# A REVIEW OF PASSIVE THERMAL COMFORT ENERGY EFFICIENCY INTERVENTIONS IN RESIDENTIAL BUILDINGS OF BLOEMFONTEIN

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## ABSTRACT

The paper presents a critique of passive and active thermal comfort strategies. Extensive review of literature on passive thermal comfort energy efficiency interventions and their benefits was under taken. The paper explains the correlation between climatic comfort and energy efficiency. The applicability of the energy management process in ensuring energy efficiency is presented. Passive thermal comfort energy efficiency interventions have been seen to provide thermal comfort as well as energy efficiency. Their major shortcoming is their disability to work in all kinds of weather, heating in the winter and cooling in the summer. There is need to optimize passive thermal comfort energy efficiency interventions so that they provide heating in the winter and cooling in the summer.

**Key words:** Passive comfort energy efficiency, Energy and Buildings

## 1. INTRODUCTION

People spend a large part of their daily life indoors. It is therefore necessary for buildings to provide pleasant indoor thermal comfort conditions. The challenge for engineers is to provide occupants with comfortable indoor environment while keeping energy cost at a low level.

Heating, ventilating and air conditioning (HVAC) systems are major components of buildings. Their purpose is to provide occupants with good air quality and comfortable thermal environment. Thermal characteristics of building envelope have significant influence on (HVAC) systems. The envelope thermal characteristics affect both HVAC equipment capacity and energy required for their operation. The building envelope comprises walls, roof, doors and floors. The envelope provides a path for heat flow between the interior and exterior environment.

Passive thermal comfort energy efficiency interventions Improves household energy efficiency which benefits residents and the economy. It brings financial and environmental rewards and improves the health and well being of residents. The major proportion of environmental impact of residential building is due to the energy consumption for space heating and cooling (Shar et al, 2008). Yilmaz and Kundakci (2006) in their recent research paper found that parallel to the population growth in the world, the energy demand is increasing and countries are searching for new methods of energy conservation.

They go on to say that consumption of energy is mostly of fossil origin and causes environmental problems and troubles in ecological cycles. (Poel et al, 2006) states that European Union (EU) member states are working intensively to improve energy efficiency in all end-use sectors by increasing the exploitation of renewable energy sources (RES) in order to tackle environmental concerns deriving from energy consumption of fossil fuels and to support self-sufficiency and energy security. They go further to explain that energy efficiency plays key role in meeting the EU target in accordance to the Kyoto Protocol commitments to reduce carbon dioxide emissions in an economic way.

Research by Pasupathy et al (2007) indicates that passive energy provides a valuable solution for correcting the mismatch between the supply and demand of energy. Lee and Chen (2008) suggest that buildings being the dominant energy consumers in modern cities, they present a unique opportunity of cutting back of energy consumption through improvement of energy efficiency.

Draft Energy Efficiency Strategy of the Republic of South Africa (2004) reports that energy efficiency reduces atmospheric emission of harmful substances such as oxides of sulphur, oxides of nitrogen and smoke. Such substances are known to have an adverse effect on health and are frequently a primary cause of common respiratory ailments. Energy efficient homes not only improve occupant health and wellbeing, but also enable adequate provision of energy services to community at an affordable cost.

Literature suggests that houses in South Africa are characterized by poor craftsmanship and design with no regard to passive thermal comfort energy efficient features Lombard et al (1999). This results in uncomfortable indoor thermal environment which leads to high electrical energy consumption from HVAC systems. Residential demand side management aims to improve electricity use in residences by promoting energy efficiency. From the electricity supply point of view, space heating presents a particular problem in South Africa. The situation will rapidly deteriorate further in the near future, as a result of the massive housing construction drive by the South African Government and the coincident electricity FOR all campaign. Electricity suppliers and the government are interested in electrical energy savings, so that capital expenditure on new generating equipment can be postponed and also minimize the impact on the environment. South African residential consumers, on the other hand see affordable electricity as a requirement for an improvement in standard of living. The problem is exacerbated by the mildness of the South African climate, which allows houses to be built with utter disregard to thermal response considerations. The fact that the heating season is relatively short makes the adoption of adhoc space heating measures popular.

