implemented rating systems for green buildings like the Green Star rating system as implemented by the Australian Green Building Council. As a result, this research was challenged by limitation of South African case studies and examples to quote as a point of reference and all South African examples could only be assessed using comparable standards around the world.

Despite this, the results of this research can be relied on because the implementation of green building principles is universal irregardless of climatic region as long as there is good understanding of the site characteristics and personality. Because the principles of Green Buildings are universal, ideas on how they have been implemented across the world can also be shared and exchanged to suit the South African climate. Above all, while an established green building council would be ideal, the green building design community has always and will always continue to exist in South Africa and they will always continue to pioneer in the design of world class standard green buildings. The reason why the result of this research can be fully relied on is that the opinion of the design professionals and each green building case study assessed in this research has been assessed on its own merit based on how consistent it is with principles of green buildings.

1.9. Report Structure

Research Introduction

This is an overview of the whole research, which introduces the topic of green buildings and outlines the purpose and importance of green building and the research objective of investigating how well spread green principles are across the building elements. This also includes an outline of the scope and limitations of this research.

Review of Green Building Principles and Techniques

A systematic breakdown of all the green principles that have potential energy efficiency benefits. This literature review explains how each green principle works, which ones are of fundamental importance to implementing it in an innovative industry like building design, and how much potential energy each principle could save in a building. The nine green principles orientation form and shape, wind design and protection, solar and renewable energy, cooling systems, warming systems, lighting systems, thermal mass storage systems, insulation, ventilation.

Review of Green Building Rating Systems

An interrogation of rating systems used to assess green buildings across the world and ideas on implementing value engineering to green building as an assessment method. The rating systems assessed include the Green Star from Australia, CASBEE from Japan, BREAAM from the United Kingdom, LEED from the United States and then ideas on how to implement Value Engineering as a rating system.

Research Design and Methodology

Description of the research type, the research design, describing the hypothesis, methods used to collect the data sample, how the green principles and building elements for each case study were recorded, graphing the principles to elements relationship. Calculations to be done

Content Analysis Data Sampling

Thorough assessment of the data sample of 24 international building case studies have been highly recommended by green building rating systems or have won highly acclaimed national and international awards in sustainable design. This includes a brief introduction to each project and then full content analysis of the Green Principles used on each project and a final energy filter of which building elements each Green Principle is applied.

Calculations, Graphs and Charts

Graphs that relate the Green Principles used and the Building Elements they are used on the collective sample of 24 green building case studies and for each of the nine individual green principles. Graphs and tables and calculations of the relationship between green principles and the building elements they are implemented on including Table of collective results, Mean and Standard Deviation, Correlation and Correlation Significance, Simple Regression Line and F-stat.

Green Building Value Engineering

A value engineering approach to studying how green building principles and techniques have been implemented on three different building types – an office block, a residential house and a school dance hall and pavilion. This includes tables of functional analysis of buildings as adapted from the core fundamental definition of Value Engineering outlined in the literature review of Value Engineering as a rating system.

Chapter 2

Principles of Green Building.

2.1. Orientation, Form and Shape

2.1.1. Orientation: Building as Periscope

Buildings can be periscopes, trained to catch the light, a view, the wind or the sun. If you design them for any of these functions they must face the correct direction … simply by facing the living rooms of a house towards the sun it is possible to save up to 30 percent on the annual heating bills of a typical house in a temperate climate. (Roaf 2001; 30)

2.1.2. Site and Energy

[In residential buildings,] the 'ideal' orientation for solar passive design [in combination with] large window openings … allow the sun to flood into the building in winter-time … Studies have shown that for a given time site with given houses, simple site replanning and dwelling orientation can almost halve energy demand per house. (European Commission 1999; 58-59)

When hard surfaces are used, pale colors are more effective in reflecting solar radiation and consequently keeping down surface temperatures, but they may cause glare. For cooling, it is best to minimize the heat absorbent and effective materials near and/or shade them from any direct sunshine … use vegetation in the form of trees or vines, and ground cover planting instead of hard surfaces. Both will lower temperatures through shading and evapo-transpiration. Consider the use of water features to provide evaporative cooling. (European Commission 1999; 60)

2.1.3. Building Form

Watson and Labs (1983; 99) claim that for any given building volume, the more compact the shape, the less wasteful it is in losing heat. Roaf (2007; 17 – 19) further adds that the greater the volume of the building the more surface area it has to gain or lose heat from. The surface area – volume ratio is very important in conserving heat transfer into and out of a building and to conserve heat or cold. The building must be designed with a compact form to reduce the efficiency of the building as a heat exchanger. (Roaf 2007; 17 – 19).

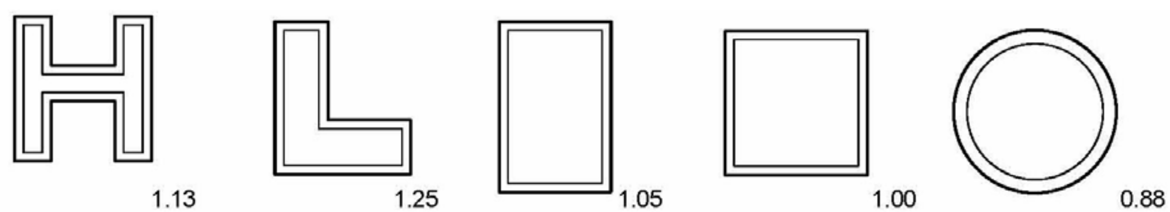


FIG 2-1 Buildings can have different perimetre: area ratios depending on their plan form (after Roaf et al, 2001; pp 19)

The concept of building in warm or hot countries means the building must become a good heat dissipater. Just like people who are hot [stretch] out to lose heat, so buildings sprawl out in warm or hot countries. In …hot climates buildings have high surface area: volume ratios but walls facing the sun are protected from radiation by verandas, balconies and wide eaves. The shallower floor plan … also promotes easy cross-ventilation of rooms for cooling. House forms in such climates are either long and thin or have a courtyard, or lightwell in the centre of the house, to maximize the building's wall area. (Roaf 2001; 21)

Making the building the right shape and the correct orientation can reduce the energy consumption by 30-40% at no extra cost. (Roaf 2001; 60)

Where possible, locate spaces requiring continuous heat on [northern] facades so that they can benefit from solar gain. Buffer the [south] with spaces which do not need heat … for optimal performance of passive solar heating, daylighting and natural cooling, the heat gaining space should face within 15 degrees of due [north]. (European Commission 1999; 60)

2.1.4. Earth-Sheltering Recess.

Buildings constructed on the surface are exposed to the full brunt of climatic stresses … most of these stresses are appreciably damped out or stabilized below grade, and this benefit can be exploited through sub-surface construction … subsurface construction fulfils requirements of many climatic design strategies, including thermal control, wind protection, stability of moisture effects on materials … soil is not a good insulator … [but] … the effective thickness of soil as insulation quickly adds up … [and beneath a certain depth] … the additive resistance of soil is sufficient to take over the insulating job by itself … like above ground houses, the solar heating potential of underground construction is a matter of orientation and design … nonetheless, the foundation, slabs and earth in contact with [the soil] provide an inexpensive form of thermal storage for solar-orientated house designs. (Watson and Labs 1983; 103)

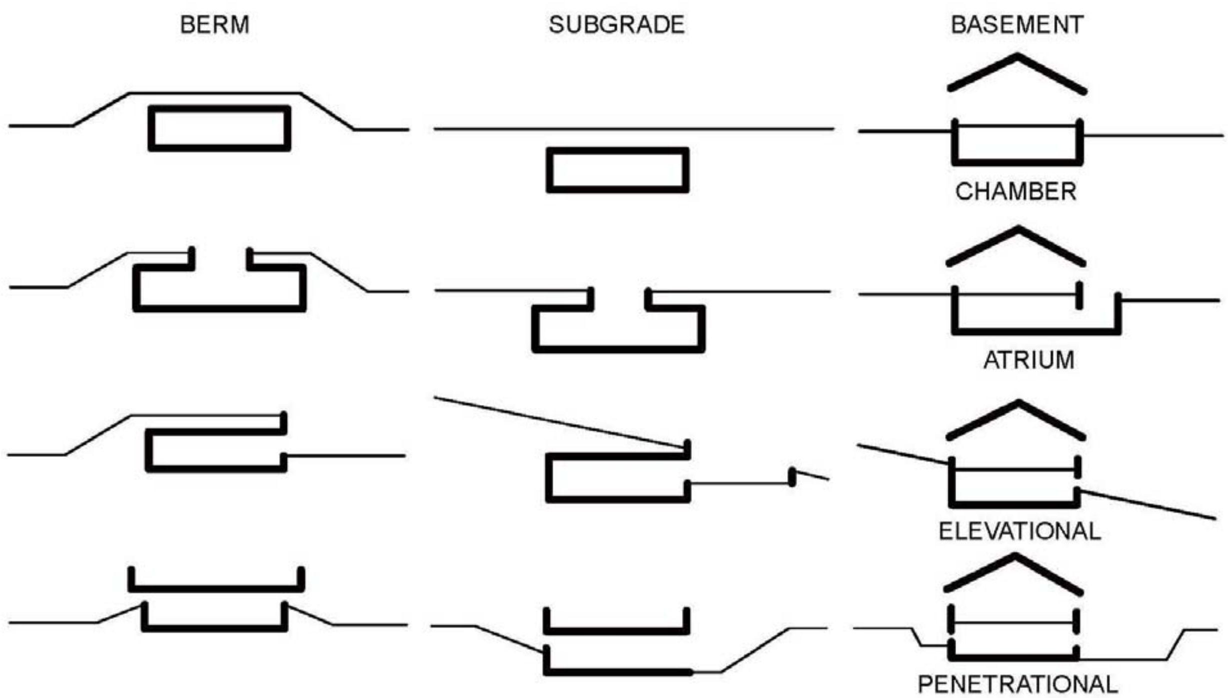


FIG 2-2:- Earth-tampering design approaches for energy-efficiency (after Watson and Labs, 1983; 104)

2.2. Wind Design and Protection

…avoid open areas, hilltops and valley floors that are directly exposed to prevailing winter winds. Existing hedgerows, hillocks and tree stands may be available as windshields … cold air flows downhill just like water, so that although a valley may seem to be shielded from cross winds, it actually may be in the midst of a steady downstream night time cold air current. The best protected sites occur on leeward slopes … in the absence of … existing landforms and tree masses, barriers can be created for wind control. Trees and shrubs are the most common but berms, fences and walls can also provide benefit. Usually, the higher the barrier, the larger the protective “wind shadow” … the energy effectiveness wind protection follows directly from the amount of windspeed reduction. (Watson and Labs 1983; 85)

2.2.1. Wind Turbulence Protection

Winter windflow against a structure affects the rate of heat loss by increasing infiltration … and by increasing conductive heat flow through the shell by the rate at which heat is convected away from the exterior shell surface …

the best approach is to keep the building and roof pitches low. This reduces the "air-dam" effect of the building and permits relatively smooth air flow … the shape of the building shell can be streamlined with respect to orientation … rounded corners reduce pressure build-up by "leading" the air stream around the structure to promote laminar flow of wind. (Watson and Labs 1983; 103)

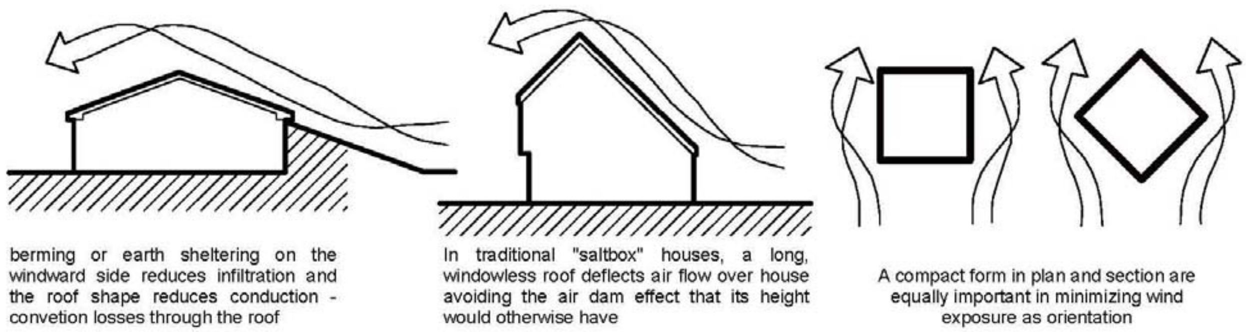


FIG 2-3:- Compact form and orientation minimises exposure (after Watson and Labs, 1983; 103)

2.2.2. Wind Channelling

Site topography will affect wind speed and direction. In many areas … the wind blows predominantly in one direction and design should attempt to deflect or reduce this without reducing solar gain. Wind speed or direction can be modified by new land forms, structures and vegetation, and the form of individual buildings can be designed to block and divert winds. Using or creating shelter can cut heat loss from buildings, through convection and infiltration, by up to 15% (Barton, Davis and Guise, 1995; 3). It can also improve the comfort of outdoor spaces.

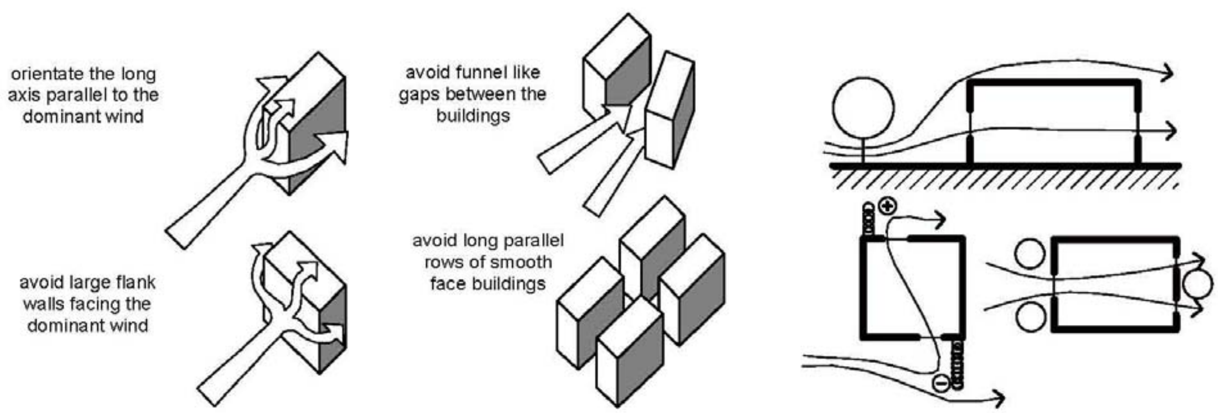


FIG 2-4:- use of building form and arrangement of building clusters to shelter external spaces (after European Commission 2001; pp58-59)

2.3. Solar and Renewable Energy

2.3.1. Solar Thermal Panels

Typical solar panels consist of a collecting plate sandwiched between an insulating backing and a glazed front. Within the panels are tubes through which the water is pumped. The optimum orientation is [north-facing], though any orientation within about 30 degrees of [north] will perform as well as a south-facing collector. (European Commission 1999; 73)

2.3.2. Photovoltaic Cells

Photovoltaic cells convert sunlight directly into electricity. They are clean, quiet, maintenance free and efficient in their use of solar energy …photovoltaic cells are used in two types of installations, known as 'off-grid' and 'grid-tied'. Off-grid installations are those where the photovoltaic cells and the grids they power are not connected to a larger electricity grid. The electricity may either be used as it is generated or it may be stored for later use in batteries. Usually the cost of batteries is quite high in this type of installation. Off-grid Photovoltaic Cells are often used in isolated rural locations for applications such as refrigeration, emergency phones, and water pumps. (European Commission 1999; 103)

The advantages of photovoltaic cells are
- The energy payback (the time for the PV to produce as much energy as is required for manufacture) is 2-5 years, while the working life of a PV panel can be well over 20 years.
- It is reliable, panel warranties are now typically for 20 years.
- They are low maintenance. Once installed they will simply require their surfaces cleaning, especially in dusty environments.
- They can provide power in locations remote from the grid and they can provide power during blackouts.
- They are transportable technology and can be moved between buildings.

(Source: Roaf 2001; 170)

2.3.3. Wind Energy
Wind energy is one of the most cost effective, renewable energy sources. Wind turbines are mostly installed in groups in wind farms which supply electricity to the grid like conventional power stations … annual power output dependant on the wind speed at the site … thus economic returns from wind turbines are better off on exposed coastal or upland sites than in sheltered areas. Wind energy is one of the most efficient energy sources in terms of land use. Only 1-2% of the land on which a farm stands is occupied by turbine foundations and access roads. The rest of the land between the turbines can be used for agricultural or other purposes. (European Commission 1999; 106)

2.3.4. Biomass/Waste Energy
Heat and/or electricity may be produced from various types of waste, including agricultural wastes, forestry wastes, municipal refuse and sewerage. (European Commission 1999; 106)

2.3.5. Solar Thermal Systems
Solar thermal systems are devices which collect the energy of the sun and deliver it as useful heat mostly for domestic hot water … there are three main types of solar collectors.
- Unglazed collectors consist of black plastic or metal pipes through which the fluid medium is circulated. They are very simple and cheap to make but can only reach temperatures of about 20 degrees C above ambient air temperatures.
- Flat plate collectors … consist of a flat insulated box through which the fluid medium circulates. They can produce temperatures of up to 70 degrees C above ambient temperature.
- Evacuated tube collectors consist of … evacuated glass tubes each containing an absorber which collects solar energy and transfer it to heat transfer fluid. These collectors can produce temperatures of 100 degrees C above ambient.

Solar thermal systems are an economical and clean source of energy … a solar thermal system can supply at least 50% of a household’s energy for hot water at virtually no running cost. (European Commission 1999; 107)

2.4. Cooling Systems
Where cooling is the dominant need the following strategies may apply
- Low surface to volume ratio.
- Reduction of the surface area facing North.
- Provision of overhangs, arcades, shutters and canopies to shade the building envelope.
- Insulation of building envelope, particularly the roof.
- Control of ventilation and infiltration when exterior air temperatures are high.

- Provision of solar chimneys to encourage stack ventilation where outdoor temperatures are sufficiently cool.
- Location of openings on shaded side of building or so as to catch prevailing winds.
- Use of 'buffer spaces' on northern facades.
- Use of thermal mass to store heat produced by solar gain thus reducing overheating in interior spaces.
- Use of courtyards to form reservoirs of cool air close t building and introduce daylight to deep building plans. .
- Use of water features to evaporate cooling.

(Source; European Commission 1999; 62)

2.4.1. Shading Devices

A wide range of shading devices are available to the architect, including blinds, shutters, louvers and structural or add-on devices … use of plants for shading should also be considered. Shading devices can be classified as fixed or movable, internal or external. Overhangs, loggias and arcades are examples … These systems, while maintaining air movement, are limited in that they provide adequate shading for only part of the day in particular seasons, and limit the amount of daylight entering the space at other times of year when natural light would be most welcome … shutters can include movable shading devices. (European Commission 1999; 70)

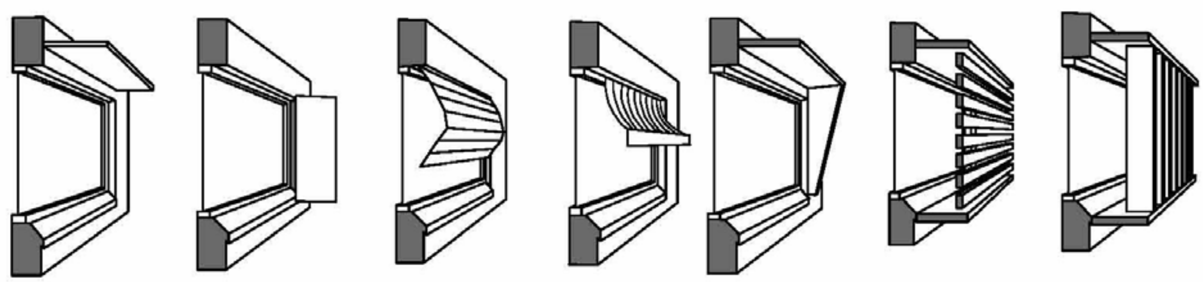


FIG 2-5 Typical fixed and adjustable external shading devices (after European Commission 1999;70)

2.4.2. Wall Shading Cooling Techniques

The colder the climate, the more insulation is needed. Reductions in solar gain through building walls can be achieved by shading devices … shading has the same effect as lowering the outside wall temperature … this in turn will reduce heat flow. A very effective means of shading walls (and window openings) is to extend or project the roof to provide a useful overhang. (Watson and Labs 1983; 158)

Outdoor evaporative cooling mechanisms can help reduce … lower indoor cooling costs by lowering air temperature surrounding the building. This reduces the cooling load transmitted through the building shell and makes natural ventilation more desirable and more effective. (Watson and Labs 1983; 97)

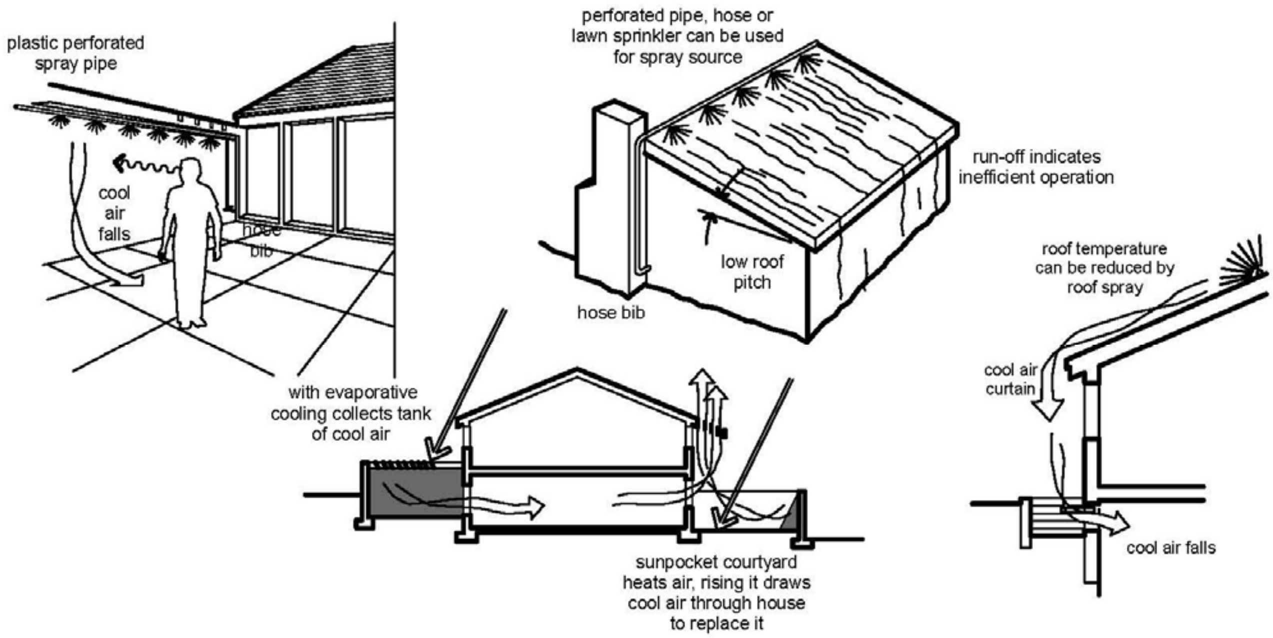


FIG 2-6:- Roof and wall cooling techniques and air flow for energy-efficiency (after Watson and Labs 1983; 96-97, 169)

2.4.3. Evaporative Cooling

Exterior building surfaces exposed to the sun can benefit from the cooling effects of surface evaporation … through roof sprays and roof washes … the primary function of a roof spray system is to relieve the roof surface of the solar load dissipating solar heat as it arrives at the roof surface. Roof spray will be of greatest benefit on roofs, (1) of lightweight construction and (2) which are exposed on the underside to an inhabited space (as opposed to an attic space). In a fairly efficient operation, over 90% of the solar load upon the roof can be alleviated. John Yellot reported in an article “Roof Cooling with Intermittent Water Sprays” “… it may be concluded that intermittent water sprays can offset the absorbed solar radiation almost completely …” (Yellot, 1978; 60-67) … Several companies supply package systems consisting of a roof surface temperature sensor, timer for intermittent spray (to prevent flooding and runoff water waste), valves, ,and a patented self-cleaning perforated spray pipe. Such systems typically mist the roof surface for 10 to 15 seconds every 10 minutes when the surface temperature exceeds 90 deg F. (Watson and Labs 1983; 169)

2.5. Lighting Systems

2.5.1. Daylighting

The amount of daylighting available in the building will be affected by the placement of the buildings on the site, the amount of overshadowing, the external landscaping and finishes. Pale surfaces on the ground and on neighbouring buildings will increase the amount of light available to the interior. (European Commission 1999; 60)

The location of trees in relation to buildings needs careful consideration, because they reduce the light transmission even when leafless in winter. One rule of thumb is to locate only smaller trees (5-10m high, depending on distance). (European Commission 1999; 60)

Artificial lighting accounts for about 50% of energy used in offices, and a significant proportion of the energy used in other non-residential buildings … the use of day lighting combined with high-performance lighting means that between 30-50% savings can be easily achieved while 60-70% savings are possible in some cases. Thus substituting daylight for energy can lead to substantial energy savings. Daylight spaces are more attractive and more economical to work and live in. in addition, a deficiency of day lighting in our living and working environment can lead to health problems … and vitamin D deficiency. (European Commission 1999; 71)

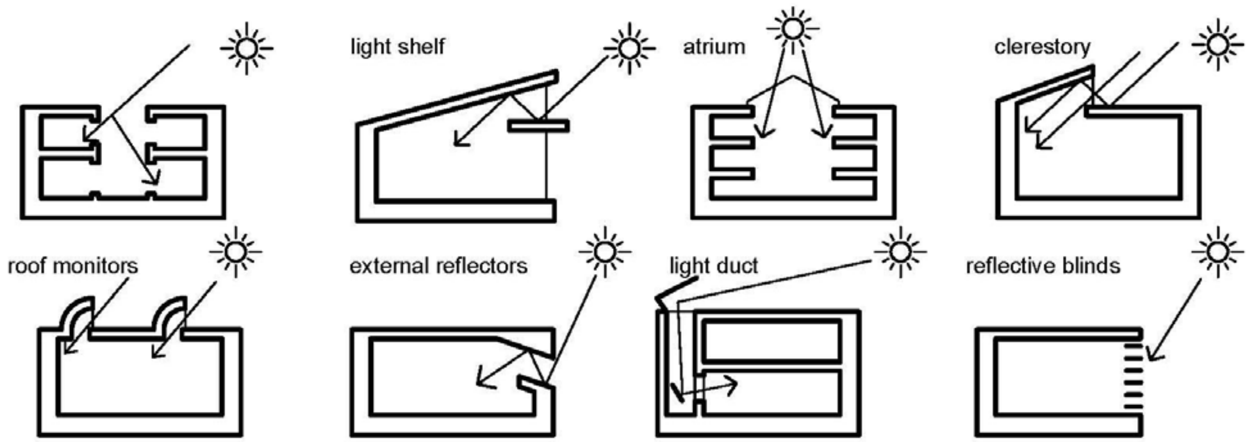


FIG 2-7:- Transparent elements as daylight devices (after European Commission 1999; pp 71)

2.5.2. Windows

As a rule of thumb day lighting will only be significant within about twice the room height of a windowed façade. Thus shallow plan buildings provide more opportunities for daylighting (as well as ventilation and cooling) than deeper ones. The level of day lighting at a point in a room depends on to a large extent on the amount of sky visible through the window from that point. Thus the provision of a significant amount of glazing near the near the ceiling is beneficial from a daylight point of view. For example tall narrow windows will provide a better daylight distribution in a room than low wide ones. For rooms at corners, windows in more than one façade or roof lights will also improve daylight distribution. (European Commission 1999; 72).

2.5.3. Lighting Controls

In a conventionally lit commercial building, controls alone can make a 30-40% saving in lighting use. Care in specifying the control system is necessary.

- Occupancy sensors help optimize the use of background lighting. There are two types of occupancy sensors: infrared and ultrasonic.
- Balancing artificial light: in rooms receiving natural light, there can be an intermittent need for artificial light depending on how bright it is outside. A fluorescent light with a ‘daylight ballast’ (which includes a light sensitive photo-cell) will vary light output according to the levels in the room, maintaining sufficient light at all times while eliminating the wasteful use of artificial light when daylight levels are already high.
- Outdoor lighting: Photocells can also be used in outdoor lighting, for example, to activate lights at dusk and switch them off at dawn. For added efficiency, the photocell can be combined with an infra-red or ultra-sonic motion detector. In this way, the lights are switched on only when daylight levels are low and there is motion in the vicinity.
- Timing devices and dimmer controls: Timers turn lights on and off at predetermined times and are useful where regular cycles of light and dark are appropriate. Dimmers will only save energy when used consistently, and can often be combined with other forms of lighting control.
- Limit the number of light fittings controlled by one switch.
- Zone light fittings and controls in relation to distance from windows.
- Make light switches accessible. Hand-held remote control switches are useful where changes in partition layout are frequent. Simple local switching of this kind can produce 20% energy savings.

2.5.4 Low Energy Lighting.

- Do not overlight the house. Use a careful selection of background lighting, task lighting and feature lighting to make sure you are not wasting money and energy. Light the floor where you want to walk, not the ceiling, and the desktop where you want to study, not the walls.
- Use lower general lighting levels.
- Avoid dark lampshades that absorb the light.
- Always use energy-saving fluorescent light bulbs that cost more to buy but work out cheaper in the long run.

Traditional filament bulbs convert around three quarters of the energy they consume into heat and not light, which may be good in winter, but is silly in summer. (Roaf 2001; 176)

2.6. Warming Systems

2.6.1. Heating Systems

Reduction in the dominant requirement the dominant requirement the following strategies can be effective

- Low surface to volume ratio.
- Maximizing solar gain.
- Reduction of the surface area facing [south] exposed to prevailing winds.
- Insulation of the building envelope.
- Control of ventilation and infiltration.
- Use of draught lobbies to separate head spaces from unheated spaces and from the outside.
- Location of entry doors from the corners and from prevailing winds.
- Use of buffer spaces on [southern] exposed facades, and unheated conservatories or 'sunspaces' on the north. The less the temperature difference between internal and outdoor temperatures, the lower the rate of heat loss through the envelope.
- Use of atria and courtyards to act as thermal buffer space and introduce daylight into deep plans.
- Use of thermal mass to store heat produced by solar gain and release it as interior temperatures fall.

