XXXIII IAHS
World Congress on Housing
Transforming Housing Environments through Design
September 27-30, 2005, Pretoria, South Africa

# Optimising Energy For Thermal Comfort In Low - Cost Housing With Particular Reference To Botswana

**Busisiwe E. Mothibi**

M. Arch. (Research) Student
University of Pretoria, South Africa email: mothibi@botec.bw

**Key words:** low cost housing, thermal comfort, energy efficiency, energy retrofits, holistic design

**Abstract:**
The paper investigates ways of optimising energy in low income housing, for sustainability in Botswana for both existing and future residential houses. The building stock and trends in building energy use will be identified. It is noted that the important source of increase in energy use in the residential buildings has come from increasing dependency on electricity. The biggest share of energy goes to water heating and the next category is space heating/cooling and lighting. The bulk of the building stock is inherited from eras of energy use that were different from the ones that the country is facing today. Some of the city's residential buildings date back to the 50's when the only fuel was firewood. The question is to what extent these buildings and future buildings can be made more energy efficient in response to higher energy demands and at what cost compared to savings in energy.

## 1. Introduction

Concern over the environment and social implications due to modern consumption is very paramount in the sustainable development debate. There is need for shift in the scale and pattern of consumption. Achieving the latter relies not only on energy efficiency of industry, the performance of business and design products but also on expectations, choice, behaviour and lifestyles of consumers. Following this worldwide debate on the impact of human consumption on the ecological system, several definitions of sustainable consumption have come out in an aim towards understanding the concept. One of the best definitions is the NCC 2004 which defines it as a "balancing act". That sustainable consumption is about consuming in such a way as to protect the environment, use natural resources wisely and promote quality of life now, while not spoiling the lives of future consumers.
Research shows that the building sector consumes approximately 40% of the world's energy (Energy book, 2002) and as such is a major player in the energy agenda. This paper questions the energy needs related to individual houses and their occupants. The inefficiency of our existing housing stock in Botswana means that large amounts of energy are required to maintain comfort temperatures. In many cases these comfort levels are difficult to achieve despite considerable expenditure on fuel. The same applies to a lesser extent of domestic hot water systems. The result is that low income earners (and some middle income) are spend more money on energy and or are unable to afford energy costs for providing essentials such as warmth. Further, houses of

those who cannot afford to heat often suffer from dampness due to condensation which is detrimental to health and increased deterioration of the building fabric.

A house consumes energy in a number of ways, for instance in the manufacturing of building materials, components and systems (embodied energy); in the distribution and transportation of building materials and components to the construction site (grey energy); in the construction of the building (Induced energy); in running the building and its occupants' equipment and appliances (Operation energy); in maintenance, alteration and final disposal of the building.

So far, measures for reduction of energy on the demand side are more promising than the supply side. Supply side may be improved by solar water heating and photovoltaic (PV) systems. This can be achieved through an integrated effort with the design of houses and services systems, because energy conservation concerns above all the thermal envelope of the dwelling. Getting the best performance from the thermal envelope requires energy considerations at design level (or redesign in terms of existing houses).

Temperatures are at their lowest at night and highest during the day. The geographic location of a building and its detailed site conditions i.e. the micro climate; determine the climatic conditions to which it is exposed. The climate and site conditions in turn affect the heating and cooling loads due level of exposure, range of air temperature, humidity levels, and air movement. Hence the design of houses derives from considered responses to climate, technology, culture and site.

## 2. Research Objective

One of the essential inputs of this century is to move towards sustainable development, sustainable design and sustainable construction. The aim of this study is to create a better quality of low cost housing through design that is matched to the site, to levels of energy and reduced material costs. To use science and technology to improve the energy efficiency of low cost housing, paying particular attention to the indoor environment comfort and to contribute towards reducing the impact of energy demand by the building sector.

## 3. The need for energy optimisation in low cost housing

As we search for ways of optimising energy in low income housing, for sustainability in Botswana for both existing and future residential houses, it is important to define the building stock and trends in building energy use and to note the climate of the country and the particular research site. The climate of the country is generally hot and dry, with extremes of temperature. The country boasts an abundance of solr energy. However, most of its energy comes from non renewable sources. It is noted that the important source of increase in energy use in the residential buildings has come from increasing dependency on electricity. That the biggest share of energy goes to water heating and the next category is space heating/cooling and lighting. The bulk of the urban housing stock is inherited from eras of energy use that were different from the ones that the country is facing today. Some of the city's residential buildings date back to the 50's when the only fuel was firewood. The question is to what extent these buildings can be made more energy efficient in response to higher energy demands and at what cost compared to savings in energy. A survey will be conducted of physical changes that could be made to the difference housing types to improve their energy efficiency. These will be termed "energy retrofits". There are three basic types of low cost house namely, the Government (or corporate) low cost house, the BHC low cost house and the SHAA low cost house and a couple are illustrated below;

*BERS is a computer simulation software used to analyse house form and specification based on standard profile data systems.