## 2. PASSIVE THERMAL COMFORT ENERGY EFFICIENCY STRATEGIES IN RESIDENTIAL AREAS

### 2.1 Passive energy systems compared to active energy systems.

(Balcomb, 2006) differentiates passive systems from active systems as follows:

| Passive energy systems | Active energy systems |
|---|---|
| Passive systems rely on natural processes of heat collection, conduction and convection.<br>Passive systems integrate the system into the architecture of the building.<br>Passive systems entail the use of normal building materials e.g. glass, doorways and insulation. | Active systems rely on pumps and controllers, which eventually need to be repaired.<br>Active systems add new systems to the outside and inside.<br>Active systems entail novel controls and devices not easily replaced at the local builder supply. |

**Table 2.1 passive systems compared to active systems.**

Passive energy efficiency helps in many areas such as the following:

- *Decreasing pollution and getting clean energy*

The major proportion of environmental impact of residential building is due to the energy consumption for space heating and cooling (Shar et al, 2008). Yilmaz and Kundakci (2006) in their recent research paper found that parallel to the population growth in the world, the energy demand is increasing and countries are searching for new methods of energy conservation. They go on to say that consumption of energy is mostly of fossil origin and causes environmental problems and troubles in ecological cycles. (Poel et al, 2006) states that European Union (EU) member states are working intensively to improve energy efficiency in all end-use sectors by increasing the exploitation of renewable energy sources (RES) in order to tackle environmental concerns deriving from energy consumption of fossil fuels and to support self-sufficiency and energy security. They go further to explain that energy efficiency plays key role in meeting the EU target in accordance to the Kyoto Protocol commitments to reduce carbon dioxide emissions in an economic way.

- *Reduce fossil fuel dependence*

Research by Pasupathy et al (2007) indicates that passive energy provides a valuable solution for correcting the mismatch between the supply and demand of energy. Lee and Chen (2008) suggest that buildings being the dominant energy consumers in modern cities, they present a unique opportunity of cutting back of energy consumption through improvement of energy efficiency.

- *Improve the health of the nation*

Draft Energy Efficiency Strategy of the Republic of South Africa (2004) reports that energy efficiency reduces atmospheric emission of harmful substances such as oxides of sulphur, oxides of nitrogen and smoke. Such substances are known to have an adverse effect on health and are frequently a primary cause of common respiratory ailments. Energy efficient homes not only improve occupant health and wellbeing, but also enable adequate provision of energy services to community at an affordable cost.

Although passive systems are simple, their execution involves subtle complexities. The system must work in all kinds of weather, heating in the winter and cooling in the summer (Balcomb, 2006). A report from United States' Department of Energy Electricity and Reliability (2006) reports that buildings using passive design principles do not have to cost more up front than conventionally designed buildings and when they do, the savings in energy bills quickly pay for themselves.

## 2.2 Thermal insulation

Thermal insulation is a material or combination of materials that retard the rate of heat flow by conduction, convection, and radiation. Thermal insulation retards heat flow into or out of a building due to thermal resistance (ASHRAE 2001). Thermal insulating materials resist heat flow as a result of the countless microscopic dead air-cells, which suppress (by preventing air from moving) convective heat transfer. It is the air entrapped within the insulation, which provides the thermal resistance, not the insulation material, Dr. Mohammad (2005).

Southern African Institute of Steel Construction (SAISC) reports that buildings are insulated against external temperature fluctuations to minimize required heating and cooling. In addition to heat from the sun and burning fuel, heat is also generated by people and use of electrical appliances (including lights).

Heat transfers through walls, windows, roof and floor of a building using a combination of radiation, conduction, and convection, and moves from higher temperature to lower temperature areas. In the summer, when it's warm outside, heat transfers through windows, exterior walls, roof, and the floor of a building to the inside. This process is referred to as heat gain. In the winter, the opposite will happen. Heat generated by heating systems moves through the building enclosure and is lost to the outside. This process is referred to as heat loss. In the summer, uncontrolled heat gain can cause the inside of the building to be uncomfortably warm, necessitating the use of appliances (fans and air conditioners) to cool the interior - resulting in higher electricity consumption and costs.

In the winter, when uncontrolled heat loss can make the building uncomfortably cold, heaters will be used, again resulting in higher electricity costs.

*Benefits of using thermal insulation*

Dr. Mohammad (2005), states that there are many benefits for using thermal insulation in buildings, which can be summarized as follows:

1. *A matter of principle:*

Using thermal insulation in buildings helps in reducing the reliance on mechanical/ electrical systems to operate buildings comfortably and, therefore, conserves energy and the associated natural resources. This matter of conserving natural resources is a common principle in all religions and human values.