(European Commission 1999; 62)

2.6.2. Vertical Air Flow Shafts

Conventional interiors can be adapted to promote to promote unrestricted rising air flow by locating open stairways in a central area to serve as a vertical ventilation conduit … another approach is to organize the entire design around an interior shaft, terminating in a skylight/ventilating monitor combination. This could be combined with a stair of fireplace, or other vertical elements. (Watson and Labs 1983; 142)

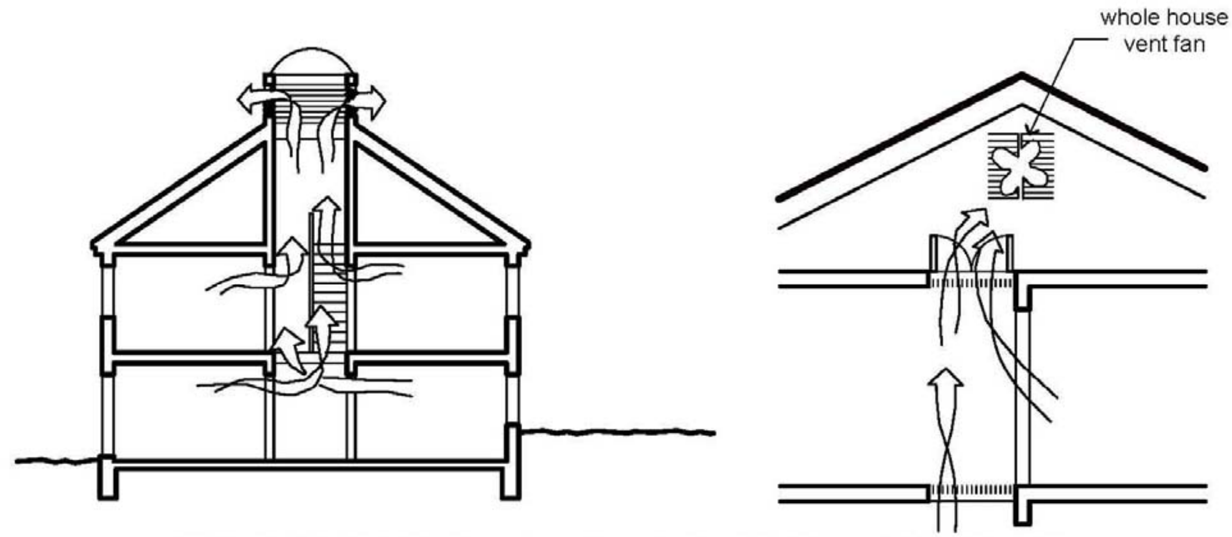


FIG 2-8:- Air shaft with skylight, floor grates and louvred ceilings (after Watson and Labs 1983; pp 142)

2.6.3. The Igloo and Bucket Effects

An important feature of building design in cold climates is the use of stratification of room air. Hot air rises while cold air sinks. This is taken advantage of in igloos … occupants of igloos live on a high shelf, to take advantage of the warmest air in the space, while the cold air sinks down and is contained in the lower entrance area in the building … Conversely, in hot climates tall rooms mean the heat and the hot ceiling are far away from the room's occupants. High level windows can allow the heat to escape from the top of the rooms … [this] stack effect is powered by … the difference between cool and warm air. This effect (in an upside down orientation) has been compared to water: if the building is a bucket with holes in, filled with water, the water will drain out of the holes, as heat will out of a building. The greater the pressure difference, the greater the … effect … this property of warm air can be used to thermally landscape the ceilings of rooms. Hot air can be chanelled around ceilings, in 'banks' or walls, to form rivers or lakes of heat that can move between areas or rooms within a building. (Roaf 2001; 25)

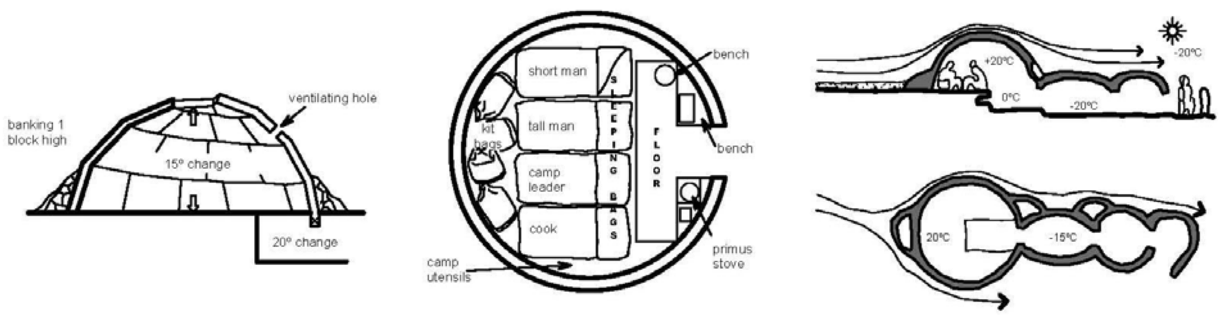


FIG 2-9:- Thermal Stratification above raised platform in igloo (after Roaf 2001; pp 24)

2.7. Thermal Mass Storage Systems

2.7.1. The Greenhouse Effect.

Imagine living in a greenhouse … glass lets light in and, with it, heat. Once solar radiation has passed through glass it hits a surface in a building and is reflected … at a changed wavelength that can no longer pass … back out through the glass, so causing the inside of the greenhouse to heat up. Once inside a greenhouse, it is difficult for radiation to pass back out, and it is why it is fairly pointless to use internal blinds because, although they shade people from direct sunlight, the heat cannot escape from the space. Conversely, greenhouses become very cold at night, because they lose heat from the building surface by radiation and eventually become almost as cold as the outside temperature. It would take a fairly brave person to actually try to live in a 'transparent' greenhouse, or suggest to someone else that they should! (Roaf 2001; 22-23)

2.7.2 Radiant Heating/Cooling Systems

Radiant heating / cooling systems supply both heating and cooling in an energy-efficient manner, by changing the temperature of the walls, ceilings, and/or floor of a space instead of heating and cooling the air. This works because the temperature experienced by the human body is approximately equal to the average of the radiant temperature and the air temperature. The radiant temperature is the average temperature of all the objects that surround the body … a radiant heating/cooling system generally consists of … pipes or tubes installed in or behind the surface of walls, ceilings, or floor of an interior space … they can reduce [or eliminate] the amount of mechanical ventilation needed to ensure comfort, and reduce the amount of ductwork needed for a conventional HVAC system by about 80%. (European Commission 2001; 110)

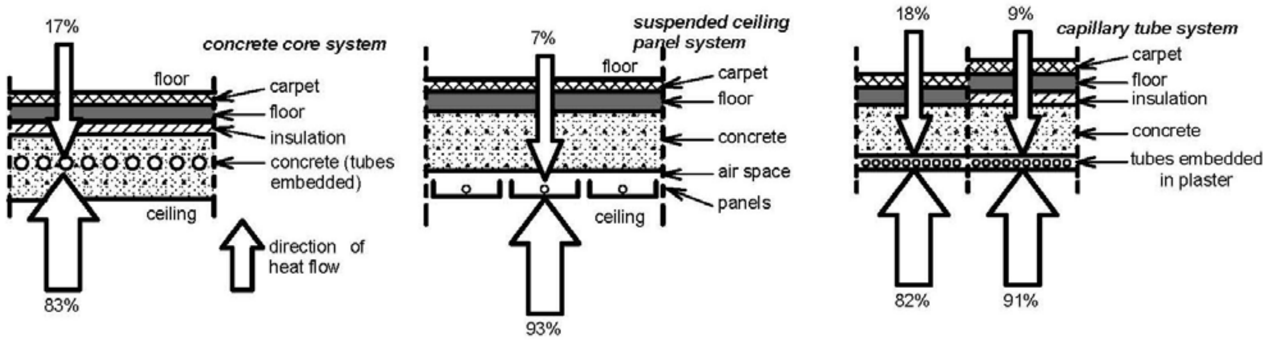


FIG 2-10:- Radiant heating systems in slabs (after European Commission 1999; pp 111)

2.7.3. Trombe Walls

[Trombe walls] consist of 150 – 500mm thick masonry wall on the south side of a building. A single or double layer of glass or plastic glazing is mounted about 10-15cm in front of the wall's surface. The exterior surface of the wall is painted a dark color to absorb solar heat, and the glazing prevents this heat from being lost to the outside. Thus the Trombe wall gradually heats up during the day with the heat penetrating slowly from exterior to the interior surface of the wall. As the interior surface of the wall heats up it radiates heat to the adjacent interior space. If the wall is the right thickness, this time lag means that the heat from the afternoon sun will start to warm the space in the evening, just as temperatures begin to drop. (European Commission 1999; 97)

2.7.4. Sunspaces

The sunspace acts as a buffer for a house, dramatically reducing heat loss. Even in the absence of direct solar gain it is a functional energy efficient device. Sunlight entering the space via glazing is stored as heat energy … a masonry wall, forming a partition between the sunspace and the rest of the house, can provide sufficient thermal mass to store absorbed heat and release it later. A natural convection loop is encourage by inserting vents at floor and ceiling level … at least two thirds of the fenestration must be openable to avoid summer overheating. If possible, provide moveable insulation to cover the sunspace glazing at night or when the weather is overcast. At night or in cold weather, the sunspace can be cut off to serve as a thermal buffer. (European Commission 1999; 75)

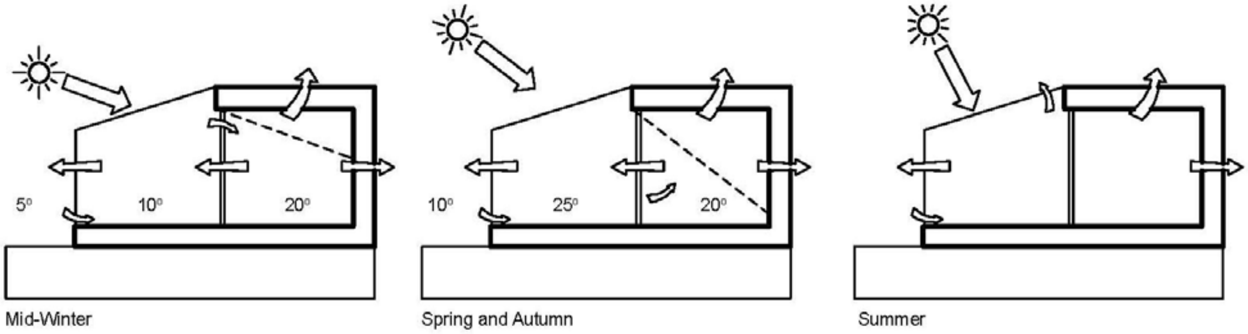


FIG 2-11:- Sunspace stores absorb heat and dissipate it later (after European Commission 1999; pp 75)

2.7.5. Atriums

Atria can noticeably improve the quality of the adjoining internal spaces, which can enjoy the fll advantages of daylight, without the accompanying climatic extremities. An atrium may retain between 30-85% of transmitted radiation, depending on the adjacent building colours and geometry. (European Commission 1999; 75).

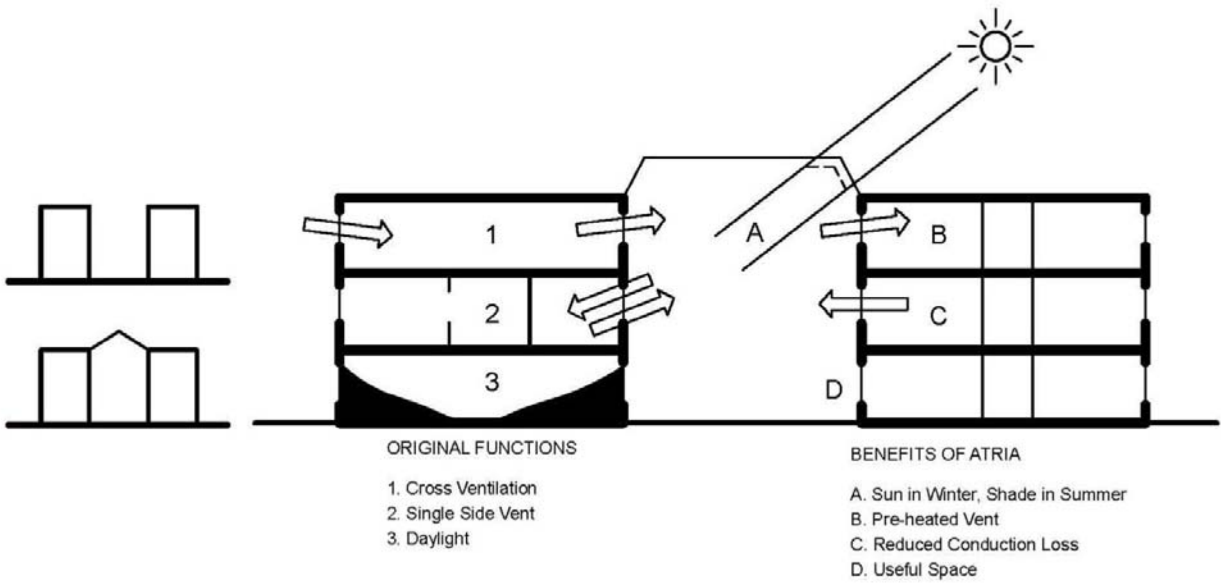


FIG 2-12:- Environmental benefits of atria (after European Commission 1999; pp 75)

2.7.6. Thermal Mass

High thermal mass is desirable to stabilize daytime temperatures and for night cooling, but may marginally increase heating cost. Thermal mass is best increased by maximizing surface area, increase in thickness is relatively ineffective. Thermal mess should not be thermally isolated from circulating air (e.g. under a raised floor or above a suspended ceiling). Secure and controllable night cooling should be provided where exposed thermal mass is intended to moderate day-time temperatures. (European Commission 1999; 64).

Masonry construction has good thermal inertia qualities, which slow down the building's response to changes in external conditions and limits internal temperature swings. A low-thermal mass building is one with a timber- or steel-framed structure and lightweight cladding panels. This gives a fast thermal response to changes in external conditions and results in large temperature swings. A concrete slab, provided that it is not covered with a lightweight finish, can act as a thermal store. (European Commission 1999; 64).

2.7.7. Centralizing Thermal Mass Radiation

In very cold climates, the rooms of buildings, just like people, hurdle together to keep warm, often around a central 'hot core', a heat source such as a fireplace … The principle is similar to that of a brick in a storage radiator. The heat comes from perhaps a fire or the sun, and it is absorbed in the thermal mass of the building, as it is in a radiator brick. Then gradually that heat is emitted back into the room over time. If a material is highly conducive, such as the copper or steel it would not store the heat and would cool down rapidly when the fire goes out, unlike the high density concrete stove that actually stores the heat and will stay warm for up to 14 hours after the fire has gone out. (Roaf 2001; pp 25-27)

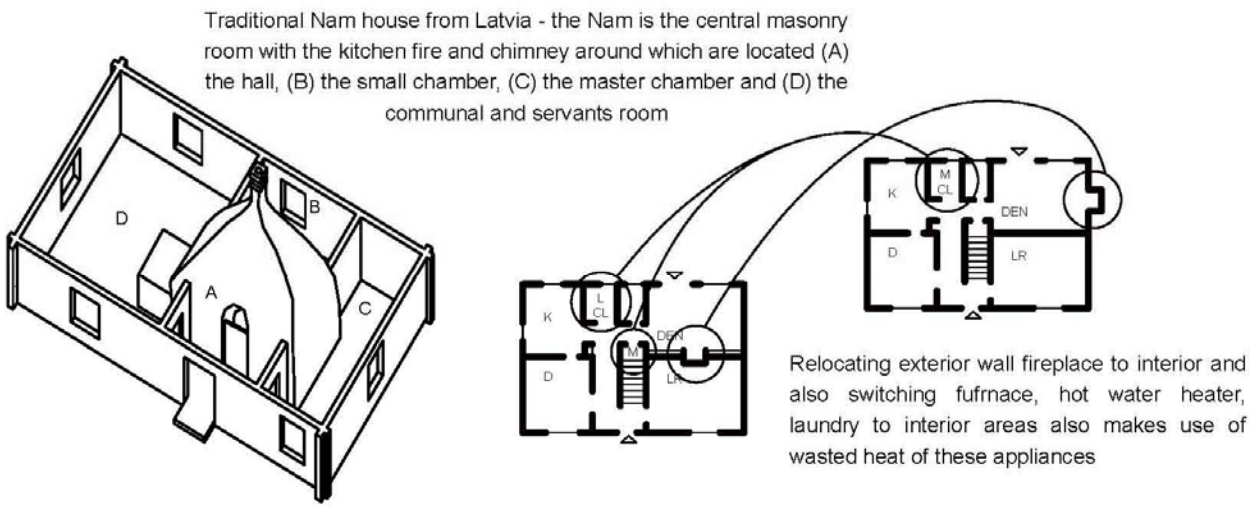


FIG 2-13:- Arranging warm and heating elements centrally to conserve energy (after Watson and Labs 1983; 101 and Roaf 2001; pp 77)

…a heat conservation principle [is] to centralize heat generating devices [like fireplaces and cooking devices] in the interior of the house … Locating ovens and stoves and other heat sources such as mechanical rooms, against interior walls will … help contain heat within the interior instead of speeding conductive losses through outside walls. (Watson and Labs 1983; 121)

Interior spaces with large [north] facing windows can overheat on a sunny day in winter. This effect, plus the fact that the sun shines for only one-third of the day during much of the heating season, makes it desirable to utilize interior materials to absorb solar heat as it arrives and to reradiate back to the interior after the sun has passed. These materials should be of high thermal capacitance, [slow at discharging heat], and located wherever surfaces are exposed to direct solar radiation for extended periods of time … the construction systems most widely used for heat storage consist of concrete and masonry. Water, though less dense than brick and mortar, is superior as a storage medium because it can store more heat per unit of volume … [three solar heat gain systems are direct gain, indirect gain and remote storage] … direct gain systems make use of high mass materials that are exposed to the interior as ordinary room elements. Floors exposed to the sun should have tile, brick, or other heat absorbing material laid on a concrete or sand bed, with no carpeting or other insulative flooring surfaces applied. Similarly, masonry walls should be left with brick, stone, concrete or tile facing when exposed to direct solar gain … best results are obtained by distributing thermal mass locations throughout the interior, some exposed to direct sun, others to diffuse or reflected sunshine, in whatever combination of masonry floor, wall, fireplace, or ceiling materials that can be practically incorporated into the house construction … indirect gain systems admit solar radiation to a non-occupied space such as a an attached greenhouse, skylight attic, or to glazed storage mass. In each case the surfaces exposed to the sun form a heat-storing and heat radiating partition with the interior living zone, usually a wall or ceiling … the storage capacity of an indirect gain system is often enhanced by ducting overheated air away from the sunspace itself into remote storage, such as a rockbin. When this is done the storage capacity of the partition itself can be reduced and nearly eliminated. This is the basis of the "solar attic" concept in which case the attic is used as a solar collector. (Watson and Labs 1983; 123)

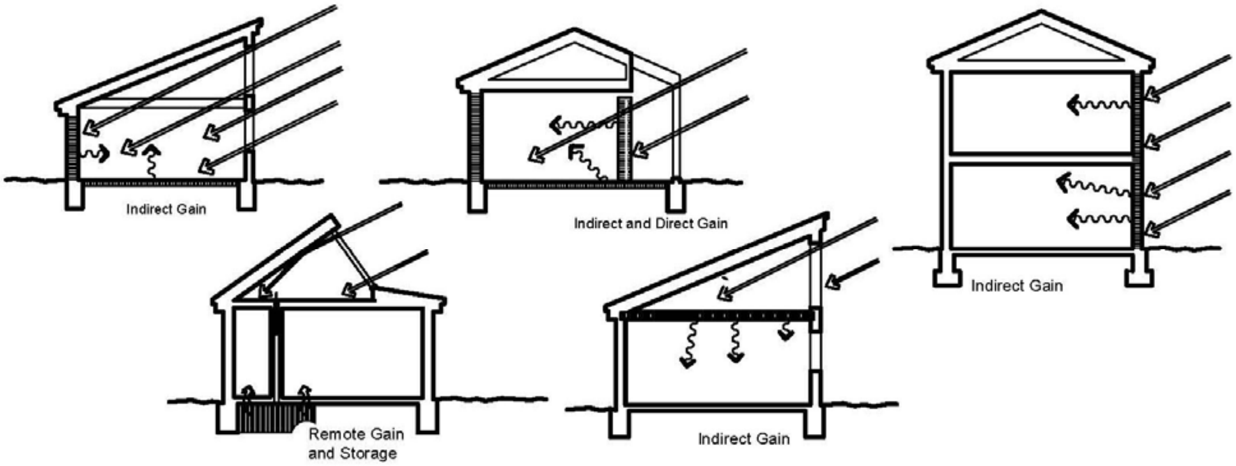


FIG 2-14:- Methods of solar gain to building interiors (after Watson and Labs 1983; 101 and Roaf 2001; pp 124)

2.7.8. Rock Beds

Rock beds can be used effectively in situations where there is an excess of energy in the form of air that is heated above the comfort level. It is desirable to remove this air for the following reasons (1) to reduce the air temperature in the space and improve thermal comfort (2) to store heat thus removed for later retrieval (3) to redistribute heat from the upper [north] side of the building where hot air tends to accumulate to the lower [south] side of the building that normally tends to run colder. … the rock bed [is placed] underneath the floor of the building, although it would be possible to place it behind one of the walls. Distribution of the heat from the rock bed to the space is entirely passive. The floor temperature or wall temperature will only be a few degrees above the room temperature. If the installation is properly designed the net result will be … heating the house from a large radiant panel. Experience with underfloor rockbeds has been very favourable … by keeping the floor temperatures 3-6 deg C of what they normally would be. By increasing the surface temperature and therefore the mean radiant temperature within the space, the air temperatures can be reduced and energy savings that are even greater than the actual amount of heat released from the rock bed can be realized. (Roaf 2001; 159)

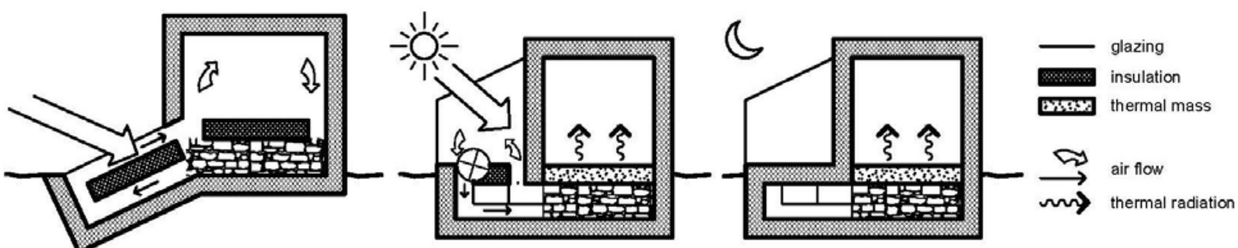


FIG 2-15:- Rockbeds used to collect and dissipate heat at night (after Roaf 2001; pp 153)

2.8. Insulation

Walls, roofs and other opaque parts of a building must be provided with thermal insulation to reduce heat loss and to maintain internal surfaces at a higher temperature … thus improving comfort levels. (European Commission 1999; 65)

2.8.1. Wall Insulation

Internal [wall] insulation will separate the thermal mass of the walls from the space, to reduce both the response time and energy required to bring to room up to comfort levels … the higher the internal capacity available as a result of locating the insulation externally means that fluctuations are reduced, but the space will take longer to heat up and cool down … Cavity insulation makes available some of the thermal inertia within the wall and … also reduces problems from thermal bridges. (European Commission 1999; 65-66)

2.8.2. Roof Insulation

Pitched roofs are usually insulated just above the ceiling level leaving the attic space unheated … the unheated space is well-ventilated and risk of condensation is low. Flat roofs may be one of two types: the ‘cold roof’ is ventilated above the insulation, while in the ‘warm roof’ the insulation … lies … below the roof covering and is unventilated. (European Commission 1999; 66)

2.8.3. Floor and Ceiling Insulation

There is evidence to suggest that heat losses through ground floors are greater than standard calculations suggest. Heat loss from the slab is not constant over the whole area of the floor, the greatest being from the edge. Insulating the edge will have as good an effect as overall insulation. Additional insulation of a suspended timber floor is usually provided in the form of either a continous layer of semi-solid or flexible material laid above the joists (and below the floor finish), or semi-rigid material between the joists. (European Commission 1999; 64)

Heat that is lost through the roof in winter first enters the attic space through the attic floor from the ceiling beneath. Either the roof or the attic floor may be insulated to restrict this flow, but the roof is the most advantageous location. This has the effect of keeping the surface-to-volume ratio small, whereas insulating the roof makes the attic space itself become part of the heated structure beneath. The … three … techniques of attic ventilation: cross ventilation, stack effect, and mechanical (fan) power, all serve the purpose of flushing out air that is heated by contact with the underside of a hot roof . (Watson and Labs 1983; 115)

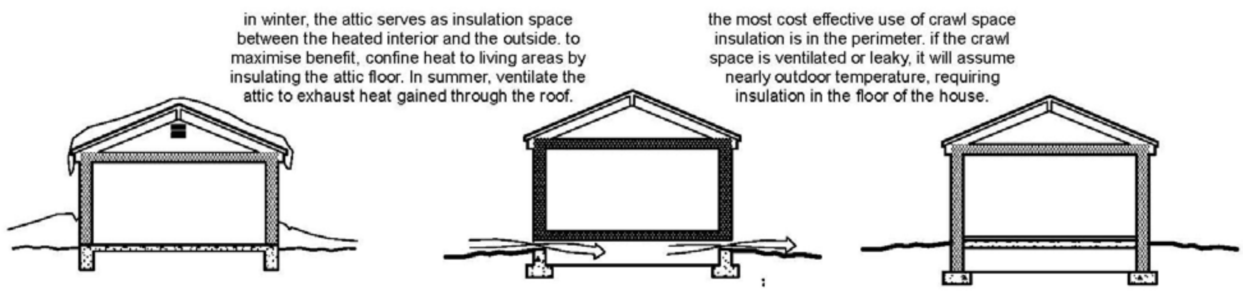


FIG 2-16:- Insulation on building elements to minimise heat loss (after Watson and Labs 1983; pp 114-116)

One way to reduce conductive losses from the floor to the ground is to raise the body of the house off the surface by constructing it over a basement or crawl space. This area then serves as a “dead air” insulation zone. Basements and crawl spaces should be insulated regardless of whether or not they are heated. Most heat loss in uninsulated basements occur at the portions above the ground. The most economical placement of insulation in a basement or crawl space is around the perimeter, [otherwise] insulation should be placed in the basement or crawl space ceiling, under the floor of the structure. (Watson and Labs 1983; 117)

2.8.4. Earth-Slab Insulation

A [floor slab on earth] has two different zones of heat transfer: (1) direct losses and gains to the perimeter of the floor slab, and (2) fairly constant thermal exchange with the ground within the central area of the slab [which is negligible]. The relative importance of these will vary with soil type, nearness of ground water level, building coverage area, and other factors … vertical placement [of insulation] isolates the cold from penetrating through the foundation and therefore offers better protection from freeze-thaw stresses. Horizontal insulation … more effectively isolates the floor from all slab-ground interactions … [so it] is more recommended when ground water level is near the underside of the slab … the immense mass of earth beneath the … slab offers great potential for storage of solar energy via direct gain systems … the foundation should be well insulated below the usual depth to keep stored heat from leaking out beneath the footing … Insulation placed horizontally at the exterior perimeter can be used to artificially “raise” the frost penetration depth. (Watson and Labs 1983; 135-136).

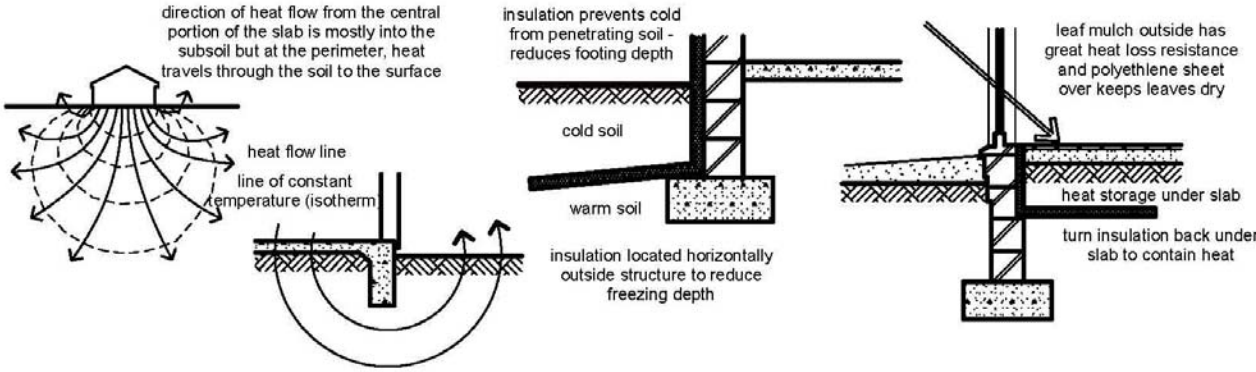


FIG 2-17:- Earth slab insulation to prevent perimetre floor slab heat loss (after Watson and Labs 1983; pp 137-139)

2.9. Ventilation

It has been estimated that … the majority of the world’s population spends some 85-90% of its time living in an internal environment of one form or another, the greater part being buildings, whether factories, offices or homes. (Holdsworth and Sealy 1992; 5)

Natural ventilation is driven by wind or buoyancy forces caused by temperature differences between the inside and outside air. To encourage cross-ventilation, there should be vents or openable windows on opposite sides of the building, without major obstructions to air flow in between. Well-designed naturally ventilated systems are generally shallow plan; with the distance from façade to façade (or atrium) not greater than five times the room height. For cellular rooms with single sided ventilation, natural ventilation will be effective only to a depth of about twice the room height. The space saved through not needing ducting in the ceiling or floor will offset any required increase in storey height. In climates where night-time temperatures in summer are … lower than day-time temperatures, night ventilation can be used in combination with thermal mass to provide cooling there should be good thermal contact between the ventilation air flow and the thermal mass. (European Commission 1999; 71)

Air-conditioning systems present the greatest source of climate change gases of any single technology. In the USA, which has only 4% of the world’s population and yet produces around 25 percent of the global CO_2 annually, over 40 percent of electricity generated is used in air-conditioning systems. (Roaf 2001; 8)

2.9.1. Wind Cooling Breeze

The direction and velocity of flow of summer breezes are influenced considerably by local land forms, tree masses, and existing structures … trees and shrubs can be used to channel air flow towards the building and may even be used to increase air velocity through the building by “funneling” air into openings. Fences, walls and adjacent structures can create air dams that increase the inflow pressures. (Watson and Labs 1983; 91).

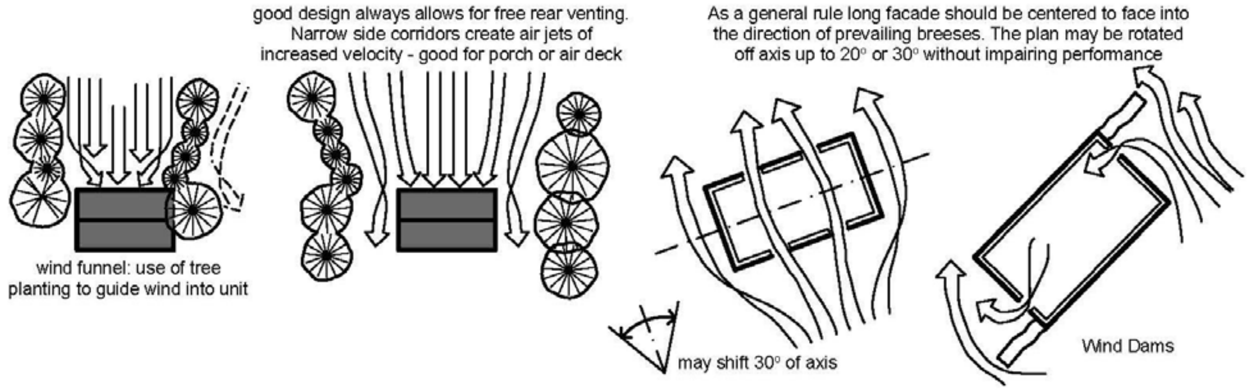


FIG 2-18:- Building form and orientation to capture wind flow (after Watson and Labs 1983; pp 90, 92,110)

Summer wind currents are best exploited for natural ventilation by orienting the building shell so that its longer façade is approximately perpendicular to the flow of the prevailing breezes … when a building shape is complex, high and low pressures can build up along a wind-exposed façade which could be used to increase air flow into window openings … the building can be shaped, and orientated to capture or funnel the flow of wind through its interior. (Watson and Labs 1983; 110).

2.9.2. Cool Summer Breeze Through Doors and Windows.

Improved "air wash" of the interior space can be achieved by locating primary inlet and outlet windows in opposite pressure areas (Watson and Labs 1983; 193). Projections from the surface of the building shell can be used to increase the volume and velocity of air flow into the structure and alter the flow pattern of air as it enters and travels through the interior … wind directing devices can either be horizontal or vertical … building projections can be used in four ways to affect air movement

(1) Increase inflow of head-on breezes.

The amount of airflow admitted from head-on breezes can be increased by enlarging the area of the windward façade, by trapping air in pressure pockets formed by overhangs, and by building shapes that funnel air into the interior.

(2) Intercept and increase admittance of oblique breezes

No significant ventilating breeze will enter an opening that is parallel to the wind flow, particularly if the opening is narrow. Placing a vertical baffle or fin on the downward side of the window, however, will dam up passing air, increasing pressure enough to admit some through the window. The effect may be produced through use of wing walls.

(3) Rechannel direction of incoming flow current

In many cases the path of internal air-flow current will be … [more] important … than the velocity or volume of the current itself. The position of a sunshade can deflect the air up out of the living zone … which is of little comfort to the occupants … but proper detailing [like leaving gaps in sunshades] can correct and remedy any possible disadvantages. (Watson and Labs 1983; 195)

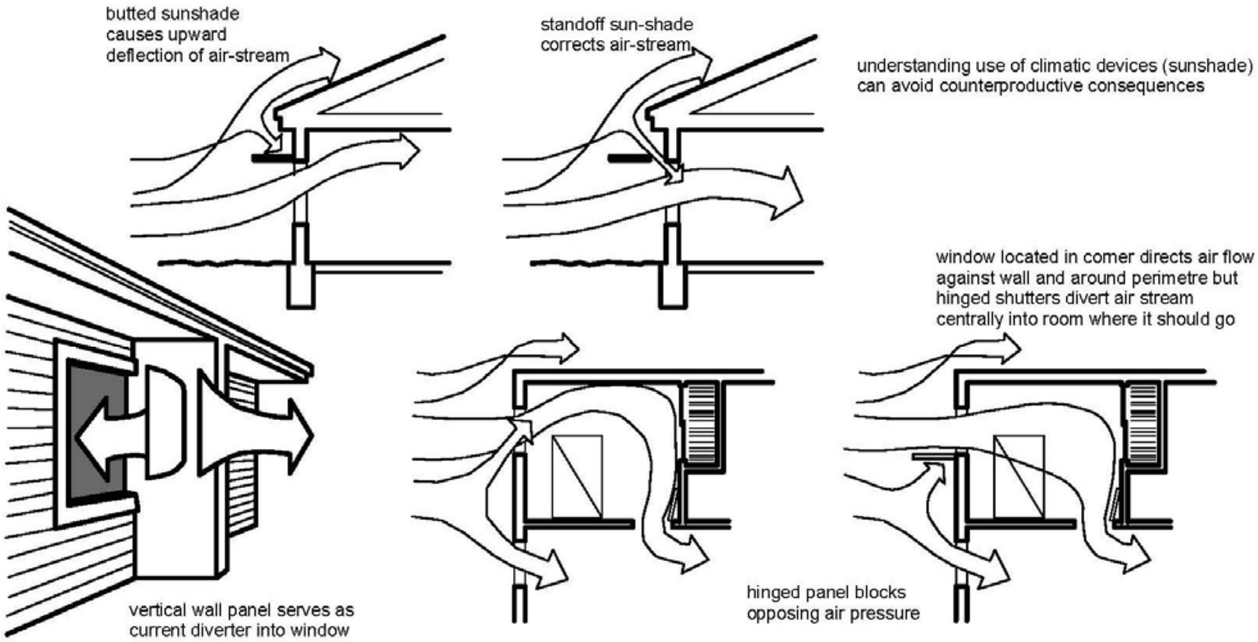


FIG 2-19:- Louvres, wingwalls and overhangs to increase air flow (after Watson and Labs 1983; pp 196)

2.9.3. Open plan for Air Flow

Any barrier or partition located in the internal air flow path between ventilating inlets and outlets will impede air circulation and the ventilation of the interior … partitioning should be adjustable [although] open partition less interiors is the surest way of achieving good air movement. (Watson and Labs 1983; 141).