Illustration 1: Typical incremental SHAA low cost house & Old institutional low cost house

SHAA housing is self built houses on subsidized Council plots. Usually people build 21/2 roomed house and keep on extending as their circumstances improve or change. While the old institutional low cost are single houses on single plots with flat metal roofs. They have no gutters and down pipes and the geyser and plumbing work are exposed. The plumbing and electrical conduits had no regard for heat losses in water pipes etc. Poor maintenance is evident which has further implications for energy consumption.

The technical potential for improving the energy efficiency and thermal comfort of houses in Botswana will be investigated, and identification of peculiar features of the building leading to energy waste e.g. cracks around energy installation, and identification of peculiar local variations in the cost of labour or materials. The idea is to identify on average retrofits to existing buildings of most types that are practical, feasible and have low capital cost compared to saving. A few characteristics of the building influence their retrofit potential such as the orientation of the building on the site, the size of the building envelope, wall and roof insulation, window treatments; wall and roof type i.e. masonry, flat roofs. Other retrofits are domestic hot water systems, and energy efficient light fittings. The investigation will culminate in design interventions that are suitable for future low cost housing of Botswana. These will be in the line of solar passive energy design or equivalent and renewable energy technologies for energy efficiency and conservation in the building. Some attempts have been made previously towards energy efficiency for commercial and institutional buildings such as the BRET study of the early 90s.; experimental staff houses by Botswana Technology Centre; and the ongoing study implemented by the Department of Energy, funded by DANIDA (Danish Government funded programme), which was preceded by a countrywide situational analysis study. The following are some of the identified challenges for implementing energy efficiency in housing; few builders are prepared to build houses which go beyond the requirement of the building regulations; house buyers are reluctant to pay additional costs of a low environmental impact house (Webzell and Fawings, 1994); difficulty in sourcing of energy efficient materials; high price and shortage of supply of energy efficient installations.

### 3.1 Considerations for Passive solar design

The different heights of the sun in winter and summer can be used to cater for comfort in winter or summer in the house. The main rooms and windows of the house should face north to catch winter sun with correct roof overhang to prevent harsh summer sun while allowing winter sun. Deciduous trees (e.g. fruit producing figs, pear or peach) can be planted outside north facing windows to shade the house in summer, while allowing winter sun when they lose their leaves.
Rooms such as bathrooms and storerooms can be placed so that they screen the unwanted western sun or placed to prevent heat loss from south facing walls; compact plan (square rather than

rectangular) and (multi storey than single storey) will reduce heat losses as it exposes as little wall area as possible.

Layout must be such that it achieves the best benefit from passive thermal design i.e. must face north. If the sits are too small to orientate the house then the sites themselves must be orientated in the right way. This means that the boundaries of the sites should run as near to the north-south and east west as possible. To achieve this, the roads should run north-south and east-west. The houses should be staggered so that they do not shade each other.

The energy efficiency strategies mentioned above can only be possible through holistic treatment of urban systems such that housing is situated for optimum orientation of most sites and optimum or near optimum relationship with other urban activities such as roads, retail and leisure. Designing energy efficient houses will reduce energy needed for upkeep of the house. Simple interventions such orientation and adding a ceiling to an existing house yield huge benefits to the occupant. Not only will they spend less on energy but will improve indoor air quality and the spin off is less emissions of greenhouse gases e.g. carbon dioxide to the earth's atmosphere.

The principle of **passive solar design** involves the application of flow energy principles and climate characteristics of a region in the design, construction and management of houses with an aim to achieve thermal comfort with minimal conventional energy input.

### 3.2 Comparison of proposed passive solar design and existing designs

The country has diverse architectural designs ranging from the traditional mud thatch house to self help housing and Government colonial type housing. A few good prototypes have also been built although they have not been copied by surrounding residential areas. From the interviews we have conducted so far, it seems the reluctance seems to stem from lack of knowledge, limited local research in this area and fear to adopt new concepts. In this section we shall undertake to illustrate the need for sustainable design in low cost housing based on indigenous practice and international best practice.