2. *Economic benefits:*

An energy cost is an operating cost, and great energy savings can be achieved by using thermal insulation with little capital expenditure (only about 5% of the building construction cost). This does not only reduce operating cost, but also reduces HVAC equipment initial cost due to reduced equipment size required. In Russia (Matrosov and Butovsky, 1994) have done experiments and come to the conclusion that thermal insulation reduces energy consumption by 20-25% in residential buildings. (Zimmermann et al 2005) alludes that thermal insulation materials reduce heat losses from buildings and this results in energy and cost savings for air conditioning and heating during the building life time.

3. *Environmental benefits:*

The use of thermal insulation not only saves energy operating cost, but also results in environmental benefits as reliance upon mechanical means with the associated emitted pollutants are reduced. (Comakli and Yuksel) investigated environmental impact of thermal insulation and found out that carbon dioxide emissions were decreased by 50% when optimum insulation thickness was used in external walls of buildings.

4. *Customer satisfaction and national good:*

Increased use of thermal insulation in buildings will result in energy savings which will lead to:

I. Making energy available to others.
II. Decreased customer costs.
III. Fewer interruptions of energy services (better service).
IV. Reduction in the cost of installing new power generating plants required in meeting increased demands of electricity.
V. An extension of the life of finite energy resources.
VI. Conservation of resources for future generations.

5. *Thermally comfortable buildings:*

The use of thermal insulation in buildings does not only reduce the reliance upon mechanical air-conditioning systems, but also extends the periods of indoor thermal comfort especially in between seasons. (Holm and Van Aswegen, 1993) studied thermal performance of low- cost housing in South Africa. They found that the interior comfort in three informal houses was improved when dwellings were lined with insulation.

6. *Reduced noise levels:*

The use of thermal insulation can reduce disturbing noise from neighboring spaces or from outside. This will enhance the acoustical comfort of insulated buildings.

7. *Building structural integrity:*

High temperature changes may cause undesirable thermal movements, which could damage building structure and contents. Keeping buildings with minimum temperature fluctuations helps in preserving the integrity of building structures and contents. This can be achieved through the use of proper thermal insulation, which also helps in increasing the lifetime of building structures.

8. *Vapour condensation prevention:*

Proper design and installation of thermal insulation helps in preventing vapour condensation on building surfaces. However, care must be given to avoid adverse effects of damaging building structure, which can result from improper insulation material installation and/or poor design. Vapour barriers are usually used to prevent moisture penetration into low-temperature insulation.

9. *Fire protection:*

If suitable insulation material is selected and properly installed, it can help in retarding heat and preventing flame immigration into building in case of fire.

*Remarks*

Providing adequate insulation in the building envelope is critical for thermal comfort and energy efficiency. Thermal insulation materials in building walls and roofs is a tool that improves energy performance by reducing energy consumption and the associated burdens arising ,from combustion of fossil fuels Ardente et al (2008). (Akbari et al. 1997) states that thermal insulation is a measure that reduces energy consumption in all weather conditions i.e. reduce heat gains during day and block path of heat flow out of building when ambient temperature is lower than inside temperature. Insulation slows the rate of heat flow through the building enclosure. Insulation is defined by its R-value, which is the measure of a material's resistance to heat flow. The higher the R-value, the more resistant a material is to heat flow. The building enclosure should be insulated continuously without gaps.

This is not easy, as there are numerous openings in the building enclosure, such as for windows, doors, electrical outlets, plumbing pipes, and lighting fixtures. All gaps or openings need to be sealed to minimize uncontrolled air flow in and out of a building.

## 2.3 Thermal mass

Continuous changes in outdoor temperature and solar radiation pose challenges for maintaining thermal comfort for people in buildings. Passive and energy conserving buildings seek to manage available thermal energy by lowering peaks in order to maintain conditions for human comfort. Thermal mass is a tool that designers use to control temperature Bruce and Kurt (n.d). The mass of a building stores solar energy received by the building during the day and then gradually releases it overnight. When there is limited mass, there are huge day to night temperature fluctuations. A large thermal mass minimizes these fluctuations resulting in improved thermal comfort and energy savings Gregory et al (2008). Thermal mass provides significant benefit in shifting peak load conditions and reducing overall heat gain or loss, provided outside temperature is moderate. This allows reduced heating, ventilation and air conditioning (HVAC) system size that results in energy and cost savings.

Thermal mass is commonly used to signify ability of materials to store significant amount of thermal energy and delay heat transfer through building component. This delay leads to three important results:

i. Slower response time tends to moderate indoor temperature fluctuations under outdoor temperature swings Brandemuehl et al., (1990).
ii. In hot or cold climates, it reduces energy consumption in comparison to that for similar low-mass building Wilcox et al.
iii. It moves building energy demand to off-peak periods because energy storage is controlled through correct sizing of mass and interaction with HVAC system.