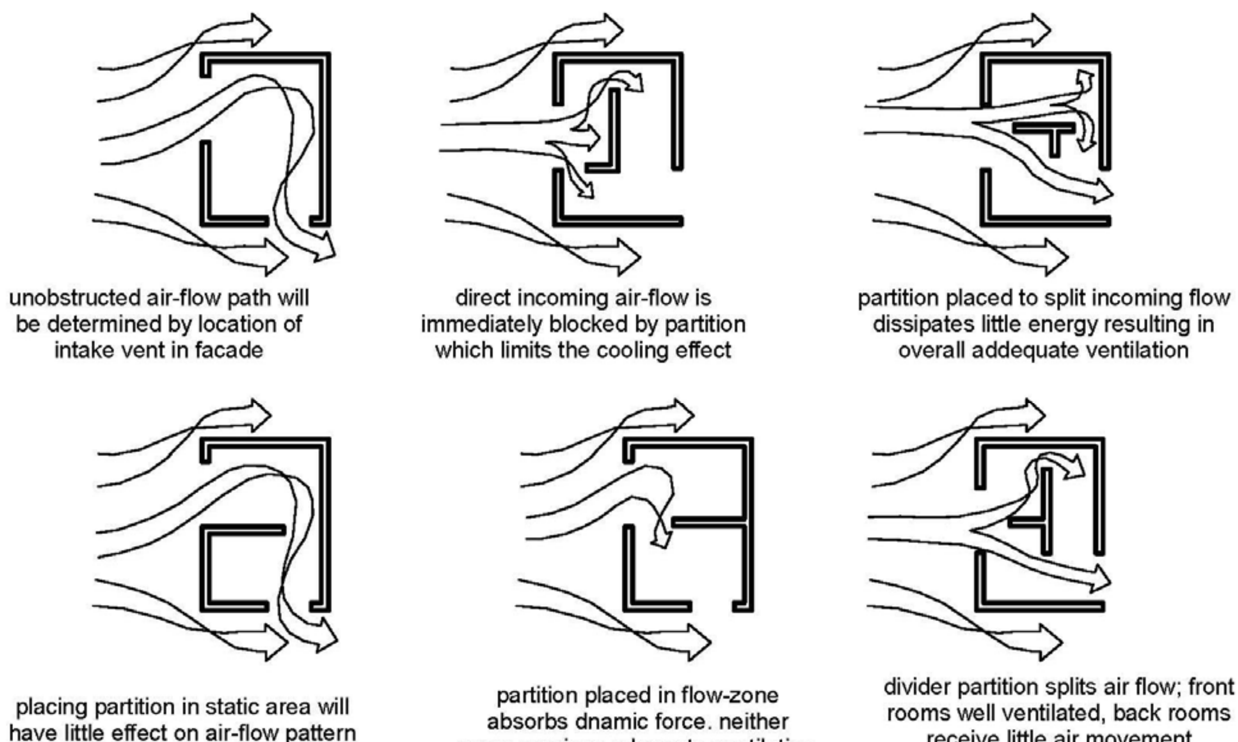


FIG 2-20:- Partitioning to block or re-channel breeze (after Watson and Labs 1983; pp 142)

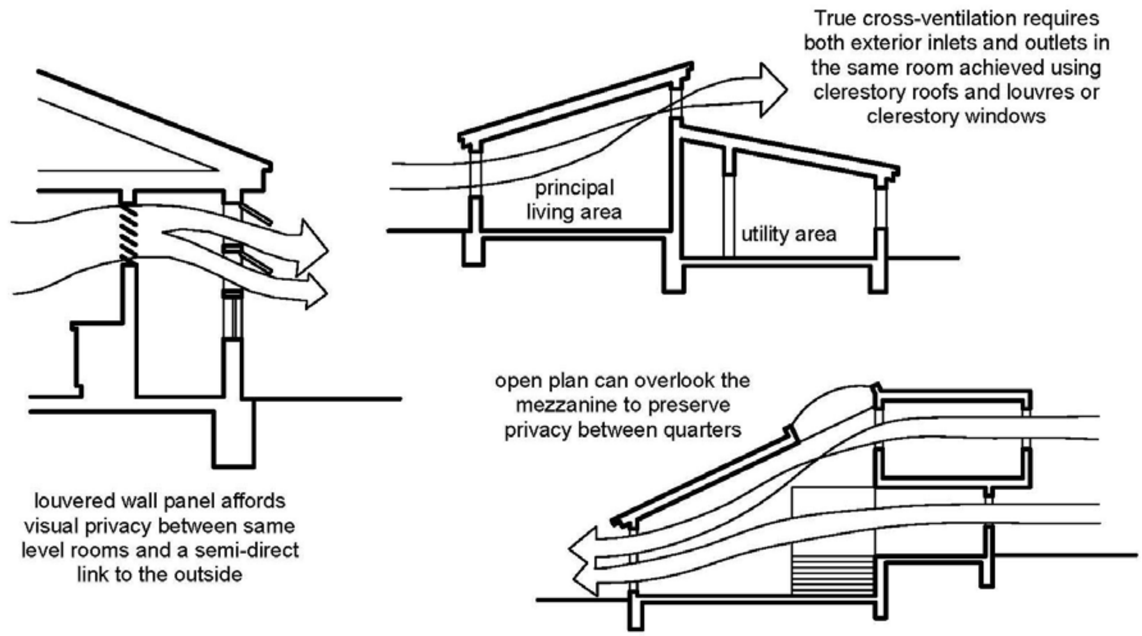


FIG 2-21:- Different heights of louvrers for air circulation (after Watson and Labs 1983; pp 140)

2.10. Conclusion

The most consistent method of using the elements of green principles to conserve energy is through use of wind and use of sunlight. Most building principles which use wind for energy-efficiency combine with other principles for their maximum benefit. For instance, use of wind channelling and wind turbulence protection both depend on building form, orientation and shape as much as ventilation green building techniques like cool summer wind breeze and open plan air flow also depend largely on orientation form and shape. Another example is that green principles of lighting and green principles of thermal mass storage depend mainly on designing with orienting with sunlight. This could mean that if a building is designed with an attitude and objective of sustainability in mind, it will simultaneously cover different principles of green architecture collectively which means that green building principles are implemented with a holistic approach.

This literature review shows the available green building principles have some potential energy efficiency benefits and has also shown that most of the energy-efficiency benefits from green building principles is rooted in the mechanics of how the green building techniques work and how they relate to their climate and environment. This literature review also shows that it is possible to classify green building principles and techniques by how they work. The classification of green buildings principles and techniques helps in building a unit of measuring which energy efficient green principles have been implemented in buildings and how many of those principles have been used. This helps in measuring the diversity of implementation and therefore the spread of green building principles and techniques in buildings.

However the most critical observation from this literature review is that there is a strong link between green building principles and energy efficiency as seen directly from mechanics and workings of each principle and technique to conserve energy. It has been observed that implementing green building principles of orientation, form and shape like placing living rooms towards the sun can save up to 30% in heating bills and halve the energy demand per house. It has also been shown that wind protection can cut heat loss from buildings by up to 15% (see chapter 2.2.2). Green Building Techniques like evaporative cooling can alleviate over 90% of the solar load on building roofs which makes buildings cooler and saving on mechanical air conditioning energy requirements (see chapter 2.4.3). Using green building principles like daylighting can save up to 50% of energy used in offices alone (see chapter 2.5.1) and green building principles like lighting controls can make a 30-40% energy saving (see chapter 2.5.3). Over 40% of energy in buildings is used for air conditioning (see chapter 2.9) so green building principles and techniques like natural ventilation systems and thermal mass storage can greatly contribute to energy efficiency by eliminating and reducing the need for mechanical air conditioning. Therefore there is a strong link between green building principles and energy efficiency.

Chapter 3
Review of Rating Systems

3.1. Green Building Rating Systems

3.1.1. Introduction

Many countries around the world have developed their own rating systems aimed at measuring and quantifying the use of green building technology in their property, architectural and construction industries. Introducing a code as a way of measuring the implementation of green building technology sets a standard which organizations can both measure and improve their implementation of the principles of green building for energy efficiency. This chapter is an overview of the prominent green building rating systems adopted around the world, how they work and where their possible shortfalls lie. Then value engineering is introduced using the principles successfully implemented in other fields and these principles are similarly applied to green building as a proposed measurement and rating system.

3.1.2. Green Star - Australia

In Australia, the Green Building Council of Australia has developed a green building rating system known as Green Star. According to the Green Building Council Australia website, each Green Star rating tool was created to assess the environmental performance of buildings in a specific sector (office, retail, healthcare, education) at a distinct phase in the development cycle (design or construction). The website also lists the 9 rating categories which are listed in Fig 3-1 below

Management Credits address the adoption of sustainable development principles from project conception through design, construction, commissioning, tuning and operation.	IEQ Credits target environmental impact along with occupant wellbeing and performance by addressing the HVAC system, lighting, occupant comfort and pollutants.
Energy Credits target reduction of greenhouse emissions from building operation by addressing energy demand reduction, use efficiency, and generation from alternative sources.	Transport Credits reward the reduction of demand for individual cars by both discouraging car commuting and encouraging use of alternative transportation.
Water Credits address reduction of potable water through efficient design of building services, water reuse and substitution with other water sources (specifically rainwater).	Materials Credits targets resource consumption through material selection, reuse initiatives and efficient management practices.
Land Use & Ecology Credits address a project's impact on its immediate ecosystem, by discouraging degradation and encouraging restoration of flora and fauna.	Emissions Credits address point source pollution from buildings & building services to the atmosphere, watercourse, and local ecosystems.
Innovation Green Star seeks to reward marketplace innovation that fosters the industry's transition to sustainable building.	

Fig 3-1: Assessment Criteria for Green Star Australia (Source: www.gbcaus.org Cited 27 August 2007)

The Green Star Rating System certifies each project with a five star rating system. Among their certified projects, the Green Building Council has awarded two Melbourne projects a 6 star international green building rating award. The first is Council House 2 in Melbourne, Australia, designed by Design Inc. The Second is the Szencorp building at 40 Albert Road in South Melbourne, Victoria, Australia, designed by SJB Architects. Both buildings are included in the sample content analysis in Appendix 1.

The biggest challenge for the Green Star rating system by the Green Building Council of Australia is that it rates the ecological performance of each building by the functional sector (office, retail, healthcare, education) all based on the distinct phases of the project cycle (design, construction) and then tries to relate these elements with ecological classifications like Management, Energy, Environmental Impact, Transport, Water, Materials, Land Use and Ecology, Emissions and Innovation. But there is no conclusive proof that functional sector, the project cycle, and their ecological rating systems are interlined and related. The function of a building might change from retail to office space, it will mean that the project will have to be re-classified. The Green Building Council in Australia has also not specified a consistent project cycle to methodically cater for the ecological criteria they rate buildings. Finally, the ecological criteria used to rate buildings are too context specific which makes it difficult to compare choices between two projects. For instance, using transport as a green building criteria will make it difficult to make a value decision between choosing to locate a building in one suburb of a city rather than another purely on the basis of the effectiveness of green building principles. This can be avoided if transport is separately addressed in a more appropriate Social Impact Assessment rather than rating it as a green building principle.

3.1.3. BREEAM – United Kingdom

The Building Research Establishment Environmental Assessment Method, abbreviated BREEAM, is the world's oldest established environmental assessment method for buildings. According to the BREEAM fact file, the Building Research Establishment Environmental Assessment Method was winner of the "Best Program" Award at the 2005 Tokyo World Sustainable Building Conference. BREEAM classifies and assesses buildings based on the following criteria.

1. Management: overall management policy, commissioning site management and procedural issues
2. Energy use: operational energy and carbon dioxide (CO_2) issues
3. Health and well-being: indoor and external issues affecting health and well-being
4. Pollution: air and water pollution issues
5. Transport: transport-related CO_2 and location-related factors
6. Land use: greenfield and brownfield sites
7. Ecology: ecological value conservation and enhancement of the site
8. Materials: environmental implication of building materials, including life-cycle impacts
9. Water: consumption and water efficiency

Credits are awarded in each area according to performance. A set of environmental weightings then enables the credits to be added together to produce a single overall score. The building is then rated on a scale of; PASS, GOOD, VERY GOOD or EXCELLENT and a certificate awarded that can be used for promotional purposes.

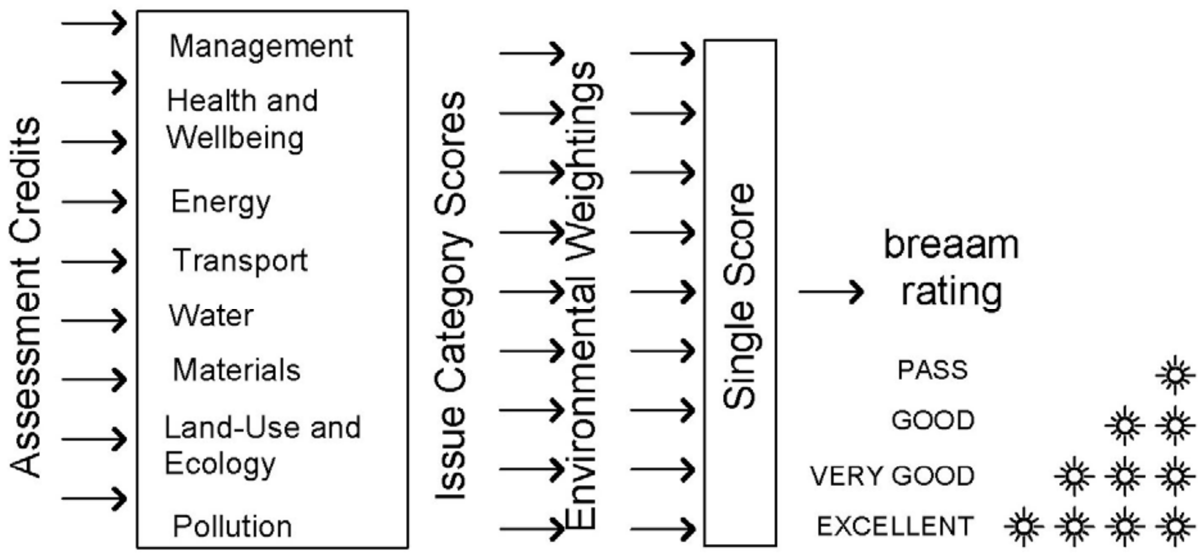


Fig 3-2: Assessment Criteria for BRE Environmental Assessment Method (Source: BREAM 1976; 24)

The biggest challenge in the BREEAM rating system is that a building is assessed mainly on the grounds of its function as is the case with the Green Star Rating System from Australia.

3.1.4. CASBEE - Japan

In April 2001, a joint project between Japan's government, industry and academia prompted the formation of the Japan Sustainable Building Consortium and the Consortium's research has produced the Comprehensive Assessment System for Building Environmental Efficiency, abbreviated CASBEE (JSBC 2004; 3). In its most basic terms, the CASBEE measures the Building Environmental Efficiency, abbreviated BEE, as a numerical and graphical ratio of the building's environmental quality and performance Q over the building's environmental loadings L.

Building Environmental Efficiency = Quality and Performance/Environmental Loadings

The assessment items in the Building Environmental Quality and Performance include (JSBC 2004; 9)

1. Indoor Environment: Noise and Acoustics, Thermal comfort, Lighting and Illumination, Air Quality.
2. Quality of Service: Functionality and Usability, Amenity, Earthquake Resistance, Durability and Reliability, Flexibility and Adaptability of Facility, Floor Load Margin.
3. Outdoor Environment on Site: Preservation and Creation of micro-organisms, Townscape and Landscape, Local Characteristics and Outdoor Amenities.

The assessment items in the Building Environmental Loading include (JSBC 2004; 12)

1. Energy: Building Thermal Load, Natural energy utilization, efficiency in building service system (including HVAC, lighting, hot water supply, elevators) and efficient operation.
2. Resources and Materials: Water resources, recycled materials, timber for sustainable forestry, low health risk materials, reuse existing structure and material and components.
3. Off-Site Environment: Air pollution, noise, vibration and odour, wind damage and sunlight obstruction, light pollution, heat island effect, load on local infrastructure.

When the total score of the Q categories (Building Environmental Quality and Performance) and total score of the L category (Building Environmental Loading) are derived, then the BEE (Building Environmental Efficiency) is calculated by dividing Q/L. BEE is usually presented on a graph with Q on the Y axis and L on the X axis and the BEE being the gradient of the line joining equal Q and L values to the origin. The higher the Q value and the lower the L value, the steeper the gradient and the more sustainable the building is. CASBEE labels buildings with an overall classification from C rating (poor) for BEE under 0.5 through B- rating for BEE between 0.5 and 1, B+ rating for BEE between 1.0 and 1.5, A rating for BEE between 1.5 and 3.0 and S rating (excellent) for BEE over 3.0 with Q over 50%. (Japan Sustainable Building Consortium 2004; 26).

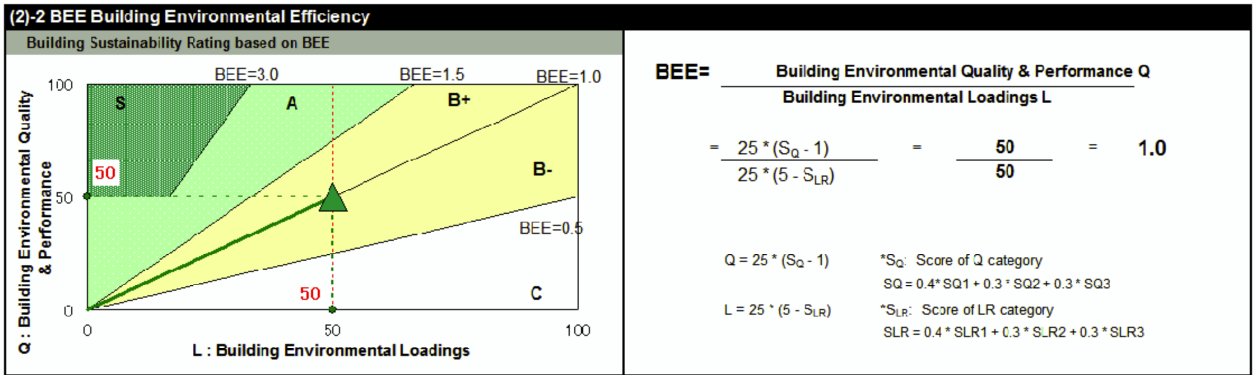


Fig 3-3: Assessment Criteria for CASBEE from Japan Sustainable Building Consortium (Source: JSBC 2004; 26)

The biggest challenge to the effectiveness of CASBEE is how it fails to recognize the context and scale of individual projects. While the system itself is relatively comprehensive, CASBEE fails to recognize how the scale of a project can affect its rating and performance. For example, a three unit apartment block might more effectively meet the assessment elements than a multi regional shopping centre and the CASBEE system does not seem to have integrated provision for scale in its scoring criteria. Green Building Value Engineering could have a more efficient and effective method of integrating scale into the rating and measurement possibly by implementing a weighting system based on how much green building technologies have been used as a ratio of how many more could have been used to achieve maximum efficiency.

3.1.5. LEED – United States

The U.S. Green Building Council (USGBC) is a non-profit organisation composed of leaders from every sector of the building industry working to promote buildings that are environmentally responsible, profitable and healthy places to live and work. LEED®, the "Leadership in Energy & Environmental Design" Green Building Rating System, is the nationally accepted standard for green buildings developed by the USGB.

As of September 2006, the LEED rating system product portfolio was classified into six different products, namely New Construction and Major Renovations, Existing Buildings, Commercial Interiors, Core and Shell, LEED for Homes and Neighbourhood Development.

All of the 6 different LEED products are rated using a common project criteria and checklist. These are

1. Sustainable Sites: with credits for site selection, development density, alternative transportation, stormwater design, heat island effect, and Light Pollution Reduction.
2. Water Efficiency: water efficient landscaping, innovative wastewater techniques, water use reduction.
3. Energy and Atmosphere: Optimised Energy Perfomance, On-Site Renewable Energy, enhanced refrigerant management, Green Power.
4. Materials and resources: Storage and Collection of Recyclables, Building reuse, Construction Waste Management, Material Reuse, Recycled Content, Regional Materials, Certified Wood.
5. Indoor Environmental Quality: Outdoor air delivery monitoring, Low-Emitting Materials, Controllabity of Systems, Thermal Comfort, Daylight and Views.
6. Innovation in Design Process and Using a LEED accredited Design Professional.

(US Green Building Council 1995; 9-10)

For the 6 different LEED products, the projects are rated using the same criteria but each criteria is given a different weighting depending on how relevant that criteria is to that particular product. For instance, the criteria "Sustainable Sites" could be given a 20 point weighting when a project is being rated using the "LEED New Construction and Major Renovations" product but the very same "Sustainable Sites" criteria could be given 5 point weighting when being rated using the "LEED Commercial Interiors" product. (US Green Building Council 1995; 10)

The final stage of the LEED rating system involves adding up the weighted project points for the respective LEED rating product being used and allocating the project total to the respective product scale. For example, in the LEED New Construction and Major Renovations rating product, if a project scores 26-32 of the 69 possible points, that project will receive Bronze certification. If the project scores 33 – 38 points it receives Silver certification. If the project receives 39 – 51 points it receives Gold Certification. If a project scores 51 – 69 points it receives Platinum Certification, which is the highest award that a LEED rating product can achieve.

The LEED rating system by the United States Green Building Council is the most comprehensive of the reviewed rating systems because it is context specific in reviewing green building criteria in relation to their functional use. However, the biggest challenge the LEED rating system faces is that the different LEED rating products have different weighting systems of the same criteria. This problem becomes particularly highlighted when, for example, a developer buys an existing building, carries out a major renovation, and finally hires shopfitters to install some commercial interiors. If the developer uses the LEED rating system, he/she would have to rate the project using three different products which could be very expensive and confusing. Because of three different weighting systems, the project will be rated silver for existing, with gold rating for renovation and a platinum rating for the commercial interior. Green Building Value Engineering avoids this potential problem by using one value system which is based on the holistic function of the component parts instead of separate potential function of the project.

3.2. Value Engineering

3.2.1. Introduction to Value Engineering.

Value Engineering is NOT an original concept. According to Norton and McElligot (1995; 4), value engineering was developed by Lawrence Miles in 1947 at General Electric in the USA during World War 2. Because of raw material shortages caused by the war, General Electric was forced to substitute materials in many of their products. Over time this forced substitution resulted in lower costs and improved product performance.

As the phenomena proved to be effective, Miles was assigned to implement a system of analysing value to substitute costly materials and methods (O'Brien 1976; 1). He successfully developed a method of determining value by an object's function and not by cost of manufacture (O'Brien 1976; 25-26). Miles expanded the function approach by developing a series of steps and techniques called Value Analysis. 'Value Analysis' was retitled 'Value Engineering' during its implementation in the US Navy to refocus its emphasis to the design stages (Norton and McElligot 1995; 5).

According to Macedo, Dobrow and O'Rourke (1978; 3), Miles named this new process Value Analysis because its scope went beyond merely analysing the cost and quality. It was clearly aimed at analysing the overall value of an item. The Value Engineering methodology is now applicable wherever there is a function to be performed and a means to measure it (Macedo, Dobrow and O'Rourke 1978; 11). A general definition by Miles states that "Value Analysis…is an approach…that identifies unnecessary costs …which provide neither quality, nor life, nor appearance, nor customer features" (Macedo, Dobrow and O'Rourke 1978; 13).

3.2.2. Applications of Value Engineering

After its inception, Value Engineering main avenue of growth was through the US Department of Defense where it was implemented in the US Navy in 1954, in the US Corps of Engineers in 1956, and in the US Air Force in 1961 (O'Brien 1976; 1-2). Value engineering has now been implemented successfully internationally in diverse industries ranging from Japanese automotive and electrical industries to the UK Aerospace and US government agencies like General Services Administration (Norton and McElligot 1995; 5-7). If Value Engineering has been success in so many diverse industries, then surely Property Development can apply the principles of value analysis with great benefit to green buildings to analyse energy efficiency in relation to building elements!

3.2.3. Applying Value Engineering to Property Development

Closer to Property Development, value engineering became a big hit in construction as early as 1962 when contractors worked with engineers, architects and owners to suggest alternatives that reduce on construction cost of buildings without impacting functional aspects. (Norton and McElligot 1995; 5). As much as this has successfully produced large savings, value engineering in construction focuses on analysis of construction materials for their technical function (e.g. "which cheaper structural material can hold the roof building for longer") and Construction Management decisions like "which part of site should the supplier deliver the bricks for smoother workflow" and methods like "How can we standardise brick-laying to quicken production". Value engineering is used to assess construction processes to minimise flows and maximise conversions. But Construction value engineering does not really analyse the functional use of Green Building Principles and Techniques to generate Energy Efficiency as this research is proposing to do so there is a large and distinct difference between Construction Value Engineering and Green Building Value Engineering.

The closest that value engineering has been implemented in Property is in Facilities Management. Williams (1994; 2.18) defines value engineering in the context of Facilities Management as elimination of 'redundant performance' by providing services to the required performance at the least cost. Williams goes on to give examples of Value engineering in facilities management like, "cleaning down internal partitions once a month instead of twice a week" and "sending credit reminders in cheaper, brown manilla envelops instead of white envelopes" (Williams 1994; 2.18). Furthermore, Smyth and Wood (1995; 5) define Just-In-Time (a Value Engineering concept) maintenance for facilities as using a building component for maximum life span, replacing building components only when they fail but taking action before having serious effect on the facility's performance. So we see that facilities analyse value to save cost by being more cost-efficient and economic in operation and running of a facility. So even in Facilities Management, Value Engineering is never used to actually analyse the functional aspects of the building elements in the facility for their energy efficiency value as this research intends to do which shows a distinct difference between Facilities Value Engineering and Green Building Value Engineering.

3.3. Functional Analysis of Green Buildings

3.3.1. Introduction

After listing and classifying the principles and techniques of green buildings which have potential energy-efficiency benefits (see Chapter 2), a secondary objective is to investigate methods to implement the energy-efficient green building principles more effectively. Property and Construction management improve effectiveness of a system using a quality management system. According to Oosthuizen, Koster and De la Rey (1998; 96), the advantages of a formalized quality system include a uniform approach to evaluating the effectiveness of corrective action, streamlining the organization's approach to all of its activities, determining the true effects of changes and monitoring improvement effectively. So while the Principles of Green Buildings that have energy-efficiency benefits have been deduced, there still needs to be a systematic approach to implementing them to increase productivity.

According to Cleland and King (1988; 514), construction and manufacturing have generally accepted quality to mean fitness for use or compliance with requirements. Cleland and King add that to achieve quality requires a clear definition of function among other elements (1988; 514). Oosthuizen, Koster and De La Rey (1998; 98) interpret meeting the criteria of fitness for use by asking the following questions; How will the product be used and what is its usage environment? How do available alternatives affect our economies and the user's economies? This suggests that an effective quality management system is rooted in the functional essence of a product.

If the essence of a quality management system lies in its function, then the system for measuring the effectiveness of green building principles must assess how the worth of each principle is rooted in its function. Different quality management systems are more effective in measuring unique functions because they are more suited to the context than other Quality Management Systems. For example, Total Quality Management's approach to quality as an attitude may be more suited to monitoring a task orientated operations management while Life Cycle Costing's approach to assessing phase in relation to cost may be more suitable to monitoring project management. Needless to say both Total Quality Management and Life Cycle Costing are important Quality Management Systems.

3.3.2. Defining Functional Analysis

Duran defines quality as fitness for use (Cleland and King 1988; 514), and Lawrence Miles describes Value Analysis as "a disciplined action system … accomplishing the functions that customer needs and wants…" (O'Brien 1976; 9). Furthermore, Miles indicates that, "the basic function is straightforward to determine, and any work done before that has been accomplished is wasted effort." O'Brien also quotes the Public Building Services that describes functional analysis by saying, "A user purchases an item or service because it will provide certain functions at a cost he is willing to pay. If something does not do what it is intended to do, it is no use to the user and no amount of cost reduction will improve its value to the user. On the other hand, expenditures to increase the functional capacity of an item beyond that which is needed are also of little value to the user…" (O'Brien 1976; 9). O'Brien then addresses the parts of a project which will receive functional analysis as the following.

- What is it?

  "A prerequisite to functional analysis is the selection of the function to be analysed" (O'Brien 1976; 10). This is usually done by diagrammatically listing and breaking down the definition and functional parameters of the product. The more exhaustive this list is the better the foundation that is set for the product fulfilling its original function. According to O'Brien (1976; 11), functional analysis is carried out by valuating the work breakdown structure in the early phases of the project. O'Brien (1976; 11) also asserts that the most productive areas of opportunity should be selected for analysis.

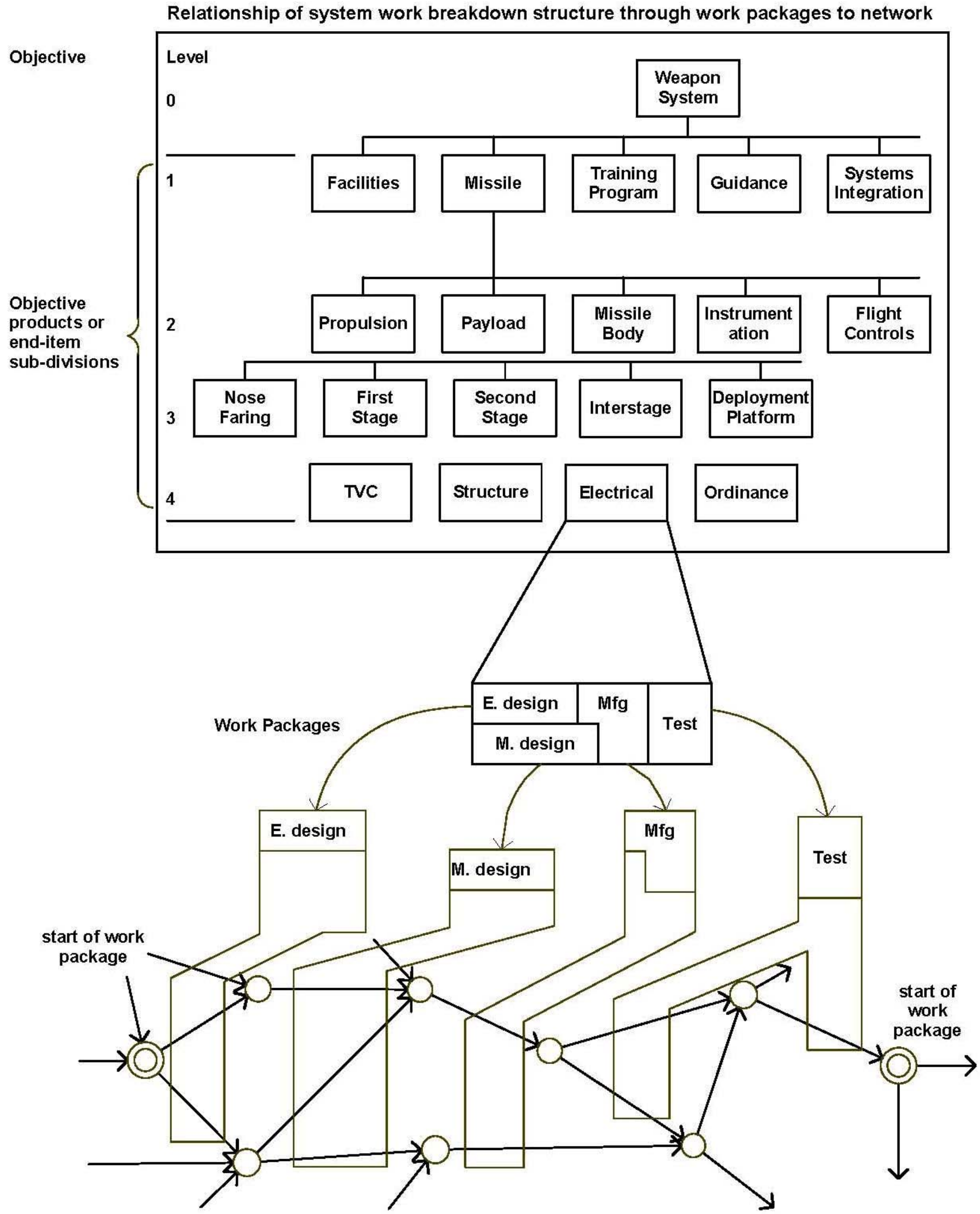


Fig 3-4: Work Structure Network of the US Navy Special Projects (Source O'Brien 1978; 10)

This principle of functional analysis can be adapted to suit the value engineering of green buildings by systematically breaking down a building into substantial elements and components for analysis. While construction technologies and methodologies differ with specific and unique contexts, the principles of building remain the same and they can be systemized for standardization and quality management. If a building is broken down into system components, then it is possible to functionally analyse each component for its energy efficiency benefits. The author has modelled the systematic breakdown of buildings into the following elementary systems and components. This particular systematic building element breakdown has specifically designed for rating green buildings and it has been preferred over existing systems which meet primary objectives of quantifying costs and technical documentation.

1. Site and landscaping
2. Structure
3. Envelope

4. Doors, Windows and Openings
5. Internal Fittings
6. Roofing System
7. Water Supply and Drainage
8. Electricity and Power
9. Mechanical Plant (HVAC)

- What does it do?
  "This is the key to the value-analysis question and it requires the definition of an item under study" (O'Brien 1976; 12). The author finds this element of functional analysis of critical importance to this research so it was exhaustively covered in the Principles of Green Buildings. However, in the context of functional analysis for value engineering, it is also important to provide a definition for "function." Kelly, Male and Graham (200; 51) define function as a characteristic activity or action for which a thing is specifically fitted or used or for which something exists. This is enhanced by Macedo, Dobrow and O'Rourke (1978; 233) who define a function as a required performance action described by a verb and a noun without identifying a specific method of performing the action. According to O'Brien (1976; 12-13), the method of definition prescribed by established value analysis procedure has two words, a noun and a verb. O'Brien (1976; 12) states that the selection of the proper two-word description is often difficult, requiring comprehensive understanding of the item under study. O'Brien (1976; 12-13) then outlines that the functional description must state the basic function in which the potential for successful analysis lies, and that the object description must be measurable and capable of quantification.

Value Engineering Functional Analysis Worksheet

PROJECT: *Courthouse* — NAME: *Martin Shoniwa*
ITEM: *Doors* — PHONE NUMBER: *076 953 2070*
BASIC FUNCTION: *Control Access* — DATE: *16 October 2008*

QUANTITY	UNIT	ELEMENT DESCRIPTION	FUNCTION Verb	Noun	KIND	EXPLANATION	WORTH	COST
		Exterior doors	Provide	Security	B	Control of Access, mandatory		
			Exclude	Weather	S	Alternates possible		
			Express	Prestige	S	Image to the public		
			Provide	Visibility	S	Entry doors		
		Office Doors	Exclude	Noise	B	Judge's Chambers		
			Contain	Noise	B	Typing Pool		
			Enclose	Space	B	Public Areas		
		Area Doors	Provide	Visibility	S	Public Areas		
			Exclude	Fire	B	Exit Passageways		
			Contain	Fire	B	Mechanical Rooms		
			Control	Traffic	B	Key Zone Points		
		Security Doors	Control	Prisoners	B	Secure passage to courtrooms		
			Contain	Prisoners	B	Cell doors; Cell Blocks		
			Exclude	Public	B	Doors from Public Areas		
			Exclude	People	B	Elevator Shaft Doors		
		Other	Provide	Privacy	B	Bathroom Doors		

FIG 3-5: Functional definitions for doorways in a complex structure (O'Brien 1978, 14)

This value analysis orientated definition of function can be adjusted to suit the value engineering of green buildings by listing the Principles of Green Design in a worksheet similar to the one above. The focus of this Green Building Principles Functional Analyses Worksheet is to outline the functional benefits of each Green Building Principle in a systematic, quantifiable, and measurable way. The sample list below is relative and specific to energy-efficient green building principles but must be adjusted to suit when implementing green building value engineering to unique and particular projects.