#### 3.2.1 Tswana traditional housing and passive solar design

The principle is not foreign to Botswana traditional housing architecture, which tended to respond to nature and notably employed energy efficient strategies for instance thermal mass (mud blocks), shading (large overhangs) and insulation (thatch roof), as shown in figure 1 below


*BERS is a computer simulation software used to analyse house form and specification based on standard profile data systems.

Illustration 2: Traditional Tswana houses from nearby Mochudi Village

### 3.2.2 Typical Institutional low cost house

Presently institutional housing design is not concerned with sustainability nor thermal comfort. The designs are focused on delivering low cost housing by numbers and using already available materials and standard plans. Recent housing offers improved variety and aesthetics but little consideration for neither energy efficiency nor comfort. They do not respond to climate nor to the obvious challenges such as drought which is presently faced by the country. Instead the result is a neat little house on single plot, on street with rows and rows of similar houses with no regard for orientation; hence some houses face south while others face north.

Illustration 3: Typical institutional housing

### 3.2.3 Early prototype housing

Some of the passive solar design principles for energy efficiency have been attempted by the Botswana Technology Centre (BOTEC) experimental low cost staff houses which were built in the early 90s. The design strategy:

a) orientation of plots & houses to the north with minimal sun exposure - east and west facade
b) semi-detached house plan
c) ventilation and stack effect
d) innovative materials for walls and ceilings, and
e) solar water heaters (renewable -energy)

Illustration 4: BOTEC Staff housing

### 3.2.4 International Case study

Reference is made to the Australian prototype home, the Prosser House, as an example of ecological sustainable design that has been constructed in the subtropical coastal climate based on passive solar design principles and a framework for environmental design. The framework defined a sustainable design in terms of reducing environmental impacts of buildings; hence a number of design strategies and technologies were used to address the framework. The design principles include energy conservation, materials and resources conservation, working with the climate, respect for site, respect for the user and holistic treatment of design relating to the urban environment. This climate responsive design can be summarised as follows:

| **Summer strategies** | **Winter strategies** |
|---|---|
| Orientation | Orientation |
| Ventilation | Solar gain |
| Solar defence | Fast response |

Recent research in the form of thermal performance assessments by Richard Hyde and Steve Watson of the Department of Architecture in Queensland, Australia reveal that the house performs within acceptable thermal comfort zones for summer and winter. Below are the summer results from the assessments.

| **Season** | **Summer** | |
|---|---|---|
| Location | External | Internal |
| Av. Max. temperature | 28.9 | 27 |
| Upper limit of comfort zone | 27.2 | |
| Achieving of comfort zone | 1.7 outside | within |
| Av. Min. temperature | 20.4 | 22.9 |
| Lower limit of comfort zone | 23.2 | |
| Achieving of comfort zone | 2.8 outside | 0.3 outside |

Table 1: Assessment of comfort zone based on average max. & min. for summer conditions

The BERS assessment program* further reveals that the building achieves a 4 star rating (out of 5 stars), in terms of compliance with Australian building codes compliance levels.

### 3.3 Possible passive solar design interventions

The basic components of the passive solar design principle include orientation of the house, optimizing direct natural light and using thermally efficient building materials. The result is a minimal or no cost intervention that is applicable to all climatic regions. Listed below are some of the possible interventions:

#### 3.3.1 Orientation of the house:

The orientation of houses should be an integral part of planning and design. Houses in the southern hemisphere like Botswana need to be positioned towards geographic north (+-15degrees) for optimal solar benefit.

#### 3.3.2 Building materials:

To achieve passive solar design, appropriate building materials are essential i.e. materials with high thermal mass that are able to store heat during the day and release it slowly at night e.g. stone, helps to slow down the rate of heat flow between inside and outside. Traditional materials such as earth bricks have higher thermal mass than the commonly used hollow core cement blocks.

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### 3.3.3 Optimum daylight:

Position and size of openings helps to optimize natural sunlight, through clever design positioning of glazing during the day such that heat gain is reduced in summer while heat loss is reduced in winter) Irurah, 2000) the size of glazing should be about 20% of total floor area (Holm, 1996) on the north of the house, while there needs to be minimal glazing on the south, east and west façades. Where affordable, double glazing will lead to even more thermal efficiency, but is rarely used by Southern African market as it is considered expensive compared to energy cost.
Most of the country uses metal window frames, yet metal conducts heat and thus does not provide insulation. Recently a few high cost houses use wood imported from South Africa. Wood is seldom used due to unavailability and cost.