## 2.4 Reflective roofs

Reflective roofs are those roof surfaces that reduce flow of heat into the building by reflecting most of incident solar radiation during hot summer days Akbari et al. (1997). Reflective roofs absorb little insolation. Research by Akbari et al (2001) found that modern urban areas have dark roof surfaces. Dark roof surfaces heat up more, thus raise summertime cooling demands of buildings.

*Benefits of reflective roofs*

*Reduced energy consumption*

Several field studies have documented measured energy savings that result from increasing roof solar reflectance. Akbari et al (1993, 1997) monitored peak power and cooling energy savings from high reflective coatings on one house and found that seasonal savings of 2.2kWh/day and peak demand reductions of 0.6kW. (Parker et al 1995) monitored nine homes before and after applying high reflective coatings to their roofs. They found that air conditioning energy use was reduced by 10-43% with average savings of 7.4kW/day (savings of 19%). Peak demand between 5 and 6 p.m. was reduced by 0.2-1 with an average reduction of 0.4kW (savings of 22%).

*Extended roof life*

According to Akbari et al (2001), expansion and contraction of a light colored roof is smaller than that of a dark one. For this reason reflective roofs last longer than dark roofs of the same material.

*Economic benefits*

(Akbari et al 2001) states that using high reflective roofs is inexpensive and has short pay back time. (Akbari et al. 1997) found that roof insulation can be saved by increasing roof reflectivity. They found that in Phoenix (United States of America) roof system with a reflectivity of 10% and ceiling insulation of R-30 has equivalent annual energy performance of a roof system with reflectivity of 50% and ceiling insulation of R-14, that is over 50% savings in required R-value of the insulation.

*Potential problems of reflective roofs*

(Bretz and Akbari 1994, 1997) found that increased reflectivity in many roofs in a city has potential to create glare and visual discomfort if not kept to a reasonable level. Extreme glare could possibly increase traffic accidence.

## 2.5 Shade trees

Shade trees intercept sunlight before it warms a building. Shade trees offer significant benefits by both reducing building air conditioning, lowering air temperature thus improving urban air quality by reducing smog (Akbari et al 2001).

*Benefits of using shade trees*

During the daytime cooling seasons trees and vegetation reduce air conditioning loads through several processes which are mentioned below:

1. *Reduced energy consumption*

Data on measured energy savings from trees is scarce Akbari et al (1997). In one experiment, (Parker 1981) measured the cooling energy consumption of a temporary building in Florida before and after adding trees and shrubs, and found cooling electricity savings of up to 50%. Akbari et al (1997) monitored peak power and cooling energy savings from shade trees in two houses and found out cooling energy savings of 30%, corresponding to average savings of 3.6 and 4.8 kW/day. Peak demand savings for the same houses were 0.6 and 0.8 kW (about 27% savings in one house and 42% in another).

2. *Mitigate urban heat islands*

Evapotranspiration refers to evaporation of water from vegetation and surrounding soils. On hot summer days a tree can act as a natural cooler using up to 100 gallons of water a day thus lowering ambient temperature (Kramer and Kozlowski, 1960). The effect of evapotranspiration is minimal in winter because of the absence of leaves on deciduous trees and lower ambient temperatures. Increased evapotranspiration during summer from trees produces an oasis effect in which the urban ambient temperatures are significantly lowered. Buildings in such cooler environments will consume less cooling power and energy. (Taha et al 1996) estimated the impact on ambient temperature resulting from large scale tree planting and found that on average trees can cool down cities by about 0.3-1°C. (Goodridge 1987, 1989) showed that when built-up areas replaced vegetation, urban centers became warm.

3. *Provides shading of building*

(Akbari 2002) explains that trees block unwanted solar radiation from striking building and this reduces cooling energy use. Shading of buildings can increase heating energy use during winter but however deciduous trees are beneficial since they allow solar gain in buildings during winter while blocking it during summer. Shade cast by trees reduces glare. According to United States' organization of Cool Communities, three well placed trees around homes can provide shade that will lower cooling costs by 10-50%.