1. Orientation Form and Shape	2. Wind Protection	3. Solar and Renewable Energy.
- Orientation - Site Energy Planning - Building Form - Earth Sheltering Recess	- Landform and Planting - Wind Turbulence Protection - Wind Channeling	- Solar Thermal Panels - Photovoltaic cells - Wind Energy - Biomass Waste - Solar Thermal Panels
4. Cooling Systems	5. Lighting Systems	6. Warming Systems
- Planning Systems - Shading Devices - Wall Shading - Evaporative Cooling	- Daylighting - Windows - Lighting Controls - Low Energy Lights	- Heating Systems - Vertical Air Shafts - Igloo and Bucket Effect
7. Thermal Mass Storage	8. Insulation	9. Ventilation.
- The Greenhouse Effect - Radiant Heating/Cooling Systems - Trombe Walls - Sunspaces - Atriums - Thermal Mass Systems (Walls, Slabs, Central Heat Source) - Rock Beds	- Wall - Roof - Floor - Ceiling - Earth Slab	- Increase Head-On Breeze. - Intercept Oblique Breeze - Rechannel Current Direction - Open plan Air Flow

FIG 3-6: Classification of Green Building Techniques into Green Building Principles (source, Author)

- What is it worth?

According to Kelly, Male and Drummond (2004; 17), worth is defined by North American value engineers as the least cost required to perform a required function or the solution that will deliver the required function at the least cost. O'Brien (1976; 14) enhances this by defining worth as a measure of value and represents the least expenditure required to provide the function required as required by the functional definition. This phase of functional analysis is where the value of each function is quantified and measured, usually in relation to its cost. Kelly, Male and Drummond (2004; 17) go on to state that function is a relationship of function over cost.

The principle of worth is implemented in value analysis by using an evaluation sheet to measure how certain principles rate in worth over a range of elements. The use of an evaluation sheet is illustrated by Macedo, Dobrow and O'Rourke (1978; 129) in a case where candidates were bidding for a project were systematically rated based on their score to a ranked list of factors which contributed to a total score.

Evaluation Factors													
Assign Scores 3 = Highest 2 = Good 1 = Adequate 0 = Unknown -1 = Potential Problem Candidates	1 Responses to directions and/or changes	2. Quality of work and deliverables	3. Knowledge of terrain an local conditions	4. Prior satisfactory work for the evaluating organisation	5. Prior Satisfactory work for the government\other clients	6. Ability to meet precise schedules, with	7. Pricing rates of staff, services and	8. Advantage of proximity to evaluating	9. Advantage of proximity o work site.	10. Testing Geology and seismic technology	11. Adequacy and availability professional	12. Use and management of sub-contractors.	RAW SCORES

Fig 3-7 Evaluation Sheet (source; Macedo, Dobrow and O'Rourke 1978; 130)

A more complex illustration of an evaluation sheet is provided by Kelly, Male and Drummond (2004; 308) and termed a weighted scoring matrix although the principle remains the same. This particular weighted scoring matrix is used to consider different types of internal partitions and rate them for certain functional criteria. A scoring exercise determines how well each type of interior partition meets each functional criteria on a scale of 1 to 5 and a weighting exercise multiplies each interior partition's score in relation to each functional criteria's importance to that project on a scale of 0 to 6. The total score determines which interior partition is more functional relative to the project team's requirements.

	Demountable	Noise Attenuation	Attractive Finish	Support Fittings	Conceal Services	Capital Cost	Maintenance Cost	Reliability of Supply	TOTAL
	4	6	3	0	5	3	4	3	
Blockwork	1 / 4	5 / 30	4 / 12	4 / 0	3 / 15	4 / 12	4 / 16	5 / 15	104
Stud	3 / 12	3 / 18	4 / 12	3 / 0	5 / 25	5 / 15	3 / 12	5 / 15	109
Metal	5 / 20	3	3 / 9	1 / 0	2 / 10	2 / 6	4 / 16	2 / 6	85
Timber	5 / 20	2	4 / 12	1 / 0	2 / 10	3 / 9	4 / 16	2 / 6	85
Polystyrene	5 / 20	1	2 / 6	1 / 0	2 / 10	4 / 12	4 / 16	2 / 6	76
Plasterboard	5 / 20	1 / 6	4 / 12	1 / 0	2 / 10	5 / 15	4 / 16	4 / 12	91

Fig 3-8 Weighted Scoring Matrix (after Kelly, Male and Drummond 2440; 310)

When implementing Value Engineering of Green Building Principles for energy efficiency, the same principle of an Evaluation Worksheet can be used and adapted to suit the context of value-analysis of green buildings. The adapted evaluation worksheet will vertically list for evaluation all the elements of construction that the author has originally modelled in the Objective Analysis above. The evaluation worksheet will horizontally list all the functional criteria that have been exhaustively outlined in the Principles of Green Building and which have been briefly summarized in the Descriptive Analysis above. Each of these functional criteria will have a relative weighting scale of 1 to 10 which determines how important that particular functional criteria is to the success of that project.

	1. Orientation Form and Shape	2. Wind Protection	3. Solar and Renewable Energy	4. Cooling Systems	5. Warming Systems	6. Lighting Systems	7. Thermal Mass Storage	8. Insulation.	9. Ventilation.	TOTAL
	A	B	C	D	E	F	G	H	H	
1. Site and Landscaping										
2. Structural System										
3. Envelope										
4. Doors, Windows and Openings										
5. Interior Fittings										
6. Finishes										
7. Water Supply and Drainage										
8. Electricity and Power										
9. Mechanical Plant (HVAC)										

Fig 3-9 Functional Criteria Worksheet

3.4. Conclusion

Green building rating systems like the Green Star from Australia and BREEAM from the United Kingdom are focused primarily on assessing the performance of green buildings based on their function. This poses a challenge in that if a building changes its function or use, then the measuring system is no longer valid. The CASBEE green building rating system from Japan fails to recognize the effect of scale and context can affect the energy performance of green buildings. Such a system becomes invalid when it measures a single family residential unit with the same method as an industrial factory without accounting for scale. The LEED rating system from the United States is probably the most comprehensive and advanced rating system but the method of using the same rating system to measure different methods of construction makes it invalid in multi-phase developments. For instance, if an existing building is renovated and at the same time new interiors designed on the same site, it makes it confusing which rating system to use.

The best way to measure the effectiveness of green buildings should be rooted in extracting the value deduced on how that green building principle works and measuring the value of that system when used to best efficiency. If the green building principles are evaluated for their energy-efficiency as in the literature review in Chapter 2, then the classification deduced and descriptive definitions derived in the Literature Review can be used to extract and measure the energy-efficient value of each principle. In that case, the rating system will not be affected by the actual function of the building and the rating system will not be affected by size of the project and the rating system will not be affected by construction type or phasing of the project like LEED.

The current value engineering methods asses the value based on either the cost of construction of the functional running of a facility. None of the value engineering methods analyse how much energy-efficiency that each building element actually contributes. Value engineering is a tool which is used to measure costs of elements in relation to their functions. Value Engineering has been used to great success in different industries to reduce cost and enhance product performance. The closest that value engineering has been used in property and construction industry was to reduce construction cost and cost efficient and more economic facility operation. But value engineering has never been used to analyse the energy-efficiency of Green Building Principles and Techniques in relation to building elements.

This literature review has concluded that green building rating systems like the Green Star from Australia and BREEAM from the United Kingdom assess the performance based on function and this poses a challenge in that if a building changes its function or use, then the measuring system is no longer valid. It has also been concluded that CASBEE green building rating system from Japan fails to recognize the effect of scale and context can affect the energy performance of green buildings and the system becomes invalid when it measures two buildings of a totally different scale in different climatic conditions. The LEED rating system from the United States has been deduced to be the most comprehensive rating system but falls short in the method of using the same rating system to measure different methods of constructing multi-phase developments.

Then the focus of this literature review shifted to the possibility of using Value Engineering as a rating system that can measure the energy-efficiency of green buildings based fitness for use of the principles involved. This started with a literature review of how value engineering was developed as a method of determining value by an object's function. The idea of functional value was then developed into a series of steps and methods that are used to extract the best value for use which has come to be known as functional analysis. Then the literature review covered all the various applications that value engineering has been implemented in starting from its roots in manufacturing and ranging from electrical, military, aerospace and even administrative services. Then the implementation of value engineering in construction and facilities management was discussed with emphasis that value engineering has never been implemented on green buildings especially for energy efficiency.

Finally, the literature review covered how to implement the methodological steps of Functional Analysis for the specific purpose of developing a green building rating system which measures the energy efficiency of green buildings through extracting value in use. This involved listing and classifying the principles and techniques of green buildings which have potential energy-efficiency benefits, the selection of the function to be analyzed by valuating the work breakdown structure of each green building principle and technique, stating the functional description in which the potential for value lies, evaluating the worth of each principle, and scaling the evaluated score in relation to the functional criteria which need to be met.

Chapter 4
Research Design and Methodology

4.1. Introduction

The primary objective of this research is to investigate how well spread green building principles are implemented for energy efficiency across building elements. The best way to measure the spread of green building principles used on a building is to map out the relationship between the number of green building techniques used in relation to how many different types of building elements those techniques are used on. This relationship expressed as a fraction of types of building elements per number of green building techniques will give a measure of how well-spread each building principle is across all the elements in the building.

So if a sample of highly rated green buildings is collected and the green building design principles which were implemented on them is studied in relation to the building elements used, then a relationship can be mapped out between the number of green building techniques used and the types of building elements they are implemented on in the building. If the green building principles are well spread across building elements, then the fraction of types of building elements per unit number of green building techniques will be closer to I because different green building techniques are being implemented on equally different types building elements. If the green building principles are not well spread and are being used on the same type of building element, then the fraction of type of building elements per unit number of green technique will be small and closer to 0 because only a few types of building elements are being used to implement many green building techniques because it is not well spread. So in essence this research is testing the correlation of number of green building techniques over types of building element they are implemented on.

4.2. Explaining the Surrogates

On the relationship between the two variables, types of building elements can never be higher than the number of green techniques but implemented because many green techniques are implemented on a constant number of types of building elements. So the fraction of types of building elements divided by number of green techniques will always be less than 1. The number of building elements will always remain constant because those building elements will always exist in one form or another in a building. However, the number of green building techniques used will always vary because it is completely up to the design professional and client and project brief on how many and which green building techniques to use on which type of building element. So for that reason, the type of number of green building techniques shall be the independent variable (x) and will dictate how much it is implemented on the type of building element which shall be the dependant variable (y).

A key challenge is to standardize the approach to this research so that it can be repeated anywhere in the world which another sample of highly rated green buildings with a long term goal of benchmarking it into the standard method of measuring the implementation of green building principles for energy efficiency. A critical difference which would expect to be met is how is how to classify the types of building elements and to a lesser extent, classifying the green building principles and techniques. Depending on different business standards and design approaches, the classification of elements to fall into each variable remains subjective and there are as many classifications as there are applications of value engineering. What matters is the principle of value engineering is correctly applied and the parameters are clearly stated as in the literature reviews (see Chapters 2 and 3) and, that being the case, the results are expected to be valid.

Another key challenge in this research is that the sample of highly rated green buildings that has been selected is so diverse with 24 buildings ranging from five different continents exposed to different climates which have been highly rated using different green building rating systems. This has been purposely done so as to expose the implementation of green building principles to the most aggressive and diverse conditions possible. The conditions for implementation may be diverse but green building principles and techniques and their application is exactly the same in green buildings all over the world. For example, the very same green building principle of Orientation, Form and Shape (discussed in Chapter 2.1) to maximise solar gain used on Greenwood trust College in the United Kingdom were also used on Edificio Malecon in Argentina and the Earth Tubes used for ventilation and moderating temperature at the Aldo Leopold Legacy Centre in the United States where used at Eastgate in Harare, Zimbabwe (see Appendix 1). So the implementation of the green building principles, which is the essence of what this research is investigating, are really the implemented the same way in different climates despite how different the green building systems measuring them are.

4.3 Hypothesis.

How well-spread are the principles of energy efficiency in green buildings across different building elements? The author is convinced that most buildings which are rated and considered as green buildings have only extensively used one principle across only a few building elements and then labelled themselves as green buildings. So this research aims to investigate the relationship between energy-efficient green building principles and the building elements to which they are applied.

The importance of this research, as fully described in the Literature review of the current Green Building Rating Systems, is that if indeed all the green building energy-efficient elements are condensed in one building element, then if a new client were to buy the building and demolish that element to make the building better fit his needs. Then the building will not be green anymore and won't be as energy-efficient as when that element is there. So it is better to spread the green building principles across the building elements for the building to stay energy-efficient even if building elements are changed.

Another advantage with a rating system that compares green building principles to Building elements is that if the building composition has to change in any way, the impact of the change to the “greenness” of the building can be more accurately measured by removing and adding (in number of principles per unit building element) the value that has been extracted and enhanced. This can then be multiplied with the rates which depend on the climatic and geographic location of the building.

4.4. Collecting a Stratified Sample of Green Buildings

A stratified sample of about 24 green buildings where then chosen. The qualifying criteria for a building to ba sampled as a green building is that it must be assessed using one of the green building rating systems and have achieved a high rating in any one of the four rating systems. In that way each sample is guaranteed to be successfully designed with the intention of using green buildings. The sample size was deliberately chosen to be over 24 green buildings so that it can generally be accepted to be a large enough sample to use statistical methods for normal distributions correlation and regression.

Below is a list of the stratified sample which was investigated, listed by location and brief building description and together with the assessment rating and a brief report of the green principles used on each building case study. For each Green Building, a library based investigation, and internet based investigation and telephonic contact and electronic contact was made with the architectural and design consultants and tenant organizations to investigate the green building principles used on this building. Most information was in the form of design drawings and descriptive reports of the Green building Principles used in the design of the building. A critical criteria of the sample selection will be to use only buildings that complete and comprehensive information on the green building design principles was able to be collected.

Then all the green principles implemented on each building were systematically listed in point format as comprehensively as possible. Then a filter chart was used to take each individual green principle which had been listed and systematically categorize which of the nine building elements it had been implemented in.

4.5. Charting the Green Principles.

The principles of green building as described in the Literature Review were listed. Then each principle was classified and subdivided into a list of all the possible techniques that can be implemented to meet that particular principle. It is important to compile a thorough and exhaustive

1. Orientation Form and Shape	2. Wind Protection	3. Solar and Renewable Energy.
- Orientation - Site Energy Planning - Building Form - Earth Sheltering Recess	- Landform and Planting - Wind Turbulence Protection - Wind Channeling	- Solar Thermal Panels - Photovoltaic cells - Wind Energy - Biomass Waste - Solar Thermal Panels
4. Cooling Systems	5. Lighting Systems	6. Warming Systems
- Planning Systems - Shading Devices - Wall Shading - Evaporative Cooling	- Daylighting - Windows - Lighting Controls - Low Energy Lights	- Heating Systems - Vertical Air Shafts - Igloo and Bucket Effect
7. Thermal Mass Storage	8. Insulation	9. Ventilation.
- The Greenhouse Effect - Radiant Heating/Cooling Systems - Trombe Walls - Sunspaces - Atriums - Thermal Mass Systems (Walls, Slabs, Central Heat Source) - Rock Beds	- Wall - Roof - Floor - Ceiling - Earth Slab	- Increase Head-On Breeze. - Intercept Oblique Breeze - Rechannel Current Direction - Open plan Air Flow

4.6. Recording Techniques Used on Building Elements.

A table is laid out for each green building principle and the full stratified sample of 30 green building case studies is listed against the 9 building elements. For each of the nine tables representing each green building principle, the number of green building techniques used on each building element in each case study for that element is noted and recorded. The end product of this phase is that each green building principle will have a table listing the number of green building techniques used on each building element over the thirty green building case studies. Then for each building element, the average number of green building techniques used for that green building principle and the standard deviation is computed. For example, on the table for the green building principle of Cooling Systems, the average number of green building techniques used in the building element could be found to be 4 and the standard deviation could be found to be 1.

Research Data Sheet

Green Building Technique 1. Orientation, form + Shape 2. Wind protection 3. Solar + Renewable Energy 4. Cooling Systems 5. Warming Systems 6. Lighting Systems 7. Thermal Mass Storage 8. Insulation 9. Ventilation	1. Site and Natural Elements	2. Structure	3. Building Envelope	4. Doors, Windows + Openings	5. Fittings	6. Finishes	7. Water Supply and Drainage	8. Heating, Ventilation + Air Cond	9. Electrical and Electronic.		
Green Building Samples											
1. CH 2 House											
2. SzenCorp Building											
3. EastGate Harare											
4. BP Green Headquarters CT											
5. IDG Building Netherlands											
6. Banner Bank Building, Idaho											
7. Boulder Offices, Colorado											
8. BRE Envirobuilding, UK											
9. California Enviro Building											
10 PNC Financial Building											
11. Toyota Motor Sales Building											
12. Puget Sound Energy Building											
13. National Geographic Building											
14. Central Internacional de Nogocios Mexico											
15. Fossil Ridge High School, Colorado											
16. Brewery Blocks Building, Washington											
17. Engesby Building, Germany											
18. Centre of Excellence Building, Sydney											
19. Pleasant Hill Building, Maine											
20. Shiodome Tower, Japan.											
21. Woodland College											
22. Wessex Water Buildinggg											
23. Kansai Electric Power Building, Japan											
24. Egg of the Earth Research Centre Japan											
25. Natura Plant Industrial Centre, Brazil											
26. Temuco Airport, Chile											
27. Earthworld Architects Building											
28. Gerding Collaborative Building											
29. HOK Building											
30. Kirksey Building											
AVERAGE											
STANDARD DEVIATION											

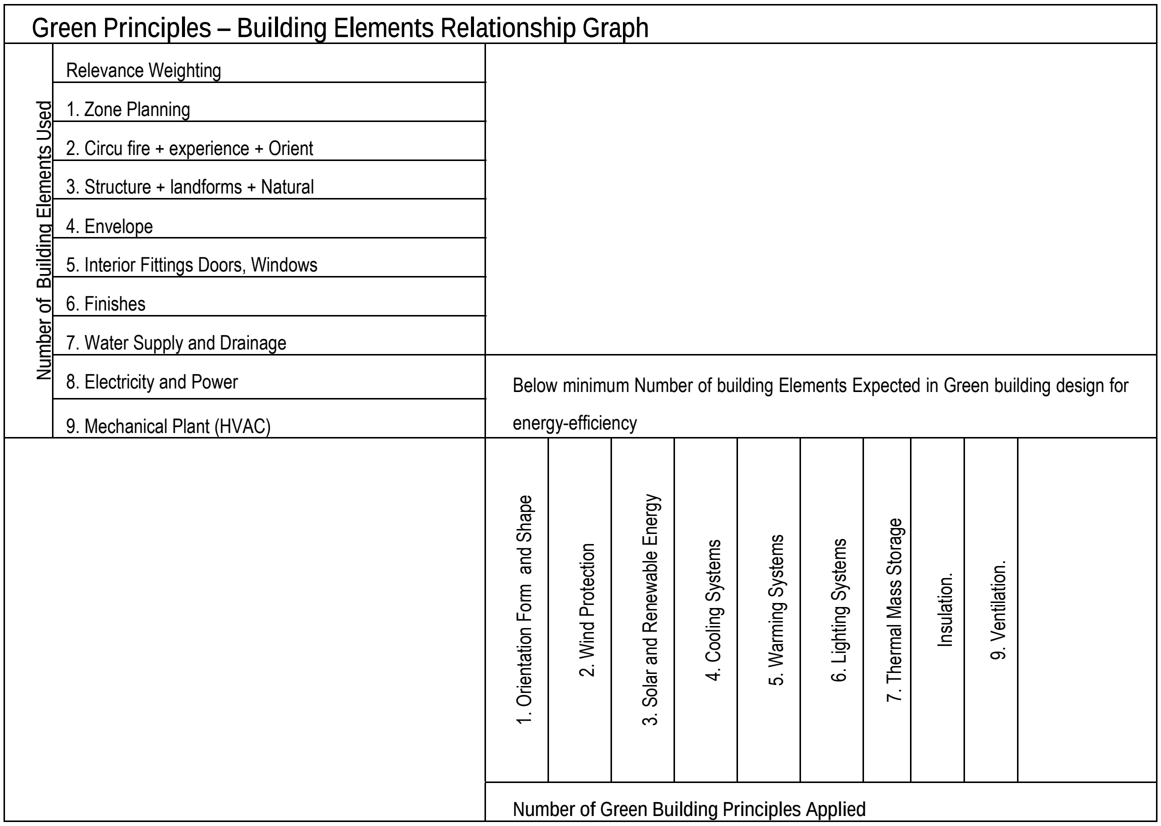
4.7. Charting the Principles to Elements Relationship.

After the nine sheets recording the each green building energy-efficiency principles used on building element has been collected and charted, a scatter diagram is going to be plotted on a graph which relates the number of energy-efficiency principles used to the number of building elements they have been applied to on each green building case study. This graph will have as dots all the case studied buildings. Then a regression line of the plots will be computed to map the relationship and calculations and analysis will be drawn from the graph.

The interpretation of the graph is as follows. The point where the Characteristic Line hits the y-axis (building elements), will be the minimum number of building elements that are considered by environmentally conscious designers in implementing green building principles for energy efficiency. The importance of this number is that when institutions are implementing policies for green building rating systems, they would ideally impose that each green building principle implemented must be spread across at least "Y" building elements for that building to be rated green. Implementing each green principle to more elements than the minimum required number of elements will then improve the green rating of the building more.

In this way, such a rating system will guarantee that each green building principle is evenly spread across the spectrum of building elements. At this point, the author recommends that weighting element of Value Engineering be introduced to the rating system. For instance, if the scope of the fittings work constitutes a higher volume of the building mass, then that building element will be given a heavier weighting. If, as another example, earlier research has shown that windows, doors and Openings conserve more energy per unit mass than the structural system of a building, then the Windows, Doors and Openings will get a heavier weighting than the Structural System. As a final example on weighting, if research has shown that a certain climatic and geographic region tends to conserve energy by buildings that are long and thin, then the structural system will have more weighting than the Electricity and Power. But the weighting of Green Building information is beyond the scope of this research and this research only covers the relationship between green building principles and building elements. So for that reason, all building elements have been given an equal weighting so that the primary goal of measuring how well spread the green principles are across building elements.

The slope or gradient of the Characteristic Line represents the number of green building principles that are used per unit building element. The importance of this slope would be that when implementing green building policies, a guideline rule of thumb at least "X" principles should be applied to each building element – any building which applies each principle to more building elements will get a better rating.



4.7.0 Calculations.

This section focuses on studying and quantifying the relationship between the number of green building principles used and the number of building elements they are applied to. Following the scatter graph which was mapped out to relate green principles and building elements and the regression line that was plotted between them, there is need to compute and interpret (1) the mean and standard deviation, (2) the correlation, (3) whether the correlation is actually due to randomness, (4) the Ordinary Least Square and hence the representative regression line. (5) F-Stat to investigate whether the value of ß0 is due to randomness.

4.7.1 Mean and Standard Deviation

The first calculation investigates the minimum adequate number of green building techniques to be used across the different green building principles for energy efficiency. The Author suspects that the average number of techniques used on each building are fewer than the number of green building principles to implement a policy of a minimum of 1 technique for each building principle.

Assuming by policy each building must implement one technique from each of the 9 green building principles, meaning that each building must have at least 9 green building principles to conclude that green building techniques are evenly spread across the range of green building principles for energy efficiency. The author is accepting a 95% level of confidence and 5% level of significance. The first hypothesis then becomes: the percentage of buildings which use more than 9 green building techniques is more 85%.

4.7.2. Correlation.

The second investigation focuses on the relationship between the number of techniques used and the number of green buildings principles used for energy efficiency. The Author suspects that there is an ideal strong correlation between the number of techniques used and the number of green building principles implemented. The author is convinced that the more the number of building elements used, the more the number of green building principles implemented and therefore the more balanced and diversified the building is in energy efficiency. If this is indeed the case, then there is a strong positive correlation between the number of building elements used and the number of green building principles implemented

$$\text{Correlation } r = \frac{\text{Covarience} \quad A, B}{(\sqrt{\text{std dev } A})(\sqrt{\text{std dev } B})}$$

$$r = \frac{SS_{xy}}{(\sqrt{SS_{xx}})(\sqrt{SS_{YY}})}.$$

$$SS_{XY} = \sum X_iY_i - 1/n(\sum X_i)(\sum Y_i)$$

$$SS_{XX} = \sum X_i^2 - 1/n(\sum X_i)^2$$

The Author is accepting a 95% level of confidence which leaves a 5% level of significance.

4.7.3 Correlation Significance

The next investigation is to check if the value of R is purely and genuinely due to randomness or if R falls in the significance range testing as 95% confidence level.

We first need to check and verify if the correlation is significant of if the correlation is a result of randomness. Our sample size n=38 and we are testing at 5%. In our case we are testing if risk and return go up together and come down together so this is a 2 tail test. So $\alpha = 0.025$. Looking at our r-tables we find that for n=40 and $\alpha = 0.025$ then $|r\ crit| = 0.312$ and $|r\ calc| = 0.334$ in this case $|r\ calc| > |r\ crit|$ and therefore r is due to randomness.

4.7.4 Simple Regression Line

If there is indeed a relationship between the number of building techniques used and the number of green building principles implemented, then a simple regression line can be graphically illustrated which shows the number of techniques used per number of green building principles implemented.

HYPOTHESIS 3: Assuming a strong correlation between the techniques used and the number of green building principles implemented, then a simple regression line can be graphically illustrated with the x coordinate being the number of green building principles implemented and the y-coordinate being the number of techniques used. The formula for the graph will be y = ß0x + ß1. The constant ß1 where the graph hits the y axis should be greater than 1 because at least one technique must be used for each green building principle and the gradient ß0 must be greater than 1 because there must be one or more techniques used on each green building principle.

$$y = ß_0 + ß_1x$$

$$ß_0 = y - ß_1x$$

$$ß_1 = \frac{SS_{XY}}{SS_{XX}}$$

4.7.5 F-Statistic

ANOVA Table

Source of Variation	Degrees of Freedom (df)	Sums of Squares (SS)	Mean Square (MS)	F-Stat (F_{cal})
Regression	1	$SS_{reg} = \frac{(\sum x_i y_i)^2}{\sum x_i^2}$	MS_{reg}	$\frac{MS_{reg}}{MS_{res}}$
Residual	n-1= 29	$SS_{reg}=SS_T-SS_{reg}$	$S^2 = MS_{reg}$	
Total	30	SST = $\sum$ yi2		

Now F-stat test of significance whether ß1 due to randomness at 1% level of significance.

From F-table, denominator degree of freedom is
n-2 = 38-2 =36

numerator degree of freedom = 1

from f table F crit = 7.39

From ANOVA f-stat=128.277

So F calc is way above the F crit and therefore ß1 is due to randomness.

Chapter 5
Data Analysis

5.0. Introduction to the Green Building Sample

A stratified sample of 24 green buildings was chosen. The green buildings in the sample have predominantly achieved the highest of ratings when assessed by the green building rating systems that were discussed in Chapter 3 and most of them have received awards for the innovative implementation of green building systems and techniques. A full outline of the 24 buildings that were reviewed is available in Appendix 1 complete with all the green building principles and techniques implemented in each building, the value engineering functional analysis data filters, the buildings awards and ratings, and the sources of information.

The sample was deliberately chosen from 5 different continents so as to eliminate the influence and effects of climatic design factors and ecosystem in the results. The sample was also intentionally chosen to include the full range of building types so as to eliminate the consistent specific implementation of green building principles and techniques of a particular building type. So the Green Building sample building types range from Office Buildings (e.g. Sample 22 – Edificio Malecon), Industrial Buildings (e.g. Sample 16 - Woolworths Distribution Centre), Leisure and Recreational Buildings (e.g. Sample 14 – Xihu Tiandi), Residential Buildings (e.g. Sample 10 – Project 7 Ten) and Government Buildings (e.g. Sample 1 -CH2).

Although the size and scale of the projects were different, it was apparent from the data collection that the project brief and the scope of work for implementing the green building principles and techniques was the same. A critical consistent theme in all the green buildings that were reviewed was the high quality in the implementation of many and innovative green building principles and techniques. It was expected that quality of the implementation of green principles and techniques would be about the fitness for use in conserving energy and the grade would be about the cost of implementing green principles and techniques, it was observed during data collection that some of the projects reviewed were of the highest quality in that they implemented lots of principles and techniques and yet maintained their low grade status in that the principles and techniques were cheap to implement.

5.1. Data Sheet

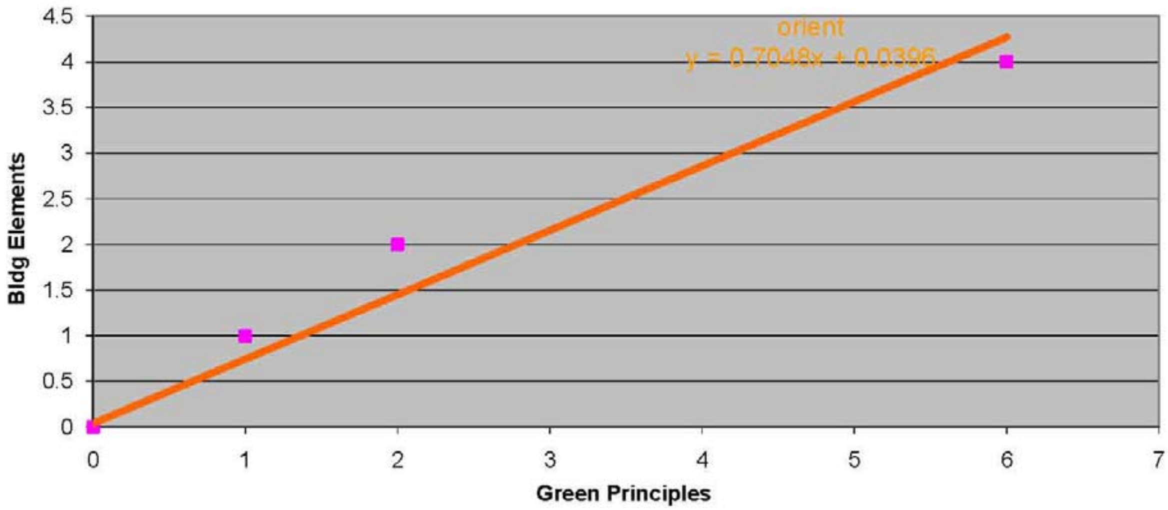
The graph below shows a summary of the data collected in a chart relating the green building principles and techniques to how they are spread across building elements. The 24 building samples are listed and for each building sample, the number of building elements the each green building principle is implemented on is recorded as a fraction so as to measure spread. A total average for each building sample is calculated to give an idea of how well spread green building principles are across building elements. The higher and the closer to 1 that this fraction is, the more spread the green principles and techniques are across the building's elements for that building sample. Also listed below all 24 building samples is the total average of how well spread green building techniques are across building elements for each green principle. The higher and the closer to 1 that this fraction is, the more spread the green principles and techniques are across the building's elements for that green building principle.

Looking at how well spread the green building principles and techniques are across building elements for each sample from the chart, the is an average of nearly 0.7 with most of the higher performing buildings achieving good spread ratios by only implementing less principles. However, an outstanding green building which implements many green building principles and techniques spread over all building elements classified is the California luxury mansion Sample 10 – Project 7 Ten designed by Grey Matter Architecture. The principles and techniques implemented are standard compared to all the building samples but the innovation comes in how they are spread across the building. The possible explanation of the spread of green principles and techniques over all building elements in Project 7 Ten is rooted in the Total Quality Management approach by Grey Matter Architecture in designing Project 7 Ten. As soon as a decision to build a sustainable design was made early on in the design process, it dictated, drove and filtered every single decision made on the building, from shape of building, construction methods and materials used.