### 3.3.4 Roof overhang:

The orientation of the house coupled by proper roof overhang and well placed vegetation, will increase thermal stability of the house. The overhang is better placed on the north side of the house and should be sized according to the sun angle in order to shield the northern windows from the sun in summer while allowing the sun's rays in winter when the sun is lower (Garner, 1999). To achieve this, the roof overhang should be approximately half a metre to shade north windows.

### 3.3.5 Ceiling:

Ceilings are a critical solution to thermal efficiency in low cost housing. The ceiling traps air and ensures reduction of heat flow in or out of the house. Result is that house is cooler in summer and warmer in winter. The average cost of a "low cost" ceiling is about P20 per square metre (US$2.85). The ceiling is a medium to high cost commodity but has maximum benefits (rendering it an absolute necessity).

### 3.3.6 Insulation:

It is an expensive intervention. However, there are various methods of application including cavity wall (very effective but expensive method), plaster and panels (construction boards). This method is not likely to be adopted for low cost housing. However, other studies like the BOTEC experimental staff housing have emphasized the need for well – fitting doors and windows (sealing of openings) to prevent draughts.

### 3.3.7 Flooring:

Floors play a big part in thermal efficiency of a house. The material needs to be of high thermal mass such as concrete, bricks, clay etc. it needs to trap heat and solar radiation from the windows and slowly release it at night. Single storey residential houses have advantage of floor material and soil underneath. Multiple storey residential buildings need to add thermal mass to upper storeys through heavy weight material which leads to higher costs

### 3.3.8 Shared walls:

This is walls shared in the form of semi-detached or row of houses, the concept is good for low cost housing as there is less wall exposure to weather.

### 3.3.9 Wind breaker:

Shield the house from wind and rain using roof overhangs on the rainy side and pay attention to details of surfaces on the wind or rain exposed sides. Walls on these sides need to be protected from dam and or wind. Vegetation belt is more effective in creating a wind barrier as it gently slows of the wind and less eddying, than a solid wall which creates turbulence.

**3.3.10 Thermal stability of the building:**

Damp proof floors: ensure floor level is min. 150 mm above ground level and ensure ground surrounding house slopes gently away from house. A damp proof membrane needs to be laid under the floor and up to 1 brick above ground to prevent rising damp. Floors with high thermal mass e.g. concrete or bricks so that the floor can store the sun's warmth and it can be used at night to warm the inside.

**3.3.11 Ventilation:**

Ventilation is vital to ensure good air quality and for preventing damp which has health implication e.g. respiratory illnesses such as TB. This is achieved by the common 300 x 300 air brick over all openings, plus cross ventilation.

The extent to which these are applied is site specific as it involves affordability. The study will propose some cost effective interventions that are suitable for Botswana's low cost housing environment. Similar to the Australian case study, it is proposed that the interventions be guided by a framework suitable to local conditions. So far the identified framework is the SBAT tool described below.

## 4. A framework for proposed new design principles

"The Sustainable Building Assessment Tool (SBAT) has been designed to help evaluate the sustainability of buildings. This is done by assessing the performance of a building in relation to a number of economic, social and environmental criteria. The tool has been designed to be particularly appropriate for use in developing countries and therefore includes aspects such as the impact of the building on the local economy, as economic issues are often a priority"(SBAT Manual). The tool can be used for both new design stages and for refurbishments. It is designed to enable different options to be evaluated rapidly and compared. The tool also enables a building to be rated in terms of its sustainability and is a good tool for benchmarking. The tool can be used alongside more complex assessment tool and can save time and expense by identifying the main problem areas, before these are used. Assessment of thermal comfort will be made with reference to the Macquarie University's ASHRAE RP – 884 adaptive model projects below:

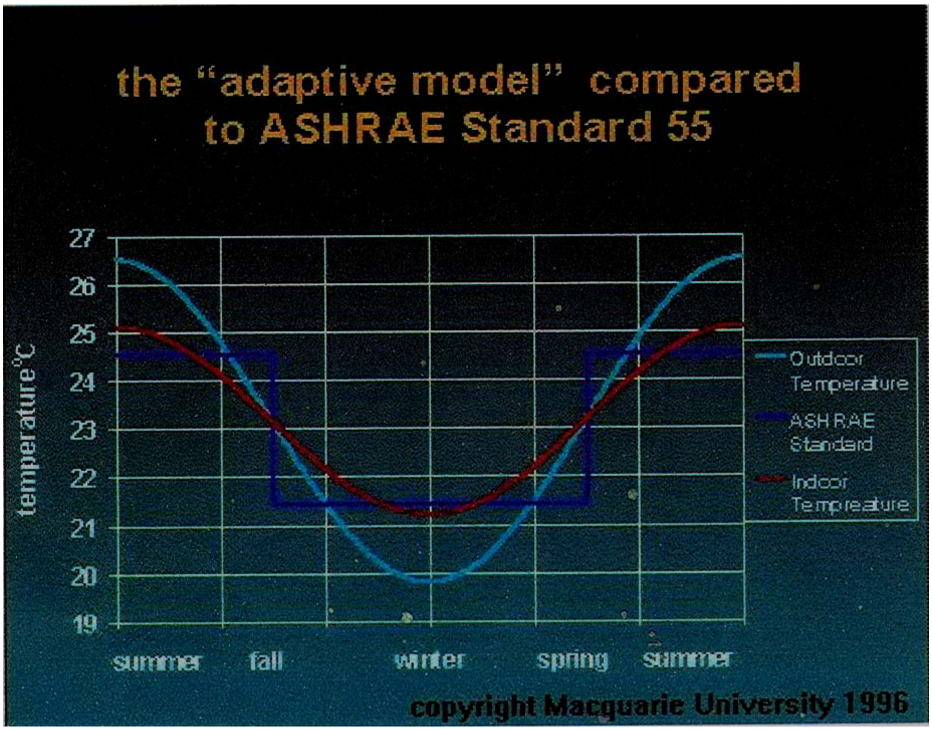


Figure 1: The Macquarie University's ASHRAE RP – 884, Thermal comfort adaptive model

*BERS is a computer simulation software used to analyse house form and specification based on standard profile data systems.

The model depicts the effects of fully exploiting the adaptability in thermal perceptions in terms of the relationship between indoor and outdoor temperatures. The idea is to reduce the thermal gradient between the two and it serves the dual purpose of reducing energy consumption in buildings.

## 5. Benefits of improved energy in low cost housing

The move towards transforming the housing environment is more than making small changes and has benefits for individuals as well as national benefits i.e.:

- Good access means savings on time, money, travel and vehicle emissions.
- Fundamental shift to better housing; better neighbourhoods; and developing better cities. The principles can be applied at the time of planning and construction or as a later intervention and need not be costly.
- Major difference to comfort, health and expenses for the household and the local authority's services and maintenance costs. Thus Less demand for health and welfare facilities and or programmes.
- Less demand for electrical power (critical for Botswana as it has been stated in the BPC annual report of 2004 that energy supply from South Africa to the tune of 70% of the countries energy demand will cease)
- Most financial investors are now concerned with ethics & ecology as much as financial returns. The life cycle of the project is now scrutinised for future energy impact in the environment.
- less demand on non-renewable energy resources

## 6. The way forward

For energy efficiency to have substantial impact in Botswana, the Government needs to lead the way as Government owns a substantial percentage of housing e.g. police, defense, public staff housing, hospital staff housing, schools etc). Moreover Government has an annual formal budget which can benefit from energy savings. International sources have also found that Government is more likely to succeed in kick starting energy efficiency in buildings because Government has access to finance and access to good technical advice. The benefits are numerous including improved health of housing stack and occupants, broad goals, long term sustainability of income and economic productivity.

Reference is made to the results of the United States 07$^{th}$ congress of the OTA report, identified the following energy retrofits for low cost housing; walls, windows, roof and lights. Solar retrofits like wall insulation were found to have high capital cost, slow payback and low return on investment. The retrofits were confirmed or predicted through energy audit and monitoring i.e. predict fuel consumption, cost and type of retrofit and post retrofit performance. In the states it was found that 90% of the retrofitted buildings resulted in a pay back in energy savings in 3 years. Once the local retrofits are identified it will be important to verify these figures for our situation.
Part of this research involves a local survey of a typical urban area in an attempt to map design and construction of the low cost housing stock. The following parameters will form part of the survey:

6.1 Types of energy sources that are commonly used in low cost housing of Botswana
6.2 The reasons for choosing certain forms of energy and appliances for the various uses such as cooking: Is it for efficiency, cost, availability, durability, safety, quality, more than one use, renewable etc.
6.3 The different types of building stock will be investigated for considerations of energy efficiency and general overview of building condition.
6.4 Typical energy (& water) use patterns for different kinds of households in Botswana:

6.5 The types of materials used for the building envelope

Lifecycle costing will be used to get the sense of what the real costs are for the different uses in the home. The proposed formula to be used is, Initial energy cost + initial appliance cost + regular energy cost +appliance maintenance cost + other regular costs = total lifecycle cost

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