GREEN BUILDING PRINCIPLES		1. Orientation Form and Shape	2. Wind Protection	3. Solar and Renewable	4. Cooling Systems	5. Warming Systems	6. Lighting Systems	7. Thermal Mass Storage	8. Insulation.	9. Ventilation.	TOTAL	
1. CH2 House Melbourne, Australia	BDLG ELEMENTS / GREEN TECH	1 / 1	1 / 1	3 / 4	8 / 10	3 / 4	4 / 8	2 / 2	0 / 0	3 / 4	25 / 34	0.735294
2. Sweetwater Creek State Park Visitor Centre, USA	BDLG ELEMENTS / GREEN TECH	4 / 6	1 / 1	3 / 7	6 / 9	5 / 6	4 / 10	2 / 2	1 / 2	1 / 1	27 / 44	0.613636
3. Eastgate Development, Harare, Zimbabwe	BDLG ELEMENTS / GREEN TECH	0 / 0	1 / 1	2 / 3	3 / 5	0 / 0	3 / 5	2 / 2	2 / 2	1 / 1	14 / 19	0.736842
4. Szencorp Building, Australia	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	3 / 6	4 / 6	3 / 4	3 / 9	2 / 2	1 / 1	2 / 3	18 / 31	0.580645
5. Sixty L Building, Melbourne, Victoria, Australia	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	3 / 5	2 / 4	2 / 3	2 / 2	1 / 1	0 / 0	4 / 5	14 / 20	0.7
6. TEPCO Research and Development Centre	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	3 / 4	3 / 4	1 / 4	4 / 5	0 / 0	1 / 1	2 / 3	14 / 21	0.666667
7. Automotive Centre of Excellence, Australia.	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	0 / 0	2 / 5	2 / 2	4 / 6	2 / 5	0 / 0	3 / 6	13 / 24	0.541667
8. National Trust Headquarters, Swindon, U.K.	BDLG ELEMENTS / GREEN TECH	1 / 1	0 / 0	3 / 5	2 / 3	1 / 1	3 / 8	4 / 6	1 / 1	2 / 2	17 / 27	0.62963
9. Aldo Leopold Legacy Centre, Wisconsin, USA	BDLG ELEMENTS / GREEN TECH	2 / 2	0 / 0	3 / 4	2 / 3	2 / 3	1 / 1	1 / 1	1 / 2	4 / 5	16 / 21	0.761905
10. Project7ten, California, USA	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	2 / 2	3 / 3	2 / 2	3 / 3	1 / 1	2 / 2	0 / 0	13 / 13	1
11. Sohrabji Godrej Green Business Centre, India	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	2 / 3	1 / 1	0 / 0	4 / 4	0 / 0	0 / 0	3 / 4	10 / 12	0.833333
12. Portland Armory, Portland, Oregon, USA	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	2 / 2	2 / 2	0 / 0	2 / 2	6 / 6	1
13. Mckinney Green Building, Dallas, Texas, USA	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	3 / 5	2 / 3	1 / 1	5 / 7	1 / 1	1 / 1	2 / 3	15 / 21	0.714286
14. Xihu Tiandi, Hangzhou, China	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	3 / 4	2 / 2	2 / 2	0 / 0	1 / 1	0 / 0	2 / 2	10 / 11	0.909091
15. BP Southern Africa, Cape Town, South Africa	BDLG ELEMENTS / GREEN TECH	0 / 0	1 / 2	2 / 3	5 / 7	3 / 4	4 / 5	2 / 2	1 / 1	1 / 3	19 / 27	0.703704
16. Woolworths Distribution Centre, South Africa	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	2 / 2	0 / 0	1 / 1	1 / 1	0 / 0	1 / 1	1 / 1	6 / 6	1
17. Innovate Green Office, Thorpe Park, U.K	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	0 / 0	3 / 5	1 / 1	2 / 4	3 / 6	1 / 2	3 / 3	13 / 21	0.619048
18. Vic Urban Melbourne Office	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	0 / 0	1 / 2	2 / 3	4 / 11	1 / 1	0 / 0	1 / 1	9 / 18	0.5
19. Greenwood Trust Woodland College. U.K	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	0 / 0	3 / 3	5 / 9	1 / 1	1 / 1	3 / 5	0 / 0	13 / 19	0.684211
20. Guarajuba Ecohouse, Brazil	BDLG ELEMENTS / GREEN TECH	0 / 0	6 / 8	1 / 1	3 / 3	1 / 1	2 / 2	3 / 4	2 / 2	3 / 5	21 / 26	0.807692
21. Edificio Malecon, Buenos Aires, Argentina	BDLG ELEMENTS / GREEN TECH	0 / 0	1 / 1	0 / 0	4 / 9	4 / 5	4 / 4	0 / 0	1 / 3	3 / 4	17 / 26	0.653846
22. Genzyme Centre, London. U.K	BDLG ELEMENTS / GREEN TECH	0 / 0	1 / 1	3 / 3	1 / 1	1 / 1	3 / 8	1 / 1	1 / 1	1 / 2	12 / 18	0.666667
23. Caravan Upgrade, Nieuwoudtville, South Africa	BDLG ELEMENTS / GREEN TECH	0 / 0	0 / 0	3 / 4	1 / 2	0 / 0	1 / 1	0 / 0	1 / 2	2 / 2	8 / 11	0.727273
24. Smithsonian Tropical Research Station. Panama	BDLG ELEMENTS / GREEN TECH	0 / 0	2 / 2	1 / 1	3 / 3	2 / 2	2 / 4	0 / 0	0 / 0	4 / 4	14 / 16	0.875
TOTAL	BDLG ELEMENTS / GREEN TECH	8 / 10	14 / 17	45 / 66	64 / 93	44 / 59	66 / 111	32 / 41	21 / 29	50 / 66	344 / 492	0.699187
		0.8	0.823529412	0.681818182	0.688172043	0.745762712	0.594594595	0.780487805	0.724137931	0.757575758	0.699186992	

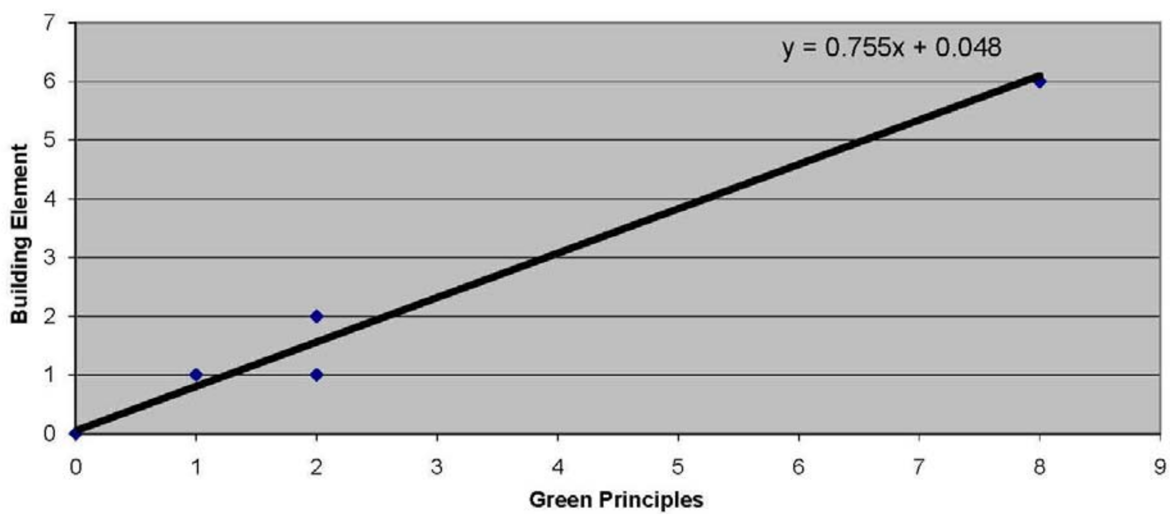
5.2. Analysis of Relationships between Building Elements to Principles.

5.2.1. Orient Form and Shape



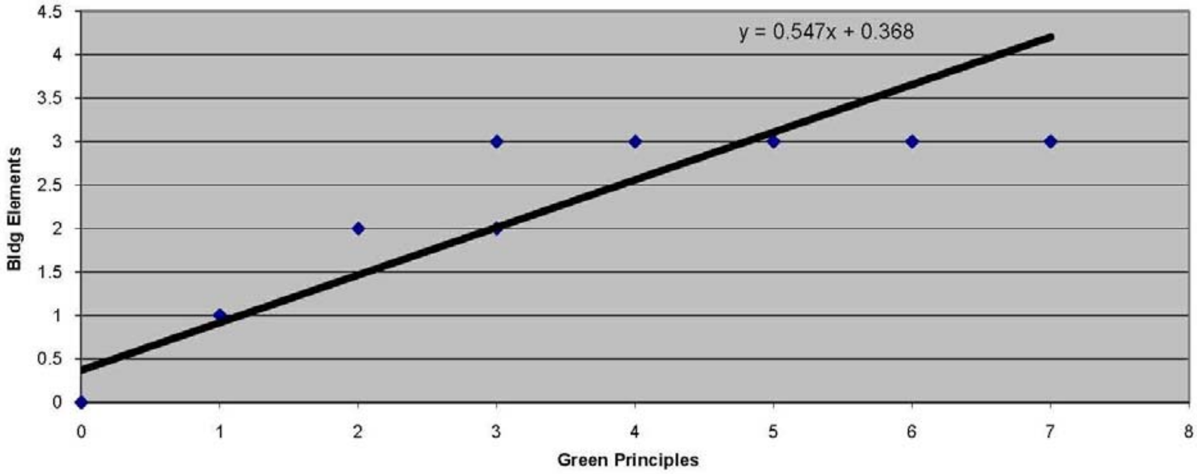
The regression line for Orientation, Form and Shape is y = 0.7048x + 0.0396. The line hits the y axis (building elements) at 0.0396 which is almost 0 and the possible explanation is that implementing this green principle is entirely dependant on the type and characteristics of the building elements used. The more elements used the more green principles used. What makes this green principle especially sensitive is that it is the one that is most dependant on the form of the building.

5.2.2. Wind Protection



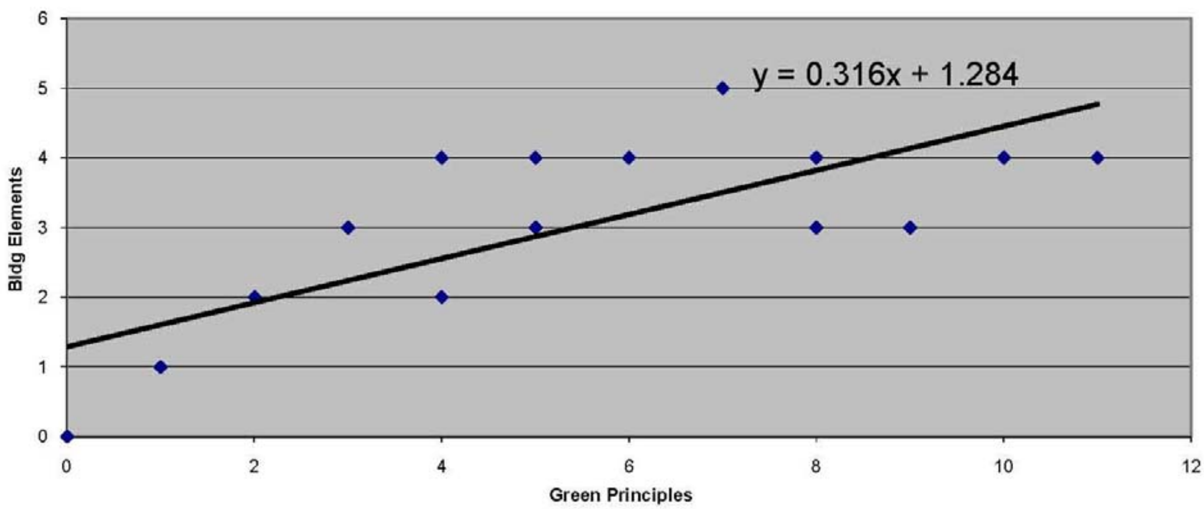
The regression line for Wind Design and Protection is y = 0.7556x + 0.0481. The regression line hits the y-axis (building elements) also at almost 0 probably because channelling the wind is largely dependent on the form and shape of the building which is in turn dependant on the building elements. So it would be expected that the number of green principles used would increase with the number of building elements used. The steep gradient of 0.7556 is probably due to the effectiveness of multiple building elements used to maximize each green building principle. This steep gradient suggests that wind protection and design is the most effective and optimal green principle to use in terms of maximizing its spread along building elements.

5.2.3. Solar



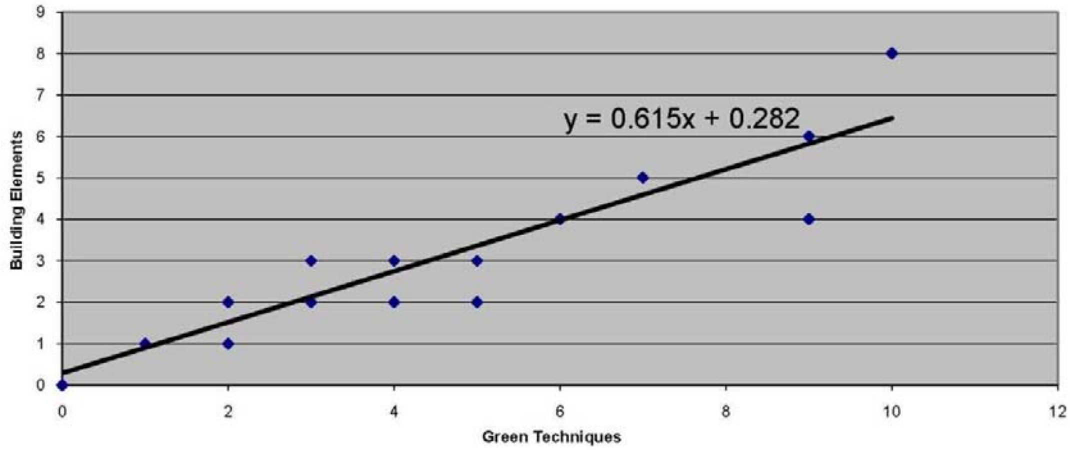
The regression line for Solar and Renewable energy is y = 0.5478x + 0.3684. This regression line intersects the y-axis at 0.3684 which suggests that Solar and Renewable energy are less dependant on a direct relationship with building elements because they are primarily used on the roof of a building so as to capture the optimal amount of energy, solar or wind. This argument is further enhanced by a lower gradient of number of green principles per unit building element which suggests that this green principle is applied on a very few number of building elements.

5.2.4. Lighting

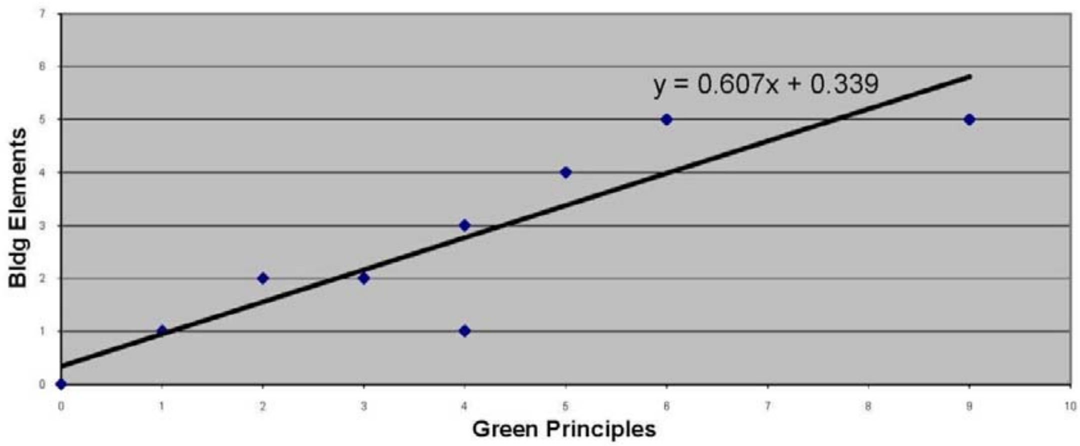


The regression line for Lighting Systems is y = 0.3168x + 1.2847. The regression line intercepts the y-axis at 1.2847, which is the highest y-intercept of all 9 principles, which suggests that the concept of lighting has been very well and consistently applied in green buildings. However, the gradient of the number of Green Principles used per unit building element is low suggests that the Lighting systems are very prevalently used but on a few building elements. This means that Lighting systems are not as well spread across all building elements and therefore may not be as effective. If this research report suggests Wind Design and Protection as the most effective green principle in terms of spread across building elements, then Lighting Systems are the least effective green principle in terms of spread across building elements. A possible reason for this is that lighting methods and techniques is not innovatively implemented by designers of green buildings and is only applied in its most conventional and traditional sense.

5.2.5 Cooling and Warming



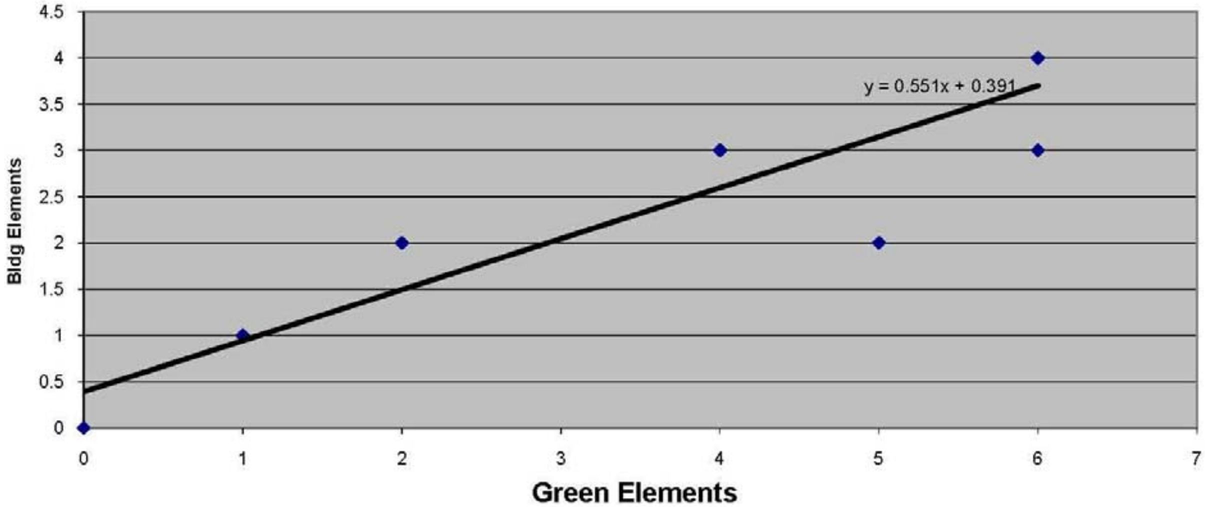
Cooling



Warming

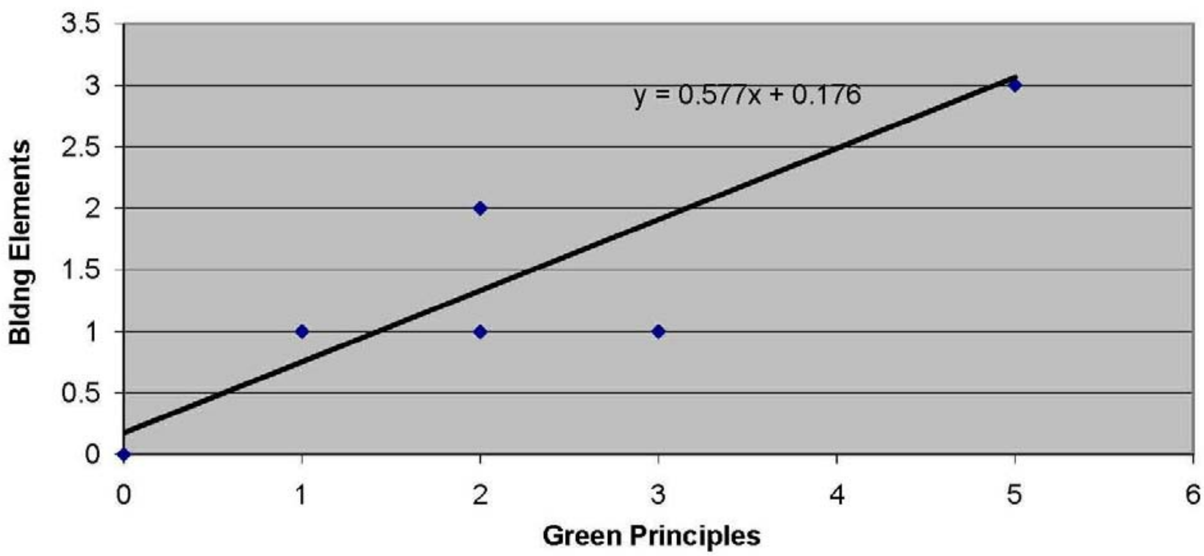
The regression line for Cooling Systems is y = 0.6154x + 0.2821 and the regression line for Warming Systems is y = 0.6078x + 0.3391. A key observation of this research is that these two regression lines are very similar to each other and have the closest relationship compared to any other pair of regression lines in the green principles reviewed. This suggests that the two green principles probably complement each other and are probably implemented on the same building elements but this does not necessarily imply that one cause the other. The regression lines for warming and cooling systems intersect the y-axis at 0.2821 and 0.3391 respectively which suggests that designers who build green generally implement these principles subconsciously when designing buildings with a sustainably mindset and attitude. The gradient of number of green principles used per unit is building element is relatively high suggesting that concept of sustainably heating and cooling a building is shared substantially across all building elements.

5.2.6. Thermal Mass Storage



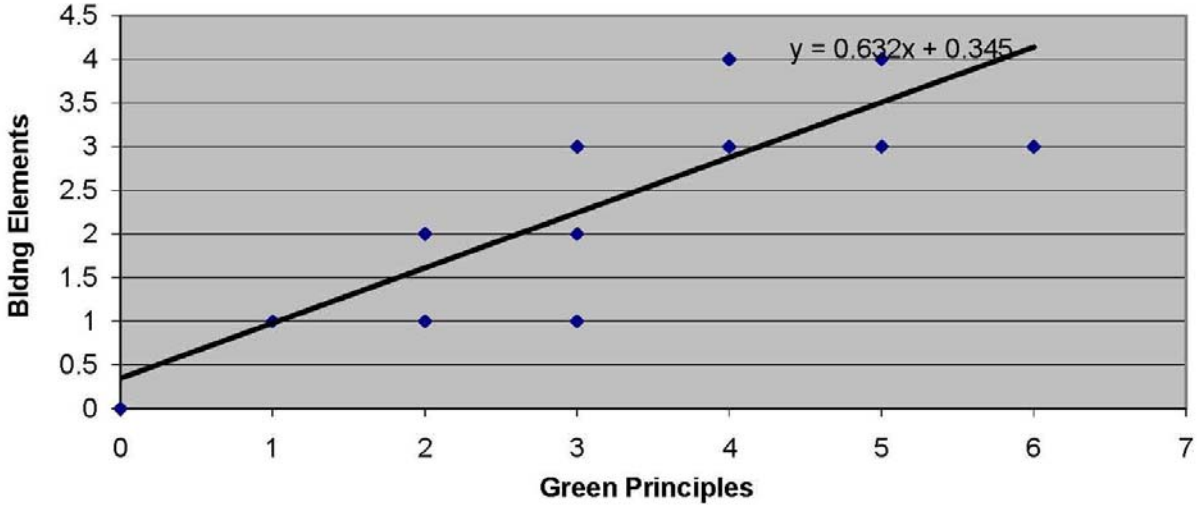
The regression line for Thermal Mass Storage is y = 0.5514x + 0.3913. this regression line intercepts the y axis at 0.3913 and a possible reason for this is that most building elements and materials used in construction are already thermal mass storage systems by nature. By the time a green building designer starts implementing this green principle most of the work is already done. However, it is more difficult to ascertain why the gradient of number of green principles per unit building element is relatively low. This is especially difficult to understand especially since thermal mass storage has high potential of collaborating with green principles like warming systems and cooling systems. A possible reason is that the principles, concepts and workings of thermal mass storage systems are in direct conflict with principles, concepts and workings of green principles like wind design and Protection and green principles like ventilation which tend to circulate air and energy away from material thermal storage sources.

5.2.7. Insulation



The regression line for Insulation is y = 0.5779x + 0.1767. This regression line intercepts the y-axis at 0.1767 which is almost 0, suggesting that insulation is largely dependant on a direct relationship with building elements into which the insulation will have to be located. The slope of the gradient for number of green principles per unit building element is rather low compared to the slope of other green principles. The possible reason for this is that insulation can only be embedded within other building elements and this limits the possibility of using insulation unique, innovative and separate techniques. However, the potential that insulation is limited to in terms of spread, insulation makes just as much in terms of exposure because in the building elements that insulation can be used, it has the potential to be used extensively.

5.2.8. Ventilation



The regression line for Ventilation is y = 0.632x + 0.3453. This regression line intercepts the y-axis on 0.3453. A reason why the y-intercept of ventilation is relatively high is possibly because Ventilation is such a critical principle of uilding healthy environments that it must be considered even before green building energy efficiency is taken into account. As a result, it is expected that ventilation as a green principle should be included in the design of green buildings. The same reason could potentially be why the gradient slope of number of green principles per unit building element is relatively high. Ventilation is probably such a critical principle of green building and also one of the more flexible in terms of using more different types of building elements and also in terms of collaborating with other green principles like Wind Design and protection and Heating Systems and Cooling Systems. As a possible result, the gradient slope of number of building elements per unit building element is relatively high as compared to the gradient slope of other green principles.

5.3. Interpreting the results

The first observation is that the mean number of Green Principles applied in green buildings is 2.278 with a standard deviation of 0.975. Now 95% of green buildings fall within 2 Standard deviation meaning that [2.278 $\pm$ 2(0.975) = (0.328; 4.228)] or 95% of green buildings use between 0.328 and 4.228 green principles in their buildings. So if a policy has to be implemented; it must state that green buildings must apply at least 0.328 green principles per building although the average number of green principles expected in a green building to be 2.278.

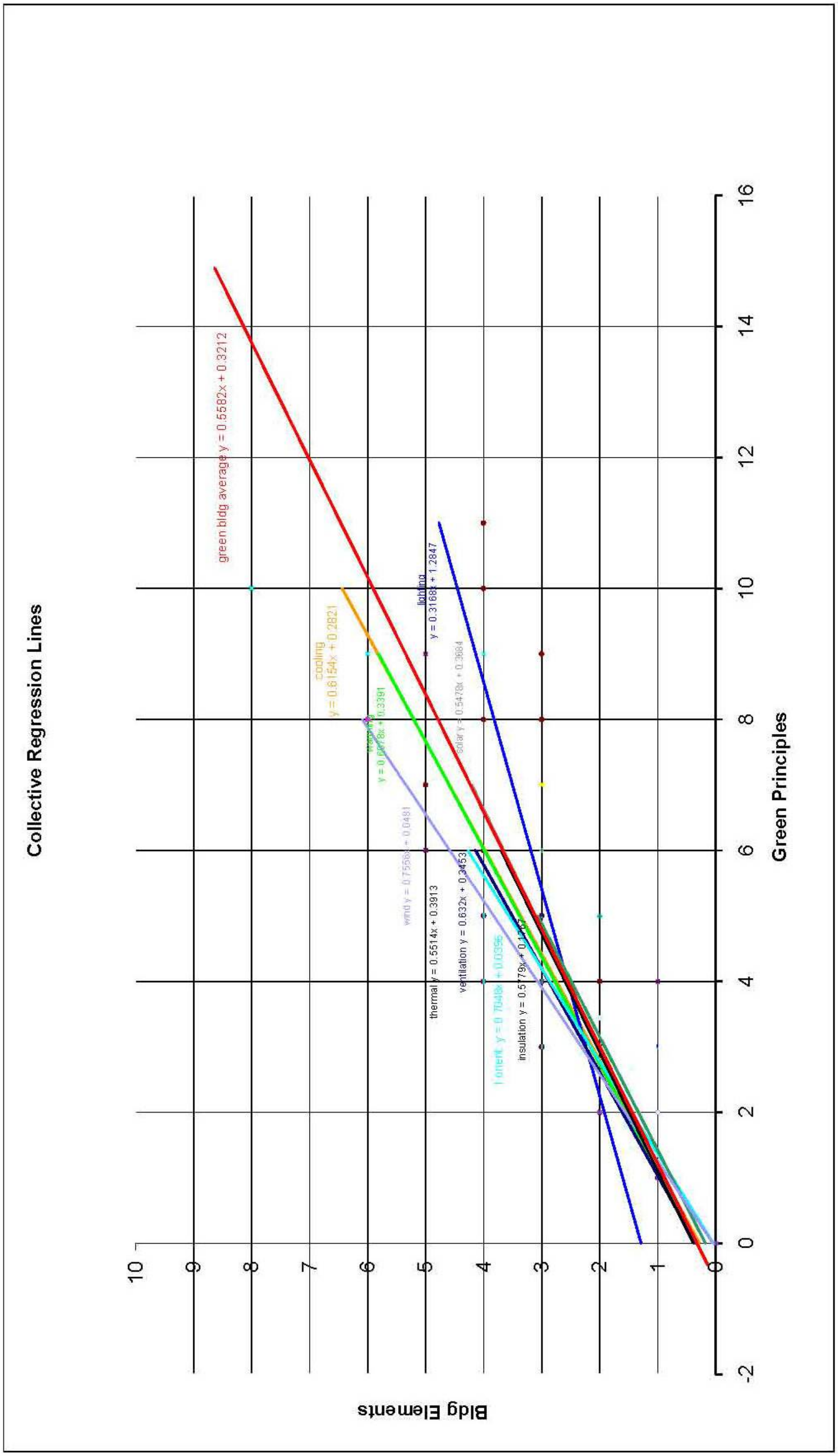
The next observation is the mean number of Building Elements used for each green principle is 1.593 with a standard deviation of 0.581. Now 95% of green buildings fall within 2 Standard deviation meaning that [1.593 $\pm$ 2(0.581) = (0.431; 2.755)] or 95% of green buildings use between 0.431 and 2.755 building elements for each green principle. So if a policy has to be implemented; it must state that green buildings must apply each green principle to at least 2.755 building elements although the average number of building elements used for each green principle in a green building is 1.593.

There is a strong positive linear correlation of 0.9361 between green principles used and the number of building elements they are used in. This means that as the number of green principles used increases, the number of building elements they are applied to increases and as the number of green principles used decreases, the number of building elements they are applied to decreases.

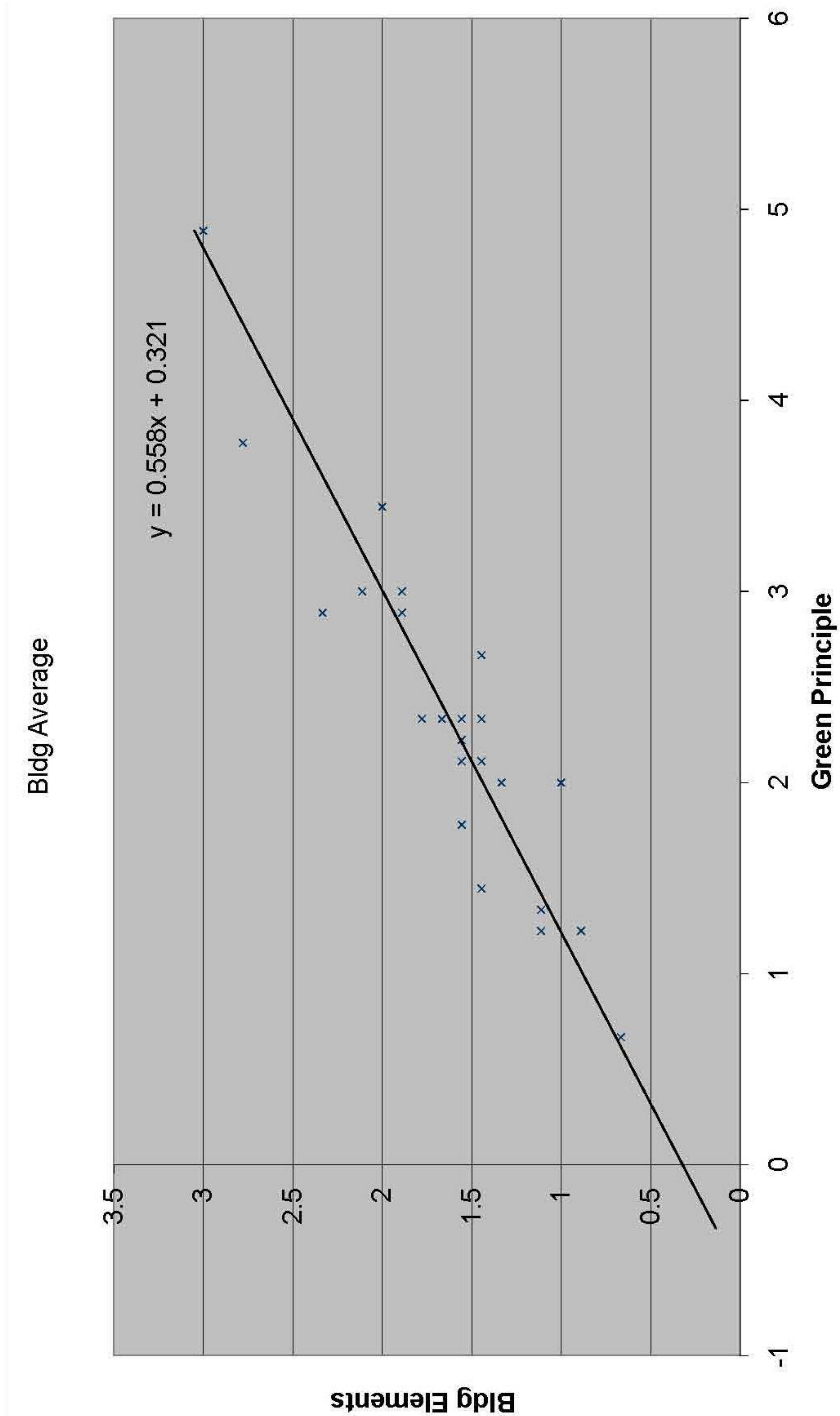
The regression line equation of the relationship between green principles and the number of building elements they are used in is $y = 0.3212 + 0.5582x$. So if a policy has to be implemented; it must state that green buildings must apply a minimum of 0.3212 green principles and each building element must account for at least 0.5582 green principles.

The following analysis breaks down the performance of each green principle in relation to the overall performance of the building's green principles used per unit building element.

So this research disproves the hypothesis that green principles are not spread out consistently across building elements. This research proves and suggests that green principles are indeed spread equally and consistently across building elements.



Collective Regression Lines
Green Principles
Bldg Elements
green bldg average y = 0.5582x + 0.3212
cooling
y = 0.6154x + 0.2821
y = 0.3168x + 1.2847
wind y = 0.7556x - 0.0481
thermal y = 0.5514x + 0.3913
ventilation y = 0.632x + 0.3453


Bldg Average
y = 0.558x + 0.321
Bldg Elements
3.5
3
2.5
2
1.5
1
0.5
0
-1
0
1
2
3
4
5
6
Green Principle

Chapter 6
Application of Green Building Value Engineering

The following suggests methods of how this research can be practically applied to the property and construction industry. This is basically the fieldwork on the application of value engineering to assess the spread of implementation of Green Building Principles and Techniques to individual case study buildings and hence systematically suggest ways to improve the implementation of green building techniques on the building and boost the energy-efficiency and its value within the local context of Johannesburg.

A driving factor in implementing value engineering to spread green building principles across building elements is the production of control systems and tools to deliver a specific and custom product as stated in point 3 of section 1.3 of Chapter 1 – Research Introduction. Energy use in a residential house, (e.g. House Simpson profiled below), is very different to energy use in a public utility building, (e.g. Parktown Girls' High School Hall), and it is also very different to energy use in a commercial office building (e.g. La-Roche Office Park), all profiled below. This Chapter conducts rigorous fieldwork using value engineering to implement green building principles and techniques on building elements of the above 3 building types as per their specific use and unique needs. The fieldwork profiles below are based on interviews with the design professionals involved in the projects and personal site visits to the buildings in operation.

The tools used to value engineer the spread of green principles and techniques across the different buildings below are rooted directly from the functional analysis definition of value engineering. These tools have been directly extracted from functional analysis method of rating green buildings as described in Chapter 3.3 and the derived tables from functional analysis are used here, including the classification tool in Figure 3-6 and the Functional Criteria Matrix in Figure 3-9.

In each of the three buildings profiled and studied below, the design architect was first interviewed and then a field investigation was conducted on the existing building into how much of each green principle and technique had been implemented. Then a brief analysis of how the green building principles and techniques are spread across building elements was carried out using a matrix as described in Chapter 3 Functional Analysis of Green Buildings. Each Green Principle and Techniques are weighted based on their contribution to the functionality of the building. Then the amount of green building techniques implemented on each element is charted and multiplied by the weighting. Then the weighting scores are added up to give the building's total performance.

Drawings of the case studied buildings are illustrated in Appendix 3.

6.0. Observations

Initial observations suggest that building structure is the least functional building element in terms of implementing energy efficiency. The most probable reason for this is that structure is the one element which green building designers have the least control of as it is handled by specialist structural engineers and as it performs a critical function of structural integrity. Internal finishes and fittings are also very weak in terms of implementing energy efficiency and this is probably because of their limited or lack of relationship with the building exterior. The site and landscaping has possibly got the highest potential for energy efficiency in all building types but has only been utilized on an average scale. This is probably because the introduction of green building principles is only considered at a developed stage and the concept of the project will already be laid out on site.

This fieldwork opens up possibilities and opportunities for further research in the relationship between green building principles, building elements and function of different building types, which is beyond the scope of this research.

House Simpson, Johannesburg

Designed by Nadia Tromp - Design Director for Paragon Habitat Architects as primary residence to client of their bigger commercial developments. Residential Buildings need to collect and save heat during the day then dissipate heat at night . Daylighting not important since people mostly at school or outdoors. Orientation highly possible on freestanding site. South-Easterly wind for protection + ventilation. Need good insulation for Johannesburg Summers.

1. Orientation Form and Shape =10

- Orientation = 3
- Site Energy Planning = 0
- Building Form = 2
- Earth Sheltering Recess = 0

2. Wind Protection = 10

- Landform and Planting = 5
- Wind Turbulence Protection = 0
- Wind Channeling = 4

3. Solar and Renewable Energy =3

- Solar Thermal Panels = 0
- Photovoltaic cells = 3
- Wind Energy = 0
- Biomass Waste = 0
- Solar Thermal Panels = 8

4. Cooling Systems =1

- Planning Systems = 0
- Shading Devices = 3
- Wall Shading = 3
- Evaporative Cooling = 1

5. Lighting Systems = 4

- Daylighting = 6
- Windows = 5
- Lighting Controls = 7
- Low Energy Lights = 0

6. Warming Systems = 2

- Heating Systems= 5
- Vertical Air Shafts = 0
- Igloo and Bucket Effect = 0

7. Thermal Mass Storage =8

- The Greenhouse Effect= 0
- Radiant Heating/Cooling Systems = 0
- Trombe Walls = 0
- Sunspaces = 0
- Atriums = 0
- Thermal Mass Systems (Walls, Slabs, Central Heat Source) = 8
- Rock Beds = 0

8. Insulation =8

- Wall = 0
- Roof = 8
- Floor = 0
- Ceiling = 7
- Earth Slab = 0

9. Ventilation. =5

- Increase Head-On Breeze=6
- Intercept Oblique Breeze=7
- Rechannel Current Direction=8
- Open plan Air Flow=1

	1. Orientation	2. Wind Protection	3. Solar and	4. Cooling Systems	5. Warming Systems	6. Lighting Systems	7. Thermal Mass	8. Insulation.	9. Ventilation.	TOTAL
	10	10	3	1	2	4	8	8	5	
1. Site and Landscaping	3 / 30	4 / 40	0 / 0	4 / 4	3 / 6	3 / 12	1 / 8	3 / 24	6 / 30	154
2. Structural System	1 / 10	0 / 0	0 / 0	2 / 2	2 / 4	0 / 0	3 / 24	1 / 8	1 / 5	53
3. Envelope	4 / 40	6 / 60	6 / 18	5 / 5	4 / 8	3 / 12	6 / 42	5 / 40	4 / 20	165
4. Doors, Windows and Openings	5 / 50	7 / 70	5 / 15	1 / 1	1 / 2	1 / 1	3 / 24	3 / 24	6 / 30	207
5. Interior Fittings	2 / 20	3 / 30	0 / 0	2 / 2	2 / 4	1 / 1	4 / 32	2 / 16	2 / 10	115
6. Finishes	1 / 10	4 / 40	3 / 9	1 / 1	3 / 6	0 / 0	2 / 16	6 / 42	1 / 5	129

Parktown Girls High School Pavilion, Johannesburg

Designed by Henry Paine as an institutional social infrastructure development of a school funded by a Parents Association with Board as client. Public utility buildings cater for shock and high impact of two extremes of capacity full use crowded to empty and quiet. Ventilation critical in public spaces and full enclosed control of warming and cooling also highly preferred. Lighting also critical however use of daylight discouraged so as to achieve lighting effect.

1. Orientation Form and Shape = 1	2. Wind Protection = 1	3. Solar and Renewable Energy = 1
- Orientation = 1 - Site Energy Planning = 0 - Building Form = 4 - Earth Sheltering Recess = 6	- Landform and Planting = 0 - Wind Turbulence Protection = 0 - Wind Channelling = 0	- Solar Thermal Panels = 0 - Photovoltaic cells = 0 - Wind Energy = 8 - Biomass Waste = 1 - Solar Thermal Panels = 0
4. Cooling Systems = 9	5. Lighting Systems = 7	6. Warming Systems = 9
- Planning Systems = 1 - Shading Devices = 8 - Wall Shading = 0 - Evaporative Cooling = 0	- Daylighting = 8 - Windows = 8 - Lighting Controls = 4 - Low Energy Lights = 1	- Heating Systems = 3 - Vertical Air Shafts = 1 - Igloo and Bucket Effect = 7
7. Thermal Mass Storage = 3	8. Insulation = 3	9. Ventilation = 8
- The Greenhouse Effect = 0 - Radiant Heating/Cooling Systems = 0 - Trombe Walls = 0 - Sunspaces = 1 - Atriums = 8 - Thermal Mass Systems (Walls, Slabs, Central Heat Source) = 0 - Rock Beds = 1	- Wall = 8 - Roof = 8 - Floor = 1 - Ceiling = 8 - Earth Slab = 9	- Increase Head-On Breeze = 0 - Intercept Oblique Breeze = 2 - Rechannel Current Direction = 0 - Open plan Air Flow = 1

	1. Orientation	2. Wind Protection	3. Solar and Renewable	4. Cooling Systems	5. Warming Systems	6. Lighting Systems	7. Thermal Mass	8. Insulation.	9. Ventilation.	TOTAL
	1	1	1	9	9	7	3	3	8	
1. Site and Landscaping	1 / 2	1 / 1	0 / 0	4 / 36	5 / 45	4 / 28	0 / 0	0 / 0	7 / 56	168
2. Structural System	1 / 2	0 / 0	0 / 0	6 / 54	6 / 54	5 / 35	6 / 18	2 / 6	8 / 64	233
3. Envelope	1 / 2	0 / 0	6 / 6	7 / 63	8 / 72	6 / 42	7 / 21	9 / 27	8 / 64	297
4. Doors, Windows and Openings	7 / 14	1 / 1	5 / 5	7 / 63	7 / 63	7 / 49	2 / 6	2 / 6	9 / 72	279
5. Interior Fittings	2 / 4	4 / 4	0 / 0	8 / 72	6 / 54	3 / 21	3 / 9	5 / 15	3 / 24	203
6. Finishes	1 / 2	1 / 1	3 / 3	5 / 45	5 / 45	8 / 56	5 / 15	1 / 3	6 / 42	212

La Roche Commercial Office Park, Parktown, Johannesburg

Designed by Rodney Grosskpff – Director – GLH and Associates Architects as personal office space for 40 staff and rent to another 60 people firm. Office buildings are high performance climate control buildings which need to cater for high volumes of people. Orientation and wind design difficult to achieve at low mass wide volume. Solar isolated for maximum internal climate control, lighting critical and also high potential in insulation. Night performance so minimum thermal storage.

1. Orientation Form and Shape = 2	2. Wind Protection = 3	3. Solar and Renewable Energy = 1
- Orientation = - Site Energy Planning = - Building Form = - Earth Sheltering Recess =	- Landform and Planting = 0 - Wind Turbulence Protection = 1 - Wind Channelling = 4	- Solar Thermal Panels = 3 - Photovoltaic cells = 1 - Wind Energy = 0 - Biomass Waste = 1 - Solar Thermal Panels = 0
4. Cooling Systems = 8	**5. Lighting Systems = 8**	**6. Warming Systems = 8**
- Planning Systems = 8 - Shading Devices = 8 - Wall Shading = 6 - Evaporative Cooling = 0	- Daylighting = 4 - Windows = 5 - Lighting Controls = 8 - Low Energy Lights = 4	- Heating Systems = 8 - Vertical Air Shafts = 8 - Igloo and Bucket Effect = 1
7. Thermal Mass Storage = 1	**8. Insulation = 1**	**9. Ventilation = 5**
- The Greenhouse Effect = 1 - Radiant Heating/Cooling Systems = 1 - Trombe Walls = 0 - Sunspaces = 0 - Atriums = 8 - Thermal Mass Systems (Walls, Slabs, Central Heat Source) = 6 - Rock Beds = 2	- Wall = 6 - Roof = 0 - Floor = 6 - Ceiling = 8 - Earth Slab = 0	- Increase Head-On Breeze = 1 - Intercept Oblique Breeze = 2 - Rechannel Current Direction = 0 - Open plan Air Flow = 1

	1. Orientation	2. Wind Protection	3. Solar Renewable	4. Cooling Systems	5. Warming Systems	6. Lighting Systems	7. Thermal Mass	8. Insulation.	9. Ventilation.	TOTAL
Relevance Weighting	2	3	1	8	8	8	1	1	5	
1. Site and Landscaping	0 / 0	2 / 6	4 / 4	1 / 8	1 / 8	5 / 40	6 / 6	1 / 1	5 / 25	98
2. Structural System	4 / 8	1 / 3	1 / 1	1 / 8	1 / 8	0 / 0	5 / 5	1 / 1	1 / 1	35
3. Envelope	1 / 2	3 / 9	5 / 5	4 / 32	4 / 32	2 / 16	5 / 5	6 / 6	6 / 30	157
4. Doors, Windows and Openings	1 / 2	2 / 6	1 / 1	2 / 16	2 / 16	6 / 48	2 / 2	3 / 3	3 / 15	109
5. Interior Fittings	0 / 0	1 / 3	3 / 1	1 / 8	1 / 8	3 / 24	1 / 1	1 / 1	1 / 5	51
6. Finishes	0 / 0	1 / 3	1 / 1	1 / 8	1 / 8	3 / 24	1 / 1	1 / 1	4 / 30	76

Chapter 7
Conclusion, Recommendation and Implications.

7.1. Conclusions

It is noted in conclusion that this research has met its hypotheses that there is a strong positive correlation between the number of green building principles and techniques implemented and the number of building materials they are implemented on (Chapter 7.10). This means that it is possible to spread the implementation of green building principles and techniques across different building elements. The spreading of Green Building Principles across many building elements has the potential benefits of introducing a systematic, structural and holistic approach to implementation which guarantees that buildings implement more energy-efficient techniques and become more effective in saving energy. Another potential benefit of spreading of Green Building Principles across many building elements is allowing better individual assessment of each green principle for its performance and in relation to how it's used on a specific building element which all gives the designer control in the green building design process. Another potential benefit of spreading of Green Building Principles across many building elements is exposing the green building principles to more physical material and volumes on which to implement their energy saving techniques. A final benefit of spreading of Green Building Principles across many building elements is the opportunity to further Classify Green Building Implementation Principles at a micro scale for the same benefits but with an effective and boosted value!

7.2. Recommendations

The author's first recommendation is that more research is needed on the weighting of individual green principles in terms of their energy-efficiency contribution to the whole. It is important to research the factors which influence the efficiency of each green building principle and by how much. This research could also be further enhanced by case study analysis and energy audits to investigate the effectiveness of each green principle relative to others especially in a regional and contextual setting.

Another essential recommended research topic would be to investigate how do different green principles complement or neutralize each other in the same building. The benefit of such a research would be to find out how to optimize the energy efficiency of green buildings. This could also involve investigations into how dependant green building principles are on the actual building form and on building elements. Furthermore, research is needed on the techniques and modelling of building information of green buildings for energy efficiency. This would help in finding the optimal and most efficient combination of green principles in a building for energy efficiency.

Finally the author recommends more research be taken to investigate methods of implementing green building principles and policies. It is important to understand whether the investment in green building principles pays off and by how much – both in energy efficiency and in financial terms. This could further be enhanced to investigate the possibility of designing green buildings that are totally energy dependant and that produce as much or more energy than they use.

A critical discovery is how useful value engineering is in action as a tool for implementing green building principles and techniques best suited to a building's function and use. This has clearly been indicated in the fieldwork carried out in Chapter 7. By first understanding building use and function, the design intent for understanding the unique need and specific function of the building type and hence energy efficiency can then be ascertained and the green principles and techniques can then be implemented to suit. This can further be enhanced by using a factoring a value system based on the usefulness of each criteria to that specific building type's needs to decide to increase the implementation of that particular that green principles and techniques. For instance, Ventilation might be critically important to a theatre design so its implementation might be multiplied by a 70% factor but insulation might not be as important so its implementation will only be multiplied by a factor of 30%. However, a deeper discussion of the relationship between building use and Green Building Principles and Techniques is beyond the scope of this research although further research is strongly suggested in this field.

7.3. Implications of this Research

The main implication is in policy implementation in green buildings. There is need to implement effective and efficient policies in energy efficiency and this research gives ideas on how to spread green building techniques effectively across building elements.

Different organizations around the world have been implemented to monitor resource conservation in buildings and these organizations have introduced methods to measure and assess how efficient buildings are in conserving resources and reducing their impact on the environment. The rating systems that these organizations use to assess how green or how sustainable a building have been interrogated to so as to ascertain the value in the claims that green buildings are sustainable. An implication of this research will be to assess the fitness for use of green building rating systems on top of using the green building rating systems to assess green buildings.

The method used to implement value engineering for energy efficiency in green buildings will be based on defining the concept of value from first principles. The roots of value engineering as a quality management tool lie in the generally accepted definition of quality for the construction and manufacturing industry as fitness for use (Cleland and King 1988; 514). Following the definition of quality as fitness for use, Kelly, Male and Drummond (2004; 17) then define value as least cost required to perform a required function. This research aims to interpolate and extrapolate this definition to formulate a value analysis method to analyse the implementation of green building principles for energy efficiency. This research has the potential to transform the way green buildings are measured and rated for their effectiveness. The focus of green building rating as from this research will be on value that each principle brings to the building elements and construction.

A final implication of this research will be that implementing Green Principles is not about rules but about understanding the principles and applying them tactfully to get best result as best suited to the context. Implementing green is not about policy but is more about attitude and moulding a certain brand of lifestyle. A potential benefit that will come out of this research will be that designers of green buildings will take a more conscious approach of understanding the principle so they can extract the most value out of it before they can find innovative and practical ways of applying the green principles and techniques.

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Appendix 1
Content Analysis Data Sampling.

CH2 House, Melbourne, Australia		
1	Architect	Design Inc
	Location	Little Collins Street, Melbourne, Australia
	Ratings	6 Green Stars from the Australian Green Building Council
	Information Sources	City of Melbourne Phone: 9658 9658 Fax: 9654 4854 http://www.melbourne.vic.gov.au/info.cfm?top=171&pg=1943 cited 2 dec 07 http://www.melbourne.vic.gov.au/info.cfm?top=171&pg=1933 cited 2 december 2007

- Phase Change Materials for Cooling
- Automatic night-purge windows
- Wavy concrete ceilings
- Façade of louvers powered by photovoltaic cells that track the sun
- Specifically designed pot-plant holders
- Thermal mass for cooling
- Plants to filter the light
- Dark colored air extraction ducts to absorb heat from the sun and help stale air rise
- Mechanical ventilation Climate Control: air delivery stratification and exhaust maintains a comfortable climate for working.
- Shower Towers for evaporative cooling by using falling droplets of water to cool air in retail spaces.
- Concrete cave-like ceilings for radiant coolth.
- Windows on the north and south facades allow cool air to enter the offices and flash out warm air, a process called purging.
- Use of LCD monitor computers which consume 50% less energy than older bulky CRT monintors.
- Use of T5 light fittings and task lighting for workstations.
- Heat from cogenerating electrical plant used for heating or cooling (via an absorption chiller)
- Use of hot water panels on roof for hot water supply.
- Use of photovoltaic cells on roof to power movement of louvers to shade west façade.
- Specially designed wind turbines to extract air from offices through ducts on the north faccade. These replace electric fans.
- Phase Change Material: Battery Storage of coolness comprising of PCM spheres surrounded by heat transfer liquid (water) that circulates through the ceiling panels on each floor.
- Lower floors generally receive less lighting than upper floors so windows larger on the lower floors than upper floors which minimizes glass size and energy loss while maintaining desirable light levels.
- Sensors that monitor daylight and adjust artificial light required accordingly.
- Light Shelves reflect sunlight into ceilings and produce a soft, indirect light, reducing artificial lighting requirements.
- Shading to control sun and glare used on north, east and west facades.
- Planting and vertical gardens for shading of north façade.
- Light colors on south elevation to reflect heat and cool air sinks.
- Perforated metal on east façade to allow natural ventilation in toilets.
- Use of vertical garden to assist in shading, glare and air quality, watered by recycled water.
- Collaboration with artists to create forms and figures that evoke a “green” feeling to the space.

1. CH2 Green Building Element Filter

Orient form and Shape	Fitt |
Wind Protection	Sru |
Solar and Renewable Energy	Enve | Fitt | Elec | Elec |
Cooling Systems	Enve | wind | Ceil | Water | Fitt | Elec | Enve | stru | Fnsh | Water |
Warming Systems	Mech | Mech | Elec | Fnsh |
Lighting Systems	Fitt | Struct | Fitt | Zone | Fitt | Fitt | Elec | Fitt |
Thermal Mass Storage	Enve | Fitt |
Insulation	
Ventilation	Fitt | Fitt | Mech | Fnsh |

Sweetwater Creek State Park Visitor Centre, Georgia, USA

2	Architect	Gerding Collaborative
	Location	Lithia Spring, Douglas County, Georgia
	Ratings	Platinum rating from US Green Building Council
	Information Sources	US Green Building Council Dan Gerding of Gerding Collaborative Freedman, D. Greening Georgia's state parks. Written for Georgia Engineer Journal (Novvember 13 2006) http://www.cxgbs.com/library/GreeningLITE.pdf cited 2 december 2007 The Gerding Collaborative. Sweetwater Creek State Park Visitor Centre http://www.gerdingcollaborative.com/pdf/SweetwaterProjectSheet.pdf Cited 2 December 07

- Long rectangular shape with the long side facing south and the short ends facing East/West to Shpe and orientation of building maximizes solar exposure and control
- Earth sheltered construction on the north side of the building
- Energy performance achieving a 34% reduction from the ASHRAE 90.1-1999 Standard
- Design of fenestration for daylighting and control of solar gain
- High insulation values – R-40 roofs, R-19 walls
- Equipment using no HCFC's or halon
- The purchase of green power is being considered for this building
- 37% of roof is landscaped with native plant species and 63% is high-reflectance/high emissivity metal roofing, resulting in reduced heat island effect and storm water runoff
- High performance building envelope.
- High Efficiency HVAC system provides optimum indoor environment for the museum's quality artifacts in the exhibit area.
- Vegetated roof serves as an outdoor plaza reducing the the square footage that would have been required to construct this area adjacent to the building.
- Siting th building with south facing and glazing placement with sunshades to reduce heating and lighting costs.
- Interior photocells and occupancy sensors to help save on lighting.
- Photovoltaic panels installed.
- Light coloured impervious surfaces
- Vegetated Roof
- 20% energy needs derived from renewable souces.
- 83% of interior spaces receive natural light and 98% interior spaces have views to outside.
- Building and site integration tucks the building into the hillside to resulting in energy efficient building envelope.
- Orientation and sun-controlling features passively warm interiors in winter and avoid direct solar gain in summer.
- Use of clerestory windows to optimize interior daylighting on north side of building.

- Use of light shelves along south facing windows to bounce light deeper into the interiors.
- Motion sensors and photocells to control general lighting in building.
- Photovoltaic array of recycled solar panels to produce 20% of building's energy needs.

2. Sweetwater Green Building Element Filter

Orient form and Shape	Stru | Shell | Stru | Syst | Stru | Fitt |
Wind Protection	Fitt |
Solar and Renewable Energy	Stru | Shell | Elec | Elec | Elec | Elec | Elec
Cooling Systems	Shell | Shell | Struc | Shell | Mech | Syst | Fitt | Fnsh | Syst |
Warming Systems	Shell | Mech | Syst | Fitt | Fnsh | Syst |
Lighting Systems	Syst | Fitt | Elec | Elec | Fnsh | Syst | fitt | Fitt | Elec | Elec
Thermal Mass Storage	Stru | Shell
Insulation	Shell | Shell |
Ventilation	Mech |

Eastgate Development, Harare, Zimbabwe		
3	Architect	The Pierce Partnership
	Location	Harare, Zimbabwe, Africa
	Awards	
	Information Sources	New York Times: February 13, 1997 "Termite Mounds Inspire Design of Zimbabwe Office Complex" By DONALD G. McNEIL Jr. http://library.wustl.edu/~listmgr/devel-l/Feb1997/0199.html cited 2 December 2007

- Use of mass of building as insulation
- Use of diurnal temperature swings from hot to cold for insulation.
- Deep overhang for shading and keep direct sun from windows and walls.
- Planting for shading
- Stack effect in atrium
- Solar panels for hot water heaters
- Natural exauhst through chimneys
- Heat energy absorbed by chimneys to improve stack effect.
- Area of windows don't exceed 25% so that direct sunlight doesn't fall on north façade.
- Balance of artificial and external light to minimize energy consumption and heat gain.
- Windows to be sealed because of noise pollution and unpredictable wind pressures and temperatures, thereby only relying on ducted ventilation.
- Windows must be light filters, controlling glare, noise and security.
- Windows have adjustable blinds.
- Extensive use of materials and construction skills
- Light and pale interior finishes for natural lighting to penetrate deeper.
- Clear Glazing for natural lighting.

3. Eastgate Green Building Element Filter

Orient form and Shape	
Wind Protection	Fitt |
Solar and Renewable Energy	Elec | Fitt | Fitt |
Cooling Systems	Fitt | Shell | Stru | Fitt | Shell |
Warming Systems	
Lighting Systems	Shell | Fitt | Fitt | Fnsh | Fitt |
Thermal Mass Storage	Mech | Shell |
Insulation	Shell | Mech |
Ventilation	Shell |

Szencorp Building, Melbourne, Australia		
4	Architect	SJB Architects
	Location	40 Albert Road, South Melbourne, Victoria, Australia.
	Ratings	6 Green Stars from the Australian Green Building Council
	Information Sources	Information from Green Building Council of Australia http://www.ourgreenoffice.com/content/resources/Casestudies/40albertroad.pdf The Commercial Offi ce Building Energy Innovation Initiative (COBEII) Sustainability Victoria www.sustainability.vic.gov.au Ground fl oor, 215 Spring Street Melbourne Victoria 3000 Australia Telephone: 03 9655 3222 Facsimile: 03 9655 3255 info@sustainability.vic.gov.au

- Openable windows on east and west facades provide cooler air crossflow.
- Thermal chimney effect in vented atrium and exhaust dampers.
- Automated natural ventilation system that adjusts according to inside and outside environmental conditions.
- Fancoil units to each area of the building provide mechanical cooling and heating required to maintain occupant comfort.
- Roof mounted three pipe air conditioning units using internal combustion engine rather than electrical conditioning units
- Low noise central vacuuming system which is 40% faster than portable machines and quiet enough to be used during office hours reducing the need for after-hour lighting and air-conditioning.
- Use of ceramic fuel cells that use chemical reactions instead of combustion reactions for electrical power. Reactions are continually fed into the process to provide ongoing power output.
- Waste heat generated during power production to be used to provide the building with hot water.
- Provision of two photovoltaic arrays to reduce grid electricity demand.
- Floor to ceiling high performance double glazing maximizes daylight penetration and is supplemented by atrium and glass in the central stairwell and additional skylights above the boardroom.
- Significant natural daylight at desk level across a third of the office space.
- Reduction of energy used on artificial lighting by use of automated lighting system which dims whenever and whereve daylight levels permit so as to optimize light levels.
- Sunlight levels controlled by high performance glazing and full length shading screens on east façade.
- Manually operated internal blinds provided on all windows and automated blinds on skylights and atriums.
- Advance Building Management System with single interface for passive and active thermal control system and for lighting control system.
- Floor zoning to monitor temperature, humidity, daylighting and lighting levels using intelligent building management system and then automatically supplementing passive supplies with active systems were necessary.
- When a zone is unoccupied, active lighting and thermal systems are shut down to save energy. Electricity, gass and water usage is remotely monitored and SMS messaging is used to alert maintenance personnel of abnormal situations.

- The DryKor dry conditioning unit dries and cools the office space simultaneously, using a process of liquid desiccant absorption of water vapour from the air

4. Szencorp Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Mech | Elec | Elec | Elec | Elec | Syst |
Cooling Systems	Mech | Mech | Fitt | Fitt | Syst | Elec
Warming Systems	Mech | Mech | Syst | Elec
Lighting Systems	Fitt | Fitt | Fitt | Syst | Elec | Fitt | Fitt | Syst | Elec
Thermal Mass Storage	Fitt | Mech |
Insulation	Fitt |
Ventilation	Mech | Mech | Water

Sixty L Building, Melbourne, Victoria, Australia		
5	Architect	
	Location	60 Leicester Street, Carlton, Melbourne, Victoria.
	Awards	Spowers Architects
	Information Sources	http://buildlca.rmit.edu.au/CaseStud/60L/60L.html http://www.60lgreenbuilding.com/genbrochure.pdf Alistair Mailer, Green Building Project Manager c/o Australian Conservation Foundation, 340 Gore Street, Fitzroy, Victoria, 3065. Phone: (03) 9926 6782 Mobile: 0429 351 097 Fax: (03) 9416 0767 E-mail: greenbuilding@acfonline.org.au

- hybrid passive and mechanical ventilation, heating & cooling
- widened internal temperature control band
- optimising natural ventilation & natural lighting
- effective management of lighting & office equipment energy demands
- high efficiency artificial lighting
- solar shading and low-emissivity double glazing
- heavyweight structure and night purging with cool air
- use of electricity derived from non-fossil fuel sources.
- Rooftop solar panels generate power used in the building (10% of building's energy needs). In times of low demand the system puts electricity back into the grid hence reducing building operating costs.
- Energy-efficiency appliances used wherever possible in the building fit-out.
- Heat that builds up during the day expelled at night by computer controlled venting system.

5. Sixty L Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Fitt | Elec | Elec | Syst | Fitt |
Cooling Systems	Mech | Mech | Fitt | Fitt
Warming Systems	Mech | Mech | Fitt |
Lighting Systems	Syst | Elec |
Thermal Mass Storage	Stru |
Insulation	
Ventilation	Mech | Mech | Syst | Stru | Elec

TEPCO Research and Development Centre		
6	Architect	Nikken Sekkei?
	Location	Japan
	Awards and Ratings	Total energy conservation rate is 35%.
	Information Sources	Yuji TSUBOTA e-mail: t0561027@pmail.tepco.co.jp

- The south side of the research building was fitted with ventilation windows with integral automatic control blinds.
- A lighting control system was also installed, which was capable of continuously dimming artificial lighting near the windows over a wide dimming range
- The ventilation window is a double window with an integral venetian blind between the two panes. Indoor air passing between the panes cools the slats of the blind and removes the solar heat. This air then exits through an outlet at the top of the window (Figure 1). In this way, the window reduces the solar heat gain and the overall heat transfer coefficient to between 1/3 and 1/2 that of ordinary windows
- To make the thermal insulation and shielding intended for the purpose of energy-saving compatible with see-through visibility that enhances the esthetical expression, heat mirror glass composed of laminated double glass with a special film membrane inserted between two glass sheets are used for the east and west glass curtain walls. This specific heat mirror glass has a heat insulating ability equal to 400% of ordinary sheet glass.
- In addition, the building's west facade is provided with brise-soleils whose slat angles are automatically adjustable according to the sun's position while the east side space is provided with interior roll blinds.
- By automatically controlling the angle of the slats, the blind stops direct solar radiation over a certain intensity from penetrating the room beyond a given distance from the window. This prevents incoming sunlight from adversely affecting thermal comfort and increasing the cooling load. If there is no sunlight, the slats are flat or raised, providing an outside view and improving the amenity's psychological aspects
- This control system calculates the level of daylight in a room according to the state of the blind. It then uses this information to dim or turn off the lights in a particular order, up to the second row from the window
- To create a comfortable and energy-efficient space in this lobby, automatically-controlled exterior blinds and double glazing with integral low-emissivity (low-e) film were installed
- PV solar modules are installed vertically on building balconies facing south, and 18kW modules on building roof tops.
- Used an ice-on-coil type ice storage system that we have studied for more than a decade. The system here consists of two brine chillers (three in future), an ice storage tank of 680m^3 and ice making heat exchangers with a total length of 26,957m
- A cold air distribution system has been developed for effective usage of the ice storage system.
- Fuel cell power generation
- L Harmonious design between architecture and building equipment
- Development of cold air distribution system using ice storage
- Realization of comfortable environment at openings and of energy conservation through control of heat and light
- High level of environmental management and energy management through the integration of information and control.
- Ventilation window sytem, which reduces heat gain/loss through the windows
- Lighting control system - equipment near the window controlled linearly according to natural light and interior lighting is controlled to keep optimum brightness
- Cold air distribution sytem adopted as an HVAC secondary system; amorphs molded transformer

6. TEPCO Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Fitt | Elec | Elec | Syst |
Cooling Systems	Fitt | Water | Mechanical | mech |
Warming Systems	Fitt | Fitt | Fitt | Fitt |
Lighting Systems	Syst | Fitt | Elec | Fitt | Syst |
Thermal Mass Storage	
Insulation	Fitt |
Ventilation	Fitt | Elec | fitt |

Automotive Centre of Excellence, Melbourne Docklands, Australia.		
7	Architect	Lyons
	Location	
	Awards and Ratings	
	Information Sources	http://www.sv.sustainability.vic.gov.au/ftp/buildings/COBEII/KBT_Casestudy.pdf

- BATISO system uses hydronic pipes embedded in concrete floor slabs used for cooling or heating by pumping warm or cool water through the pipes.
- The thermal mass of the slab provides comfortable radiant heat exchange to the space below.
- It also saves costs by reducing the size of cooling plant and mechanical reticulation required, and substantially cuts energy consumption and operational costs.
- Active chilled beams use a water-driven system to deliver cooling to the office space on the second fl oor where there is no concrete slab above. The chilled water controls the temperature of the beams which helps to manage the building's overall temperature. As hot air rises, the chilled beams cool the air. Active chilled beams are energy effi cient and complement the BATISO system.
- Stored rainwater is pumped through the building at night and then cooled by automated spraying onto the roof surface. The sprayed water is cooled primarily by evaporation and radiation exchange to the night sky as it fl ows across the roof surface. This passively chilled water is then circulated again through the BATISO system to remove more heat from the building, bringing inside temperatures down in readiness for the following day.
- On nights that are too hot to achieve suffi cient building cooling using the passive system, actively chilled water is automatically pumped through the slabs to achieve the required chilling.
- The east entry is a three-storey, full-height void with a glazed façade. The space is vented and controlled with mechanical louvers, and draws air from the offices and out of the building. In this transitional space, temperatures will be allowed to fluctuate over a wider range than in the offices.
- Daylight reaches deep into internal spaces through a combination of skylights, internal glazing and a carefully designed façade.
- Energy efficient T5 lighting units supplement natural light. The system incorporates light sensors and automatic dimming as natural lighting permits, ensuring optimum balance of lighting comfort and energy effi ciency
- Internal glazing is used extensively to improve access to outside views and transmit daylight.
- Mixed-mode natural ventilation provides air through different means—active and passive, according to outside weather conditions.
- The perimeter offi ce and teaching areas are ventilated through automatically operated openings in the façade for cooling and ventilation, whenever external conditions permit. This delivers both fresh air and large energy savings.
- Low-level louvres on some façades, and wind cowls in the roof of the atrium provide an air discharge path through the building. At other times, the ducted 100% fresh air system provides internal thermal comfort

7. Automotive Centre of Excellence Green Building Element Filter.

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	
Cooling Systems	Water | Mech | Water | Mech | Water
Warming Systems	Water | Mech
Lighting Systems	Fitt | Fitt | shell | Elec | Syst | Fitt |
Thermal Mass Storage	Water | Mech | Water | Mech | Water
Insulation	
Ventilation	Mech | Fitt | Mech | Syst | Fitt | Fitt |

National Trust Headquarters, Swindon, U.K.		
8	Architect	Fielden Clegg Bradley
	Location	Swindon, U.K.
	Awards	Awarded BREEAM Excellent Rating + Winner of the RIBA Sustainability Award 2006 + International FX Interior Design Award 2005 + Best Commercial Building, Brick Awards 2005 + AJ100 Sustainability Award 2006 + BCO Innovations Award 2006 + BIFM Sustainability Award 2006 + BIFM New Build Award 2006 + OAS/IAS Best Bespoke Development 2006 + Building Sustainability Awards 2006 shortlist + Dedalo Minosse International Prize 2006 + British Construction Industry Award 2006
	Information Sources	For a detailed account of the sustainability strategy for Heelis, see the new edition of Environmental Design: An Introduction for Architects and Engineers (ISBN 0-419-23760-7) published September 2005.

- the maximization of day lighting
- reducing energy use
- thermal performance
- The deep-plan two storey building was orientated to provide the best influx of light into all floors.
- large openings to allow light to the lower floor through series of north lights, two courtyards and an atrium
- 1554 photovoltaic panels are situated on the southern aspects of the saw-toothed roof, providing a good percentage of the building’s electrical power
- almost all natural light to the offices comes via the north-lights
- two-storey, deep-plan building with the main public elevation, internal layout and roof all orientated to face due north-south to control solar gain and daylighting
- The roof was pitched at a 30° angle to maximise potential output from photovoltaic panels (PVs)
- First-floor voids bring daylight from the rooflights to the ground floor
- two courtyards allow ventilation into the centre of the deep plan
- To provide thermal mass for summer night-time cooling, the roof is formed from 80 mm thick exposed pre-cast concrete panels with high levels of insulation
- There are first-floor mezzanines within the open-plan spaces, and two thirds of the office can be directly roof lit
- Artificial lighting is controlled by detectors and dimmers, keeping electrical energy for lighting to an absolute minimum
- building should be naturally ventilated, using the stack effect, which uses the buoyancy of hot air to exhaust at high level, thus introducing fresh air into the lower occupied level. Air is introduced through automatic opening windows and panels.
- The automatic openings are controlled by the building management system (BMS) to maintain comfortable temperatures within the building
- maintain comfortable temperatures within the building. In summer these are achieved by ventilating at night to cool the exposed concrete roof soffit and first-floor slab.

- The photovoltaics, which provide the shading to the rooflights have a primary purpose of generating electricity. At 1300m2 the array is one of the largest in the country and provides up to 15% of the total electrical load of the building.

8. National Trust Headquarters Breen Building Element Filter.

Orient form and Shape	Syst |
Wind Protection	
Solar and Renewable Energy	Syst | Elec | Stru | Elec | Elec
Cooling Systems	Syst | Syst | Elec
Warming Systems	Syst |
Lighting Systems	Syst | Fitt | Syst | Syst | Syst | Fitt | Elec | Syst |
Thermal Mass Storage	Syst | Fitt | Fitt | Zone | Shell | Shell |
Insulation	Shell |
Ventilation	Zone | Syst |

Aldo Leopold Legacy Centre, Wisconsin, USA

9	Architect	The Kubala Washatko Architects
	Location	Baraboo, Wiscosin, USA
	Ratings	LEED Platinum Award from the US Green Building Council
	Information Sources	Courtesy of the Architects. US Green Building Council

- Use of daylight to reduce interior lighting needs.
- High standards of insulation to keep the building cooler in summer and warmer in winter.
- Window positioning and design for cross ventilation
- Overhangs to allow the sun in during winter and block out the sun during summer.
- Thermal flux zone to reduce heat flow between the main offices and the outdoors.
- Smallest and most efficient mechanical equipment selected for air conditioning.
- Photovoltaics collect extra electricity during the summer which is credited to the national power grid to be reclaimed and used during the winter.
- Earth Tubes – cement pipes buried under the building to assist in ventilation and circulation of air and moderate the temperature of the air.
- Radiant floor system for the heating and cooling of the air.
- Ground source heat pump serves a radiant floor heating system.
- Carefully thought out site design to separate high use and low use energy areas.

9. Aldo Leopold Legacy Centre Green Building Element Filter.

Orient form and Shape	Zone | Syst |
Wind Protection	
Solar and Renewable Energy	Elec | Syst | Zone | Syst
Cooling Systems	Shell | Zone | Shell |
Warming Systems	Shell | Zone | Shell |
Lighting Systems	Syst |
Thermal Mass Storage	Shell
Insulation	Shell | Shell |
Ventilation	Fitt | Syst | Mech | Mech | Elec |

Project7Ten, California, USA		
10	Architect	GREY matter architecture
	Location	710 Millwood Avenue, Venice, Carlifornia
	Ratings	LEED Platinum Rating from the US Green Building Council
	Information Sources	Courtesy, Melinda Gray, GRAY Matter Architecture. http://www.project7ten.com/site/function.htm http://www.jetsongreen.com/2007/07/project7ten-to-.html Posted by Preston D K at 01:12 AM JULY 19, 2007 CITED 3 DECEMBER 2007

- Use of window design as an insulation barrier.
- Use of window design as an efficient light source.
- Use of recycled denim insulation to fill the walls.
- Radiant heating, warm water pumped through the floor, to heat the house.
- Use of electric solar panels designed to produce more electricity than required for family of four.
- Solar panels double up as overhangs for shading and to prevent direct sunlight entering the home during hot summer days.
- Thermostatically controlled skylights allow hot air to escape when building is too hot and close automatically when the house cools down.
- Only Energy Star approved appliances used to ensure that all appliances are as energy efficient as possible.
- Only compact fluorescent bulbs or LED lighting used instead of incandescent bulbs which are highly inefficient with short life spans and which throw off unnecessary heat.
- Motion detectors fitted on many light fixtures, both interior and exterior – leave a room and a few minutes later the lights turn themselves off!

10. Project7ten Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Elec | Fitt |
Cooling Systems	Shell | Fitt | Syst
Warming Systems	Fitt | Syst
Lighting Systems	Fitt | Elec | Syst |
Thermal Mass Storage	Shell |
Insulation	Fitt | Shell |
Ventilation	

CII - Sohrabji Godrej Green Business Centre Hyderabad, India		
11	Architect	Karan Grover
	Location	Hyderabad India
	Ratings	Platinum Award by the US Green Building Council
	Information Sources	www.architectureweek.com/2004/1027/environment_2-1.html •www.rmi.org/sitepages/pid1138.php •www.greenbusinesscentre.com •inhome.rediff.com/money/2004/jul/13green.htm •http://infochangeindia.org/ ALL CITED 03 December 2007

- Two 45-foot wind towers and screen walls provide air pre-cooled by 10 degrees to the air-conditioning system, thereby reducing the amount of energy required for cooling.

- has photovoltaic panels built into it to generate solar energy that takes care of 20% of the building's annual energy requirements
- Likewise, the electrical fixtures have been automated to save power
- ; 90% of the building does not require any artificial lighting during the day because its circular design allows sunlight to reach every part of it.
- variable speed motors for its blowers and pumps, and the elaborate use of sensors feeding back to the controls
- Circular shape for space and light. Main courtyard and smaller courtyards improve light. All enclosed spaces have natural light!
- In low light, efficient bulbs are triggered on by occupancy sensors.
- 90% of the building has daylight and views.
- Solar cells provide 20% of electricity.
- Wind towers precool air by spraying water and that reduces energy load on air conditioners.

11. CII - Sohrabji Godrej Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Elec | Syst | Elec |
Cooling Systems	Water
Warming Systems	
Lighting Systems	Syst | Shell | Zone | Fitt |
Thermal Mass Storage	
Insulation	
Ventilation	Shell | Shell | Mech | Syst |

Portland Armory, Portland, Oregon, USA		
12	Architect	GBD Architects,
	Location	Portland, Orgeon, USA
	Ratings	LEED Platinum award by the US Green Building Council
	Information Sources	US Green Building Council

- Displacement ventilation brings fresh air into occupied spaces and distributes it through an under floor system to improve indoor air quality and save energy.
- In the office area, chilled beams work in concert with the ventilation system to heat and cool the space.
- The CFD model's analysis of air movement ensured proper placement of the chilled beams and floor diffusers for maximum efficiency.
- Skylights in the office area illuminate the open lobby and administrative spaces with natural light, and sensors monitor light levels and dim electric lights when not needed to conserve energy.

12. Portland Armory Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	
Cooling Systems	
Warming Systems	
Lighting Systems	Fitt | Syst |
Thermal Mass Storage	Shell | Syst |
Insulation	
Ventilation	Syst | Shell |

Mckinney Green Building, USA		
13	Architect	HDR Architecture
	Location	Dallas, Texas, USA
	Ratings	LEED Core & Shell Platinum Certification rating
	Information Sources	Courtesy HDR Architecture www.hdrgreen.com US Green Building Council

- Photovoltaic panels as a renewable energy source to reduce pollution associated with non-renewable energy production.
- Daylight-enhancing façade with high-efficiency glazing system to reduce operating cost and allow entry of natural light.
- Efficient, smart Ergo-light™ system throughout tenant spaces for energy efficiency and appropriate lighting level for tasks.
- Energy Efficient Ground Source Heat Pump System
- Geo-thermal wells for mechanical efficiencies.
- 62 percent reduction in energy use (versus a building that meets basic ASHRAE 90.1 standards) due to an energy-efficient building envelope, use of sunshade devices, an under floor air distribution system, efficient fenestration and high insulation R-value for roof and walls.
- Rooftop photovoltaic system that supplies approximately 10 percent of the building's electric demand, and designed to accommodate future expansion.
- A two-year contract with a Texas wind energy provider.
- Use of occupancy and daylight sensors for lighting control and energy savings.
- Open plan design that maximizes daylight filtration and views to the outdoors.
- High daylight glazing that allows sunlight to penetrate into the building, while exterior sunshades bounce daylight deep into the building core.
- Reduced water usage due to waterless urinals, and low-flow toilets and faucets.
- Reduction in site irrigation requirements because of drought-tolerant landscaping.
- Designated HOV parking spaces, plug-in stations for alternative fuel vehicles and bicycle racks/shower facilities.
- Underground stormwater storage system for rainwater harvesting.
- Low- or no-VOC paints, adhesives and sealants.
- Formaldehyde-free wood panels and FSC-certified wood products.
- 46 percent of materials manufactured regionally, and 11 percent with post-consumer and post-industrial content.
- Light trespass minimized on this site, eliminating light pollution helps with nocturnal environments and reduces nighttime glare.
- Maximizing the use of daylight to reduce the need for artificial illumination.
- Underfloor air distribution to all tenant spaces.
- Use of 120 geothermal wells with 8 miles geothermal piping undernearth the surface of the parking lot.
- Large photovoltaic system on the roof for renewable energy.
- Solar hot water heating system
- The remaining electrical energy for this building supplied by West Texas Wind Energy Fram.
- Use of Energy Star compliant roof system on building.
- Roof reflects heat away from the building with less impact on the local "heat island effect."

13. Mckinney Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Elec | Shell | Elec | Syst | Elec |
Cooling Systems	Fitt | Fitt | Shell
Warming Systems	Fitt
Lighting Systems	Shell | Fitt | Elec | Syst | syst | Fitt | Fitt |
Thermal Mass Storage	Shell |
Insulation	Shell |
Ventilation	Mech | Shell | Mech

Xihu Tiandi, Hangzhou, China		
14	Architect	Benjamin Wood (Wood and Zapata Inc)
	Location	Hangzhou's celebrated West Lake, China
	Ratings	US Green Building Council Platinum Certification
	Information Sources	Courtesy of the Architects. US Green Building Council Sustaniable Renaissance by *Eric Huang Yu Peng, Deputy Project Manager, LEED AP* *August 9, 2005* http://www.edcmag.com/CDA/Archives/0f710104cd697010VgnVCM100000f932a8c0

- Use of the cavity in the between the underground Diaphram wall and Basement wall as a cooling and heating air duct called an earth tube sourced by a relatively constant underground soil temperature.
- Radiant cooling and heating in public semi-open corridors with pipes placed underneath paving tiles in different floors.
- Use of exhaust air from retail areas as cooling and heating for inner courtyard circulation zones, thus reducing energy consumption.
- Photovoltaic panels on the roof to convert sun to electrical energy stored in a battery bank for landscape lighting.
- Air conditioning system provides cooling, heating and domestic hot water and its absorption chiller uses natural gas as a heat source.

14. Xihu Tiandi Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Elec | Syst | Mech | Mech
Cooling Systems	Zone | Mech
Warming Systems	Zone | Mech
Lighting Systems	
Thermal Mass Storage	Fnsh |
Insulation	
Ventilation	Shell | Zone

BP Southern Africa Region, Cape Town, South Africa		
15	Architect	Kuger Roos Architects
	Location	Cape Town, South Africa
	Awards	
	Information Sources	Kuger Roos Architects The Property Magazine March 06 Eric Noir http://www.sustainablesettlement.co.za/event/SBE2003/Proceedings/Abstracts/Noir.pdf cited 4 December 07

- Ventilation stacks at the outer edges.
- Recessed windows.
- Double glazed windows.
- Light shelves to provide extra shade.
- Light shelves to bounce light deeper into the building.
- Glass pyramid skylights provide natural light into the building core.
- Plants and trees planted on the ground floor.
- Photovoltaic cells.
- Thermal solar panels provide 10% of the building's electricity.
- Movement sensitive low energy lighting throughout interior turns off lights when staff leave workstations and meeting rooms making sure empty rooms are not lit unnecessarily.
- Open plan offices with triple volume internal street.
- Thermal zoning, arranging internal spaces into positions with most stable climates for work stations and most volatile climates for circulation and pause areas and lobbies.
- Site orientation to avoid wet and mild winter winds but to capture the dryer and stronger summer winds to benefit from cooling capacities.
- Dynamic roof skin that allows for breathing and ventilation.
- Recessed facades to avoid summer sun hitting and thermal warming.
- Low winter sun allowed into the building to provide heat gains.
- Evaporative cooling by seawater through a heat exchanger delivered by chilled ceilings.
- Rockstore cools the building while flushing accumulated heat.
- Stack effect combined with thermal chimneys draws natural chilled air from the rock store.
- Specially designed thermal desks evacuate heat generated by computer equipment during hot conditions or dissipates it into the working space during cold conditions.
- Chilled ceiling cools down the raising heat resulting in extremely comfortable cold air dripping from the ceiling without draft.
- In cold conditions, hot water circulated to pre-heat the structure in the early mornings.

15. BP Southern Africa Green Building Element Filter

Orient form and Shape	
Wind Protection	Syst | syst
Solar and Renewable Energy	Elec | Elec | Fitt |
Cooling Systems	Fitt | Fitt | zone | Shell | water | Ceilings | Fitt
Warming Systems	Fitt | Fitt | Zone| Shell |
Lighting Systems	Fitt | Fitt | Elec | Syst | Zone |
Thermal Mass Storage	Shell | Water
Insulation	Fitt |
Ventilation	Shell | Shell | shell |

Woolworths Distribution Centre, South Africa		
16	Architect	R&L Architects
	Location	Midrand, Gauteng, South Africa
	Awards	South African Property Owners top award at in 2007
	Information Sources	Courtesy John During, Partner at R&L Architects Eric Noir, Green By Design Architects

- Office lights dim automatically depending on the amount of daylight and will switch off automatically if no movement is detected.
- Because of the vast area of the building, there was a danger of creating an 'urban heat island' – ie. the building would reflect heat rather than absorb it as agricultural land would. To remedy this fact, grass is being planted on the roof of selected areas.
- This increases the bio-diversity of the site and adds to the roof insulation for areas such as the main offices, gatehouses and ablution blocks
- Central energy control system.
- Use of evaporative cooling technology for the mechanical refrigeration system.
- Hot water generated by thirty solar panels.

16. Woolworths Distribution Centre Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Syst | Elec
Cooling Systems	
Warming Systems	Shell |
Lighting Systems	Syst |
Thermal Mass Storage	
Insulation	Shell |
Ventilation	Water |

Innovate Green Office, Thorpe Park, U.K		
17	Architect	Rio Architects
	Location	Thorpe Park, Leeds, U.K.
	Ratings	BREEAM Excellent: Best ever-scoring BREEAM building - 87.5%.
	Information Sources	Andy Pearson interviewed 25 September, 2007 BREEAM Awards 2006

- Building so well insulated that there is virtually no heat demand.
- Long axis of the two buildings orientated north to south for maximum daylight penetration in the morning.
- External elevation windows cover more than 50%.
- Internal blinds provided to control excess heat gains and reduce glare.
- Use of natural day lighting so that electric lighting only required 20% of working year.
- All fittings include daylight sensor and presence detectors to ensure lights do not remain on unnecessarily.
- Concrete structure combines precast wall panels and hollow core ceining units designed to maximize thermal mass.
- Use of a fan-assisted ventilation system to circulate cooler air through ducts in concrete ceilings and floor slabs.
- Vertical fins between windows to provide additional solar shading.
- No fenestrations to north and south facades to keep solar gains to a minimum.
- Concrete walls and ceilings exposed to give the interior a high thermal mass.

- Shell finished externally with a 250mm layer polystyrene insulation which makes the building behave like an electric storage heater.
- Summer cooling strategy involves using passive night time cooling to chill the thermodeck slabs.
- Use of thermal mass to store additional cooling energy provided by the chiller in slabs.
- Floors zoned to allow temperature control to depend on occupancy.

17. Innovate Green Office Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	
Cooling Systems	Fitt | Fitt | Shell | shell | Zone
Warming Systems	Zone
Lighting Systems	Syst | Fitt | Syst | Syst |
Thermal Mass Storage	Stru | Shell | Fitt | shell | Fitt | Shell |
Insulation	Shell | shell
Ventilation	Mech | Fitt | shell |

Vic Urban Melbourne Office, Victoria, Australia		
18	Architect	Hassell Pty ltd
	Location	Melbourne, Victoria, Australia
	Ratings	5 Green Stars from Green Building Council Australia
	Information Sources	http://www.sv.sustainability.vic.gov.au /ftp/buildings/COBEII/VicUrban_Casestudy.pdf

- central core and four glazed facades allowing for abundant natural light and space by maintaining an open plan environment that groups teams together rather than placing them in closed offices.
- Central core placement of all services for optimal efficient and equitable access, which frees up outer areas for workstations in open plan configuration maximizing natural light at desks as well as external views.
- Avoided installation of suspended ceilings leaving exposed concrete slab which provides exposed thermal mass which delivers amenity through coolth.
- Large, high performance window units allow natural light to enter the building.
- Glare, heat and amount of light monitored by sensors, and the building management system automatically activates the blinds, ventilation, comfort control and lighting accordingly.
- Desk layout evaluated using daylight modeling and 90% 0f workstations within 8 metres of daylight. This provides energy savings through reduced need for artificial light.
- Highly efficient T5 fluoro-incandescent lights featured as standard throughout.
- Office floor plan divided into lighting zones each less than 70 sqm area so that small sections of lighting can be operated independently.
- Lights turned on manually each morning and they automatically turn off at 6:30pm each evening. For those working late each zone can then be switched on in the evening and will remain lit for an hour before switching itself off.

18. Vic Urban Melbourne Office Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	
Cooling Systems	Syst | Syst
Warming Systems	Syst | fitt | Syst
Lighting Systems	Syst | zone | syst | Syst | Fitt | Syst | Syst | Zone | Elec | zone | Syst
Thermal Mass Storage	Shell
Insulation	
Ventilation	Syst |

Greenwood Trust Woodland College. U.K		
19	Architect	Simmonds Mills Architects and Builders.
	Location	Ironbridge Gorge, Shropshire, U.K
	Awards and Ratings	70% reduction in total energy demand as compared to a conventional buiding.
	Information Sources	Courtesy: Simmonds Mills Architects and Builders. Tel: +44 (0) 1952 433252

- Orientation to optimize solar radiation and warming the building.
- Wall and roof glazing positions to optimize solar radiation and warming the building.
- Large overhangs to prevent overheating in summer.
- Plants grown over some windows to prevent overheating in summer – leaves cutting out the sun in summer but in winter leaves are stripped off and windows allow sun in.
- Warm stale air extracted in ceiling and used to preheat incoming cold air.
- Warm moist air from showers and wc used to preheat incoming cold air.
- Separate heat recovery unit with own electric preheater in main hall – all heat exchangers maintain an average temperature of 11 degrees centigrade meaning minimal heating needed for comfort.
- Cellullose insulation in ceiling and in walls and polystyrene insulation in floors under the concrete screed.
- Air-tightness and vapour control sheet carefully fitted.
- Low emissivity glass to doors and windows. Insulation to doors and windows. Double glazing to doors and windows.
- Dense concrete block internal partitions to store heat during warmer periods and to remain warm during cooler periods.
- Use of Low energy lights used where possible.

19. Greenwood Trust Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	
Cooling Systems	Shell | Stru | Fitt |
Warming Systems	Syst | Shell | Fitt | Stru | Mech | Mech | Elec | Fitt | Fitt
Lighting Systems	Elec
Thermal Mass Storage	Shell
Insulation	Fitt | Shell | Fnsh | Shell | Fitt |
Ventilation	

Guarajuba Ecohouse, Brazil		
20	Architect	Dr Rosangela Tenorio
	Location	Monte Gordo community, tropical areas of Brazil (Northeast region)
	Awards	A prototype on sustainable housing in tropical regions
	Information Sources	Rosangela Tenorio School of Architecture, University of Auckland, New Zealand Received 24 February 2005; revised 5 May 2005; accepted 10 October 2005. Available online 28 November 2005. http://www.sciencedirect.com/science?_Cited 5 December 2006

- Passive cooling strategy by promoting air movement by cross ventilation or induced by fans.
- An open plan solar orientation to protect the glazing areas from the sun and to direct the window opening areas to the prevailing breezes.
- Location of rooms on the north-east side where summer breezes are predominantll north-east.
- Maximize cross ventilation by orienting towards the prevailing breezes.
- Interaction of the outdoors and treatment of potential barriers to the path of breeze through the house.
- Use of adequate window openings to allow maximum airflow.
- Incorporating fans to promote air movement.
- High performance windows and wall insulation prevented both heat gain and loss and enhanced thermal performance.
- White coated central roof used to improve performance with radiant barrier system and bulk insulation lined internally with plasterboard.
- Walls painted with light color and combined with bulk and radiant barrier system.
- Thermal mass used in living areas.
- High efficient compact fluorescent lighting and high-efficient appliances used.
- utility grid-connected PV roof system is used at this project and a solar hot water system.

20. Guarajuba Ecohouse Green Building Element Filter

Orient form and Shape	
Wind Protection	Fitt | syst | zone | Syst | Stru | Shell | Elec | syst
Solar and Renewable Energy	Fitt
Cooling Systems	Syst | stru | Fitt |
Warming Systems	Fitt |
Lighting Systems	Fnsh | Elec
Thermal Mass Storage	Fnsh | shell | Shell | Zone |
Insulation	Shell | fnsh |
Ventilation	Syst | Mech | Syst | Fitt | Mech |

Edificio Malecon, Buenos Aires, Argentina		
21	Architect	Helmuth, Obata Kasabum
	Location	Buenos Aires, Argentina
	Awards	AIA top ten green project.
	Information Sources	Courtesy Dr Raj Barr-Kuma http://architecture.cua.edu/courses/arch509//Antionio%20Paz%20Edificio%20Malecon.pdf cited 6 December 2006.

- Shape of building a long narrow slab to minimize solar gain on structure with east and west ends pinched.
- Broad northern face with primary solar exposure shaped to track the sun and fully screened with deep sunshades that eleiminate direct solar radiation during peak cooling months.

- South face equipped with high parfomance curtain wall systems as other facades to minimize solar gain.
- Green roof insulates podium from solar radiation and manages storm water runoff.
- Building's shape and size to minimize solar loads on the building and maximize natural ventilation on the building.
- Cladding and mechanical system to reduce the building's energy gain as well as the passive cooling and heating of its interior spaces.
- Curved shaoe of building allows sunscreens to effectively shade the glass during peak summer months.
- Shallow dimension of tower slab, (17.5 metres maximum depth), allows the prevailing winds to flow through the entire building.
- Narrow slab dimension with full height glazing reduces need for general office illumination during most of the day, which significantly reduces electrical energy consumption.
- Super low emissivity glass in curtain wall throughout the building to control solar gain during periods of direct solar radiation.
- Aluminium louvers at each floor for natural convection in the tower as the skin and building mass warm and cool during the day.
- Solid walls backed up with concrete and rigid insulation.
- Green roof to reduce hat gain on entire building podium.
- Only high efficiency compact fluorescent fixtures used for general illumination in the tower supported by limited amounts of incandescent lighting and sufficient power to support task lighting.

21. Edificio Malecon Green Building Element Filter

Orient form and Shape	
Wind Protection	Shell
Solar and Renewable Energy	
Cooling Systems	Stru | shell | Fitt | Shell | Fitt | Mech | shell | Fitt | Shell
Warming Systems	Stru | Shell | Fitt | Fitt | Mech
Lighting Systems	Shell | system | Elec | Syst
Thermal Mass Storage	
Insulation	Shell | Shell | Shell |
Ventilation	Stru | shell | Shell | fitt |

Genzyme Centre, London, U.K		
22	Architect	Behnisch and Partners
	Location	London, U.K.
	Awards	AIA Top Ten Green Project for 2004
	Information Sources	http://leedcasestudies.usgbc.org/energy.cfm?ProjectID=274 http://www.aiatopten.org/hpb/overview.cfm?ProjectID=274 http://www.treehugger.com/files/2006/10/the_greeness_of.php http://www.detail.de/rw_5_Archive_En_HoleArtikel_5525_Artikel.htm http://www.genzyme.com/genzctr/genzctr_leed.pdf

- A concrete slab construction that helps to hold energy and moderate temperature changegs in the building.
- A unique cooling system that uses waste steam from a nearby power plant to cool the building,
- roof mounted solar panels
- Double glass curtain wall that covers 32% of the building for both insulation and fresh airflow throughout the building.
- 75% of all employees to work using natural light alone.
- The building's central atrium acts as a huge return air duct and light shaft. Fresh air moves into the atrium and up and out exhaust fans near the skylight.
- Natural light from the fully glazed facade and from the atrium (brought in by solar-tracking mirrors above the skylight) is reflected deep into the building.

- a The central heating and cooling systems are powered with steam from an adjacent power plant. The steam drives absorption chillers for cooling during the summer and is exchanged directly into heat for heating during the winter.
- Sunshading louvres incorporated in the windows deflect light via reflecting soffit mirrors into the depth of the offices.
- On the roof, seven heliostats that follow the sun reflect light into the hall space via a “bridge” with fixed mirrors.
- efficient fans, motors, and equipment and an extensive building management system, reduce the projected overall energy cost
- Daylighting for Energy Efficiency
  - Design an open floor plan to allow exterior daylighting to penetrate the interior
  - Use atrium for daylighting
  - Use building elements to redirect daylight and control glare
  - Use skylights for daylighting
  - Use light pipes and/or active tracking skylights for daylighting
- Photovoltaics
  - Use a photovoltaic (PV) system to generate electricity on-site
- Other Energy Sources
  - Consider a cogeneration system to provide heat and electricity
- Lighting Controls
  - Use modulating photoelectric daylight sensors
  - Use occupancy sensors
- HVAC Distribution Systems
  - Size fans and pumps properly to meet the loads
- HVAC Controls and Zoning
  - Provide sufficient sensors and control logic
  - Use direct digital control (DDC) systems

22. Genzyme Centre Green Building Element Filter

Orient form and Shape	
Wind Protection	Elec |
Solar and Renewable Energy	Mech | Syst | Elec |
Cooling Systems	Mech |
Warming Systems	Mech |
Lighting Systems	Syst | Fitt | Fitt | shell | Fitt | Fitt | Syst | Syst |
Thermal Mass Storage	Shell |
Insulation	Shell |
Ventilation	Fitt |Fitt |

Caravan Site Upgrade, Nieuwoudtville, South Africa

23	Architect	Eco-Design Architects
	Location	Nieuwoudtville, Northern Cape, South Africa.
	Awards	Silver Award 2006 by Holcim Competition for Sustainable Design, Africa region
	Information Sources	Courtesy of Holcim Foundation for Sustainable Design and the Architect. www.ecodesignarchitects.co.za info@ecodesignarchitects.co.za 021 462 1614 4/Fl The Armoury, 160 Sir Lowry Rd, Cape Town, 7925

- Straw Bale Walls.
- Planted roofs.

- Existing vegetation provides westerly sun protection.
- Vacuum tube collectors and flat plate solar water heating.
- L-shaped chalet to help shade the veranda from the hot westerly sun.
- Biogas digesters.
- Efficient appliances and fittings.
- PV for low level appliances and lighting.
- Straw bale and planted roof systems with controllable vents for cross ventilation, shutters, and decidous planted pergolas.

23. Caravan Site Upgrade Green Building Element Filter

Orient form and Shape	
Wind Protection	
Solar and Renewable Energy	Elec | elec | Fitt | Elec |
Cooling Systems	Stru | syst |
Warming Systems	
Lighting Systems	Elec |
Thermal Mass Storage	
Insulation	Shell | Shell
Ventilation	Shell | Stru |

Smithsonian Tropical Research Institute Research Station. Panama		
24	Architect	Kiss + Carthcart Architects
	Location	Bocas Del Toro, Panama.
	Ratings	Platinum LEED rating from US green Building Council
	Information Sources	US Department of Energy. http://femp.buildinggreen.com/overview.cfm?ProjectID=263 Cited 6 December 2006. Courtesy also to Kiss + Carthcart Architects

- Interior volumes shaded by large photovoltaic roof which minimizes direct heat gains.
- Narrow plan together with the space between the two roofs allows cross ventilation to keep the building cool while providing daylight and views.
- Transluscent lower roof, together with partially transparent photovoltaic roof admits an optimum of 5% of daylight into interior rooms for daylighting.
- The 38 KW photovoltaic upper roof produces approximately 75% of the building's energy needs.
- Raising the entire building on concrete piers helps catch prevailing breezes for passive cooling.
- *Air-conditioning is zoned so that individual rooms can be cooled separately.*

24. Smithsonian Green Building Element Filter

Orient form and Shape	
Wind Protection	Shtru | Shell
Solar and Renewable Energy	Elec |
Cooling Systems	Shell | Zone | Syst
Warming Systems	Zone | Syst
Lighting Systems	Shell | Stru | Shell | Shell |
Thermal Mass Storage	
Insulation	
Ventilation	Shell | Stru | Zone | Syst

Appendix 2

Charts and Calculations

A2.1 Table

y	(y) sq	x	(x) sq	xy
2.777777778	7.716049383	3.777777778	14.27160494	10.49382716
3	9	4.888888889	23.90123457	14.66666667
1.555555556	2.419753086	2.111111111	4.456790123	3.283950617
2	4	3.444444444	11.86419753	6.888888889
1.555555556	2.419753086	2.222222222	4.938271605	3.456790123
1.555555556	2.419753086	2.333333333	5.444444444	3.62962963
1.444444444	2.086419753	2.666666667	7.111111111	3.851851852
1.888888889	3.567901235	3	9	5.666666667
1.777777778	3.160493827	2.333333333	5.444444444	4.148148148
1.444444444	2.086419753	1.444444444	2.086419753	2.086419753
1.111111111	1.234567901	1.333333333	1.777777778	1.481481481
0.666666667	0.444444444	0.666666667	0.444444444	0.444444444
1.666666667	2.777777778	2.333333333	5.444444444	3.888888889
1.111111111	1.234567901	1.222222222	1.49382716	1.358024691
2.111111111	4.456790123	3	9	6.333333333
0.666666667	0.444444444	0.666666667	0.444444444	0.444444444
1.444444444	2.086419753	2.333333333	5.444444444	3.37037037
1	1	2	4	2
1.444444444	2.086419753	2.111111111	4.456790123	3.049382716
2.333333333	5.444444444	2.888888889	8.345679012	6.740740741
1.888888889	3.567901235	2.888888889	8.345679012	5.456790123
1.333333333	1.777777778	2	4	2.666666667
0.888888889	0.790123457	1.222222222	1.49382716	1.086419753
1.555555556	2.419753086	1.777777778	3.160493827	2.765432099
Σ (y)	Σ (y) sq	Σ (x)	Σ (x) sq	Σ (xy)
38.22222222	68.64197531	54.66666667	146.3703704	99.25925926
N=24				(Σ xy) sq
				9852.400549

A2.2 Mean and Standard Deviation

Average x

$\bar{x}_i = \Sigma (x) / n = 54.667 / 24 = 2.278$

$\bar{x}_i^2 = 5.188$

Standard Deviation x

$$S = \sqrt{\left\{ \left[1/(n-1)\right] \times \left[\Sigma(x_i^2) - \underline{n}\, (\bar{x}_i)^2\right] \right\}}$$

$$S = \sqrt{\left\{ \left[1/(23)\right] \times \left[146.370 - 24(5.188)\right] \right\}}$$

$S_x = 0.975$

Average y

$\bar{y}_i = \Sigma (y) / n = 38.222 / 24 = 1.593$

$\bar{y}_i^2 = 2.536$

Standard Deviation y

$$S_y = \sqrt{\left\{ \left[1/(n-1)\right] \times \left[\Sigma(y_i^2) - \underline{n}\, (\bar{y}_i)^2\right] \right\}}$$

$$S_y = \sqrt{\left\{ \left[1/(23)\right] \times \left[68.642 - 24(2.536)\right] \right\}}$$

$S_y = 0.581$

A2.3. Correlation.

$n = 24$

$\Sigma\, y_i = 38.222$

$\Sigma\, (x_i^2) = 146.370$

$\Sigma\, x_i = 54.667$

$\Sigma\, (x_i\, y_i) = 99.259$

$\Sigma\, (y_i^2) = 68.641$

$$R_{xy} = \frac{SS_{xy}}{\sqrt{(SS_{xx})}\,\sqrt{(SS_{yy})}}$$

$$SS_{xy} = \Sigma\,(x_i\, y_i) - \frac{1}{n}\left[\Sigma\,(x_i)\right] \times \left[\Sigma\,(y_i)\right]$$

$$SS_{yy} = \Sigma\,(y_i)^2 - \frac{1}{n}\left[\Sigma\,(y_i)\right]^2$$

$$SS_{xx} = \Sigma\,(x_i)^2 - \frac{1}{n}\left[\Sigma\,(x_i)\right]^2$$

$$SS_{xy} = (99.259) - \frac{1}{24}\left[54.667\right] \times \left[38.222\right] = 12.198$$

$$SS_{xx} = (68.641) - \frac{1}{24}\left[38.222\right] \times \left[38.222\right] = 21.852$$

$$SS_{yy} = (146.370) - \frac{1}{24}\left[54.667\right] \times \left[54.667\right] = 7.770$$

$$R_{xy} = \frac{12.198}{\sqrt{(21.852)}\,\sqrt{(7.770)}} = 0.9361$$

Therefore there is a strong positive correlation between Green Building Principles and the number of building elements they are used in.

A2.4 Correlation Significance

The next investigation is to check if the value of R is purely and genuinely due to randomness or if R falls in the significance range testing as 95% confidence level.

From r-tables for sample size n=24 testing at 5% level of significance. In this case, green principles and number of building elements used go up together and come down together so this is a 2 tail test. So $\alpha = 0.025$.

Looking at r-tables for n=24 and $\alpha = 0.025$ then $|r\ crit| = 0.396$ and $|r\ calc| = 9361$ in this case $|r\ calc| > |r\ crit|$ and therefore r falls in the random range and not the significance range therefore r is due to randomness.

A2.5 Simple Regression Line

$$ß_1 = \frac{SS_{XY}}{SS_{XX}}$$

$$ß_1 = \frac{12.198}{21.852}$$

$$ß_1 = 0.5582$$

$$y = ß_0 + ß_1 x$$

$$ß_0 = y – ß_1 x$$

Substituting values for average x and average y into the equation from 6.1 above

$$ß_0 = 1.593 – (0.5562 \times 2.278)$$

$$ß_0 = 0.3212$$

So regression line is given by

$$y = 0.3212 + 0.5582x$$

THIS IS THE REGRESSION LINE OF THE GRAPH WHICH RELATES THE GREEN PRINCIPLES USED TO THE NUMBER OF BUILDING ELEMENTS THEY ARE APPLIED TO.

A2.6 F-Statistic

Now F-stat test of significance whether ß1 due to randomness at 1% level of significance.

ANOVA Table

Source of Variation	Degrees of Freedom (df)	Sums of Squares (SS)	Mean Square (MS)	F-Stat (F_{cal})
Regression	1	$SS_{reg} = \frac{(\sum x_i y_i)^2}{\sum x_i^2}$	MS_{reg}	$\frac{MS_{reg}}{MS_{res}}$
Residual	n-1	$SS_{resi}=SS_T-SS_{regr}$	$S^2 = MS_{reg}$	
Total	n	$SS_T = \sum y_i^2$		

$$SS_{reg} = \frac{(\sum x_i y_i)^2}{\sum x_i^2}$$

$$SS_{reg} = \frac{9852.400}{54.667} = 180.227$$

$$SS_{total} = \sum y_i^2$$

$$SS_{total} = 68.641$$

$$SS_{resi} = SS_{total} - SS_{regr}$$

$$SS_{resi} = 68.641 - 180.227$$

$$SS_{resi} = -111.585$$

$$MS_{reg} = \frac{SS_{reg}}{df_{reg}} = \frac{180.227}{1} = 180.227$$

$$MS_{resi} = \frac{SS_{resi}}{df_{resi}} = \frac{-111.585}{23} = 4.852$$

$$(F_{cal}) = \frac{MS_{reg}}{MS_{res}} = \frac{180.227}{4.852} = 37.149$$

Source of Variation	Degrees of Freedom (df)	Sums of Squares (SS)	Mean Square (MS)	F-Stat (F_{cal})
Regression	1	SS_{reg} = 180.227	MS_{reg} = 180.227	F_{cal} = 37.149
Residual	23	SS_{resi}=111.582	MS_{res} = 4.852	
Total	24	SS_T = 38.222		

From F-table, denominator degree of freedom is
n-2 = 24-2 =22

numerator degree of freedom = 1

from f table F crit = 7.94

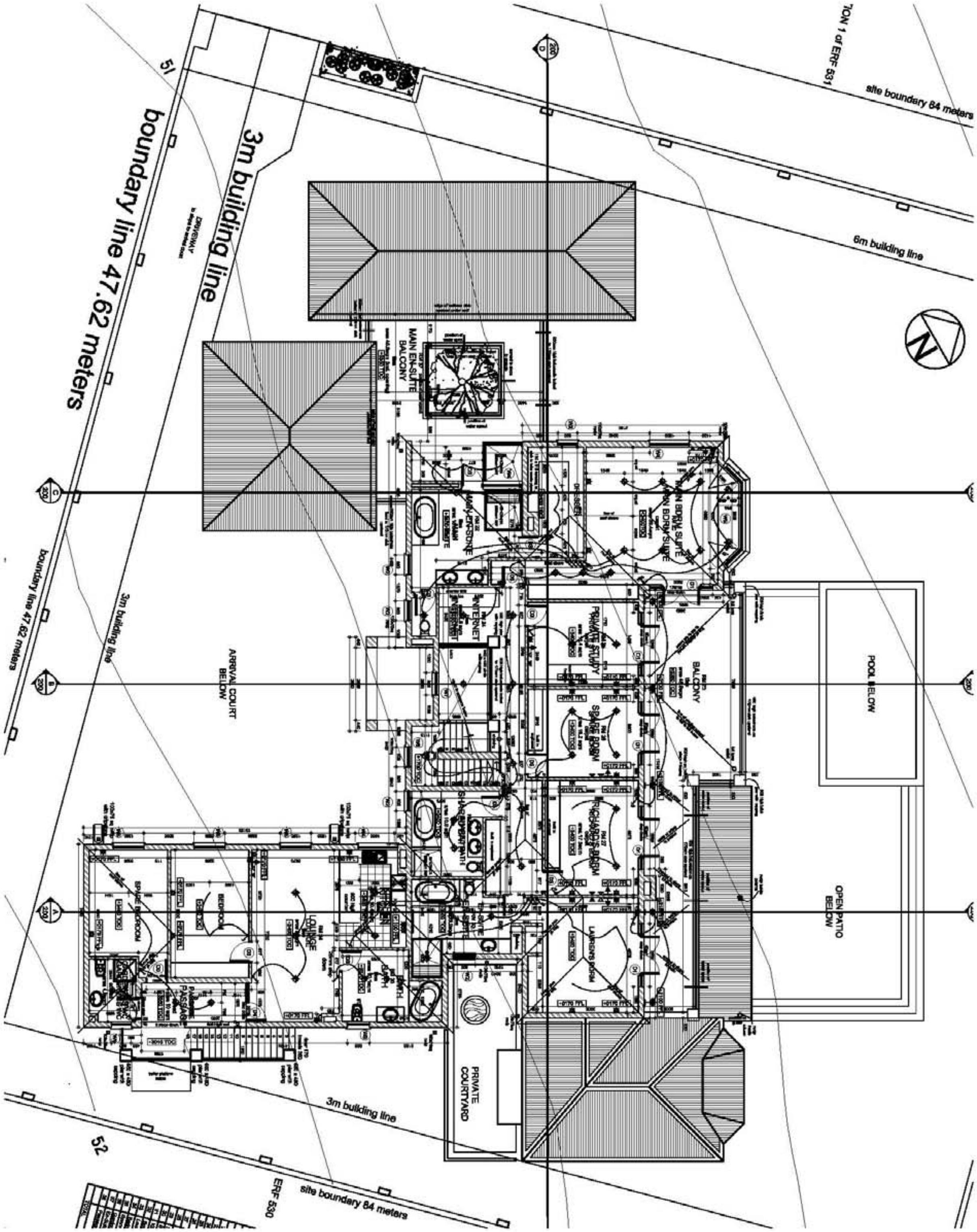
From ANOVA f-cal=37.149

| f-cal (37.149) | > | f-crit (7.94) |

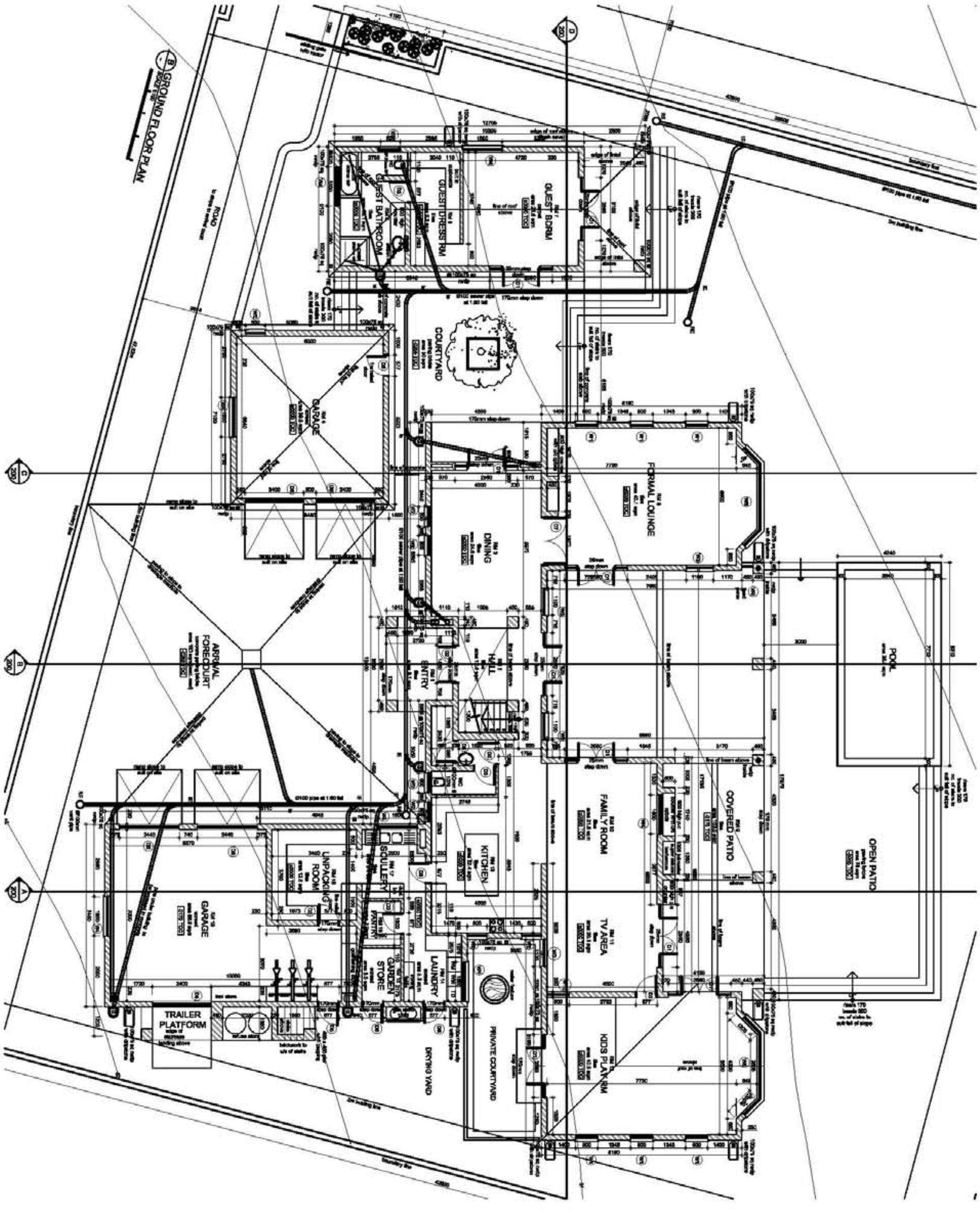
So F calc is way above the F crit and therefore ß1 is due to randomness.

Appendix 3

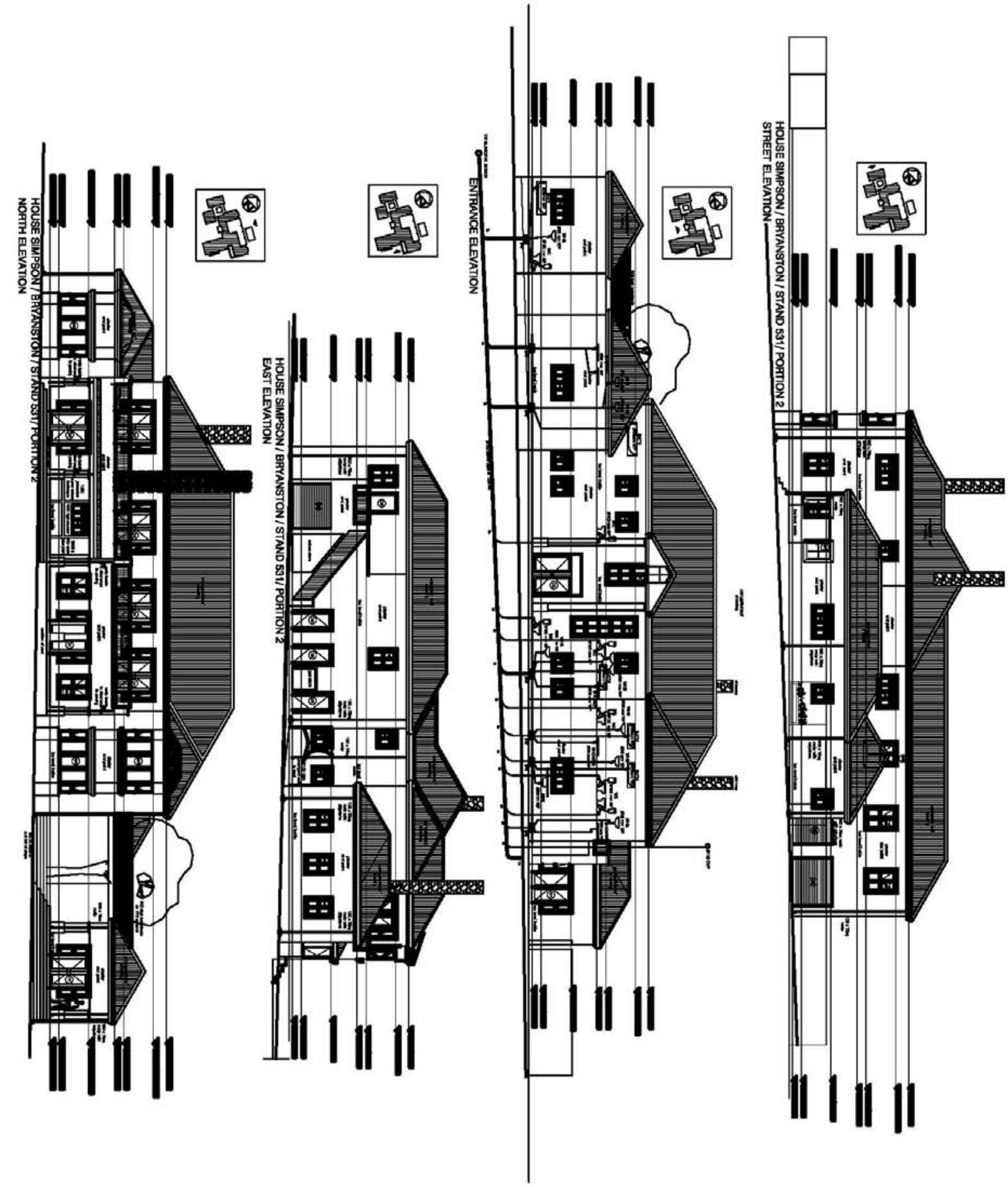
Green Building Value Engineering Case Study Drawings



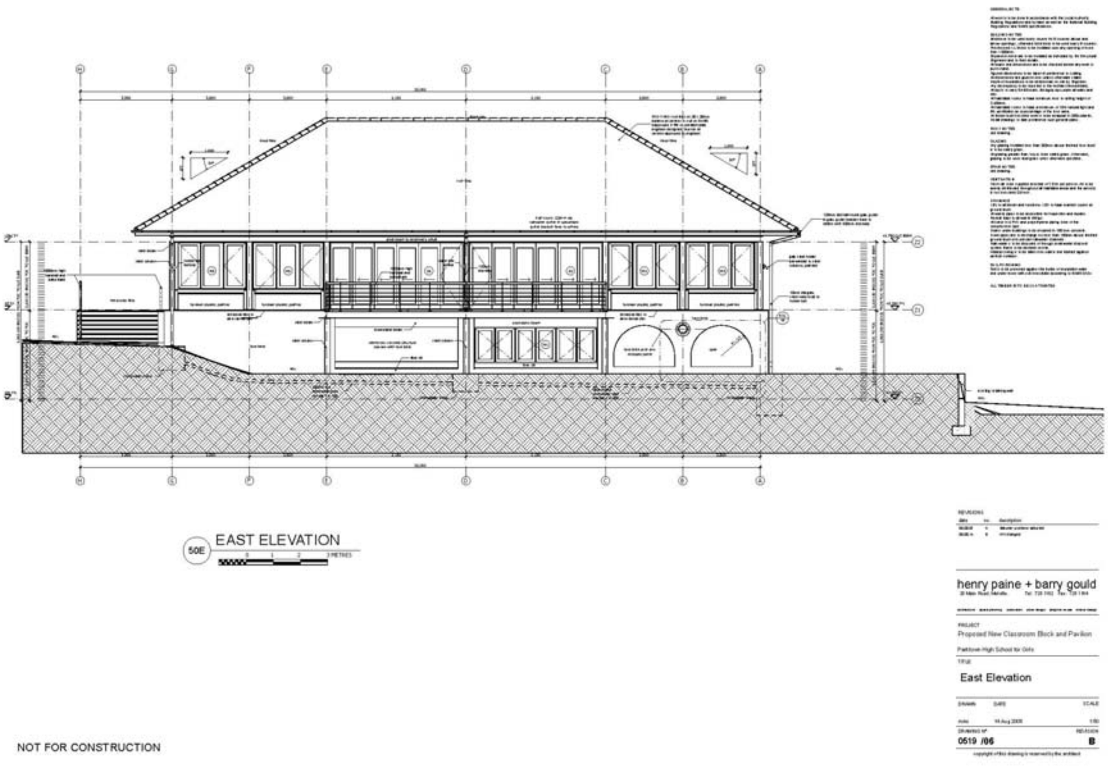
(Paragon Architects 2004; 1)

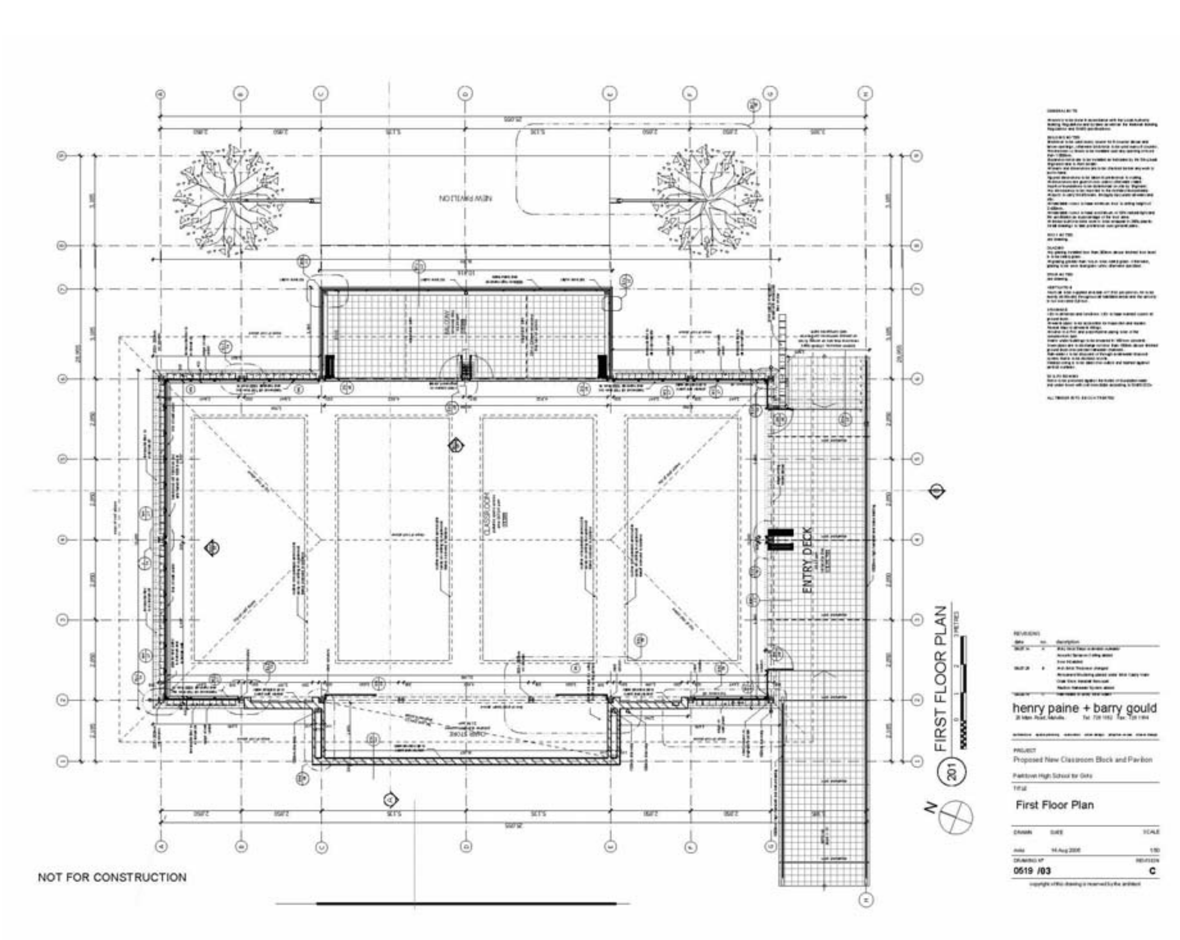


(Paragon Architects 2004; 2)

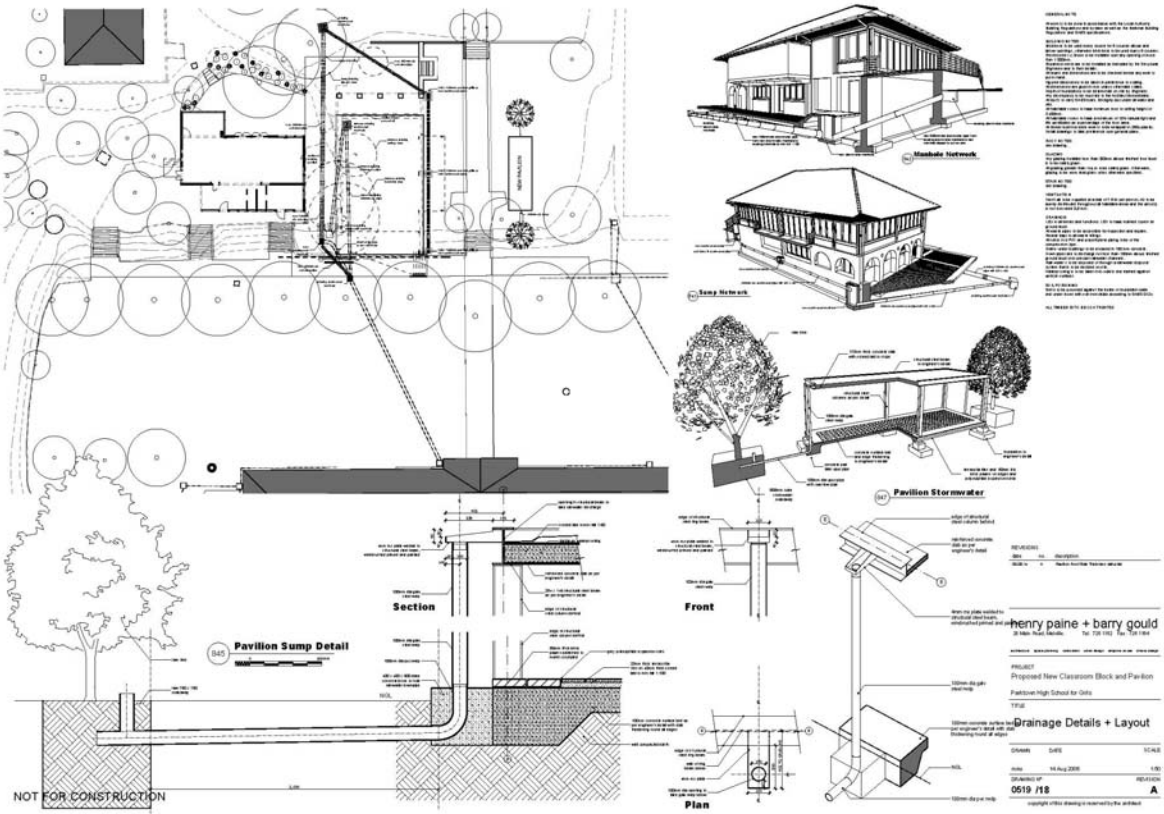


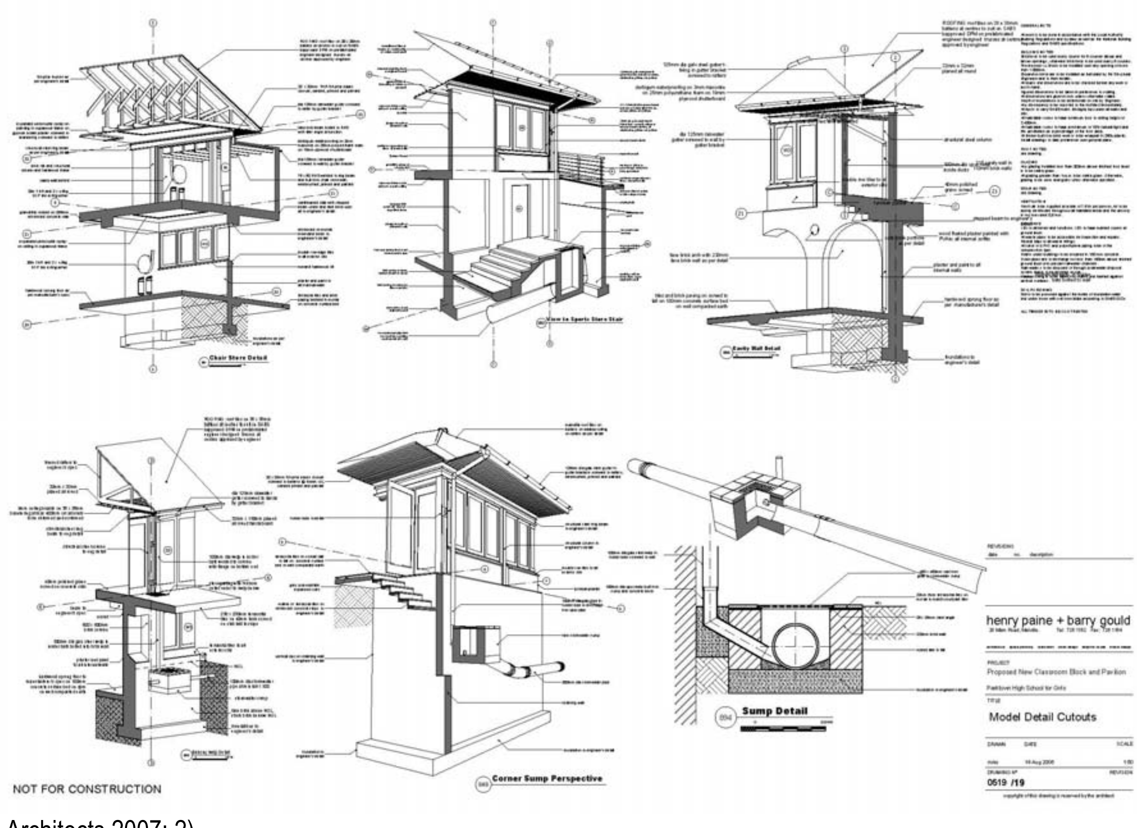
(Paragon Architects 2004; 3)



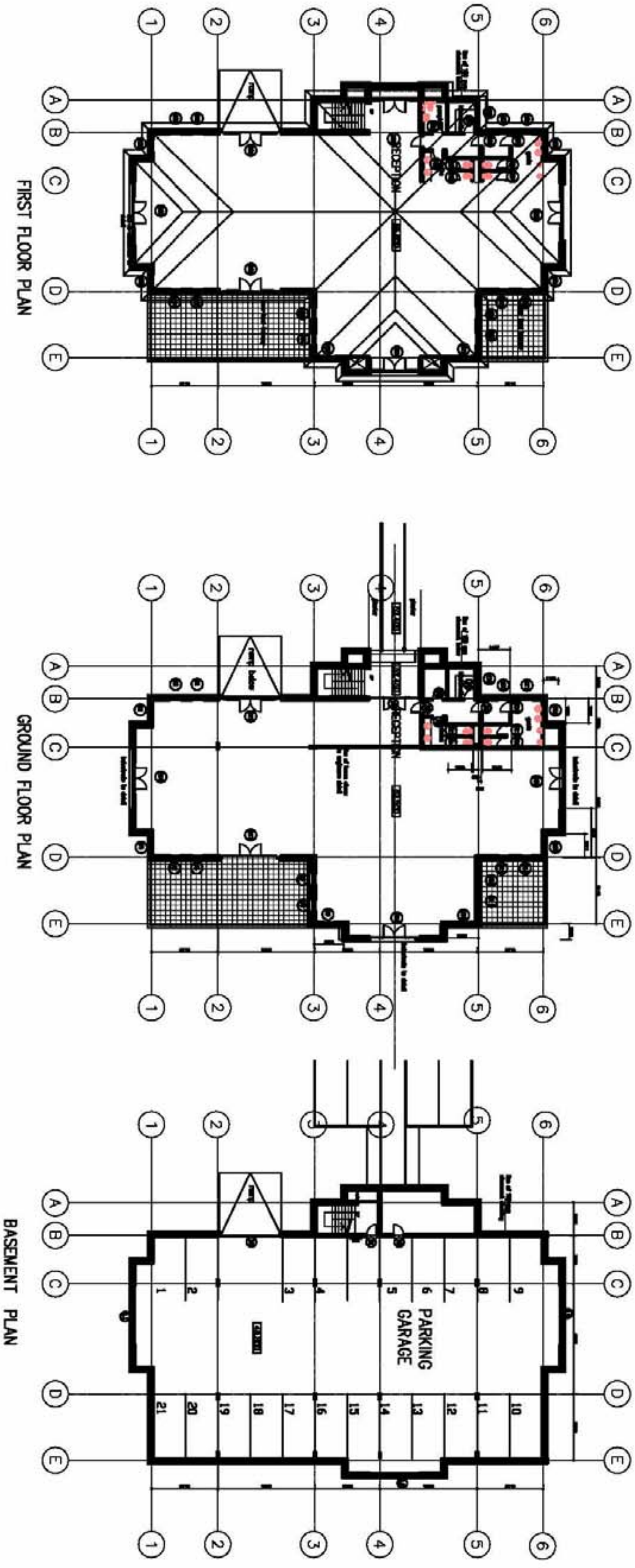


(HPBG Architects 2007; 1)

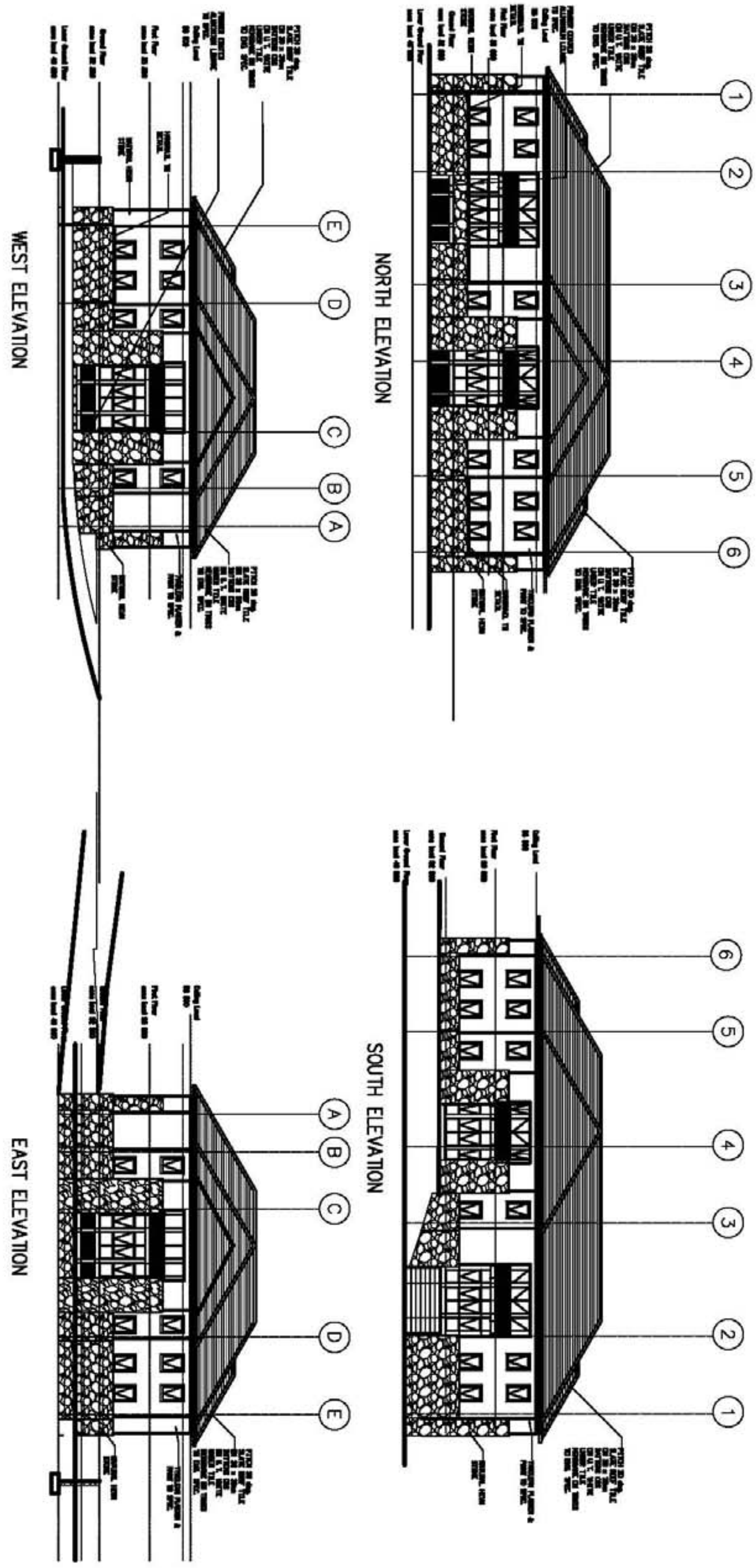




(HPBG Architects 2007; 2)



(GLH and Associates Architects 2004; 1)



(GLH and Associates Architects 2004; 2)