4. *Wind shielding*

Trees act as wind breaks which lower ambient wind speed. In addition to energy saving potentials, this improves comfort conditions. (Akbari 2002) states that through wind shielding, trees affect a building's energy balance in three ways:

i. Lowering wind speed on a building shell result to slower dissipation of heat from sunlit surfaces. This in turn produces higher sunlit surface temperatures and more heat gain through building shell.

ii. Lower wind speed results in lower air infiltration into buildings. The reduction in infiltration has major impact on reducing cooling energy requirements especially for old and leaky houses.

iii. Lower wind speed increases the effectiveness of open windows during summer, resulting in increased reliance on natural cooling.

DeWalle et al (1981) used mobile homes to measure the wind breaking effects of trees on energy use. In a follow-up experiment, Heisler (1989) measured the effect of trees on wind and solar radiation in a residential neighborhood. (Huang et al. 1990) used the data provided by Heisler and simulated the impact of wind speed reduction on residential buildings heating and cooling energy use. Their simulations indicated that a reduction in infiltration because of trees would save heating energy use. Similar simulations by Akbari and Taha (1992) estimated heating energy savings in the range of 10-15%.

*5. Air pollution reduction*

Urban trees affect air pollution through two major processes: (1) cooling of the ambient temperature slowing smog formation process. (2) dry deposition by which airborne pollutants (both gaseous and particles) are removed from air. Trees directly remove pollutant gases (carbon monoxide, oxides of nitrogen, sulphur dioxide) through leaf stomata (Smith, 1994; Fowler, 1985). (Nowak 1994) performed an analysis of pollutant removal by urban trees in Chicago and concluded that through dry deposition; trees on average remove about 0.002% (0.34 g/m2/year) of carbon monoxide, 0.8% (1.24g/m2/year) of nitrogen dioxide, 0.3% (1.09g/m2/year) of sulphur dioxide from air.

*6. Other benefits*

Other benefits associated with urban trees include improvement in quality of life, increased value of properties, decreased rain run off water and hence protection against floods (McPherson et al 1994). Trees directly take in atmospheric carbon dioxide. (Rosenfeld et al 1998) estimated that the direct intake of carbon dioxide is less than one quarter of the emission reduction resulting from savings in cooling energy use.

*Potential problems of shade trees*

Potential problems of trees were studied by (Benjamin et al 1996). They found out that some trees emit volatile organic compounds that exacerbate the smog problem. In dry climates and areas with serious water shortages drought resistant trees are recommended. Some plants need significant maintenance that may entail high cost over the life of the trees. Tree roots can damage underground pipes, pavements and foundations. Proper design is needed to minimise these effects.

Also trees are a fuel source for fire, selection of appropriate tree species and planting them strategically to minimise the fire hazard should be an integral component of tree planting programme.

*Remarks*

Urban trees provide a range of services for residents that can influence the quality of the environment. As illustrated trees in the Chicago area (United States of America) can moderate local climate and reduce building energy use (Akbari et al. 1992), improve air quality (McPherson and Nowak 1993), and sequester and avoid carbon dioxide (Nowak 1993, Rowntree and Nowak 1991). Other studies have found that urban forests reduce storm water runoff (Lormand 1988; Sanders 1986), increase property values (Anderson and Cordell 1988), and provide a connection to nature, relaxation, or spiritual joy (Dwyer et al. 1992). Quantifying the value of these and other benefits and the costs associated with urban trees can assist planners and managers optimize their return on investment. Additionally, tree planting and care are the least expensive ways to slow build-up of carbon dioxide, since trees absorb carbon dioxide and release oxygen.

## 2.6 Green roofs

Earth pledge foundation, (2002) defines green roof as lightweight, engineered roofing system that allows for propagation of rooftop vegetation while protecting the integrity of the underlying roof. Becker et al, (2003) defines a green roof as that roof which purposely has plants growing on it.

*History of green roofs*

Becker et al, (2003) alludes that green roofs have been in use for long time. Green roofed structures in Ireland date back at least five thousand years. Ancient Mesopotamians are said to have been using green roofs for at least this long as well. In Norway, grass covered roofs have been used for hundreds of years as a form of insulation. Thus in this respect, green roofs is not a new idea, but rather an ancient technology that has a number of applications for modern buildings.

The process of heat transfer into the planted roof is different when compared to conventional bare roof of a building. Solar radiation, external temperature and relative humidity are reduced as they pass through plants that covers roof. The plants with biological functions, such as photosynthesis, respiration, transpiration and evaporation absorb significant proportion of solar radiation Kruche et al (1982).

*Benefits of using green roofs*

The presents of green roof on a building can be seen to have a number of benefits both inside and outside. Traditional roof construction methods and designs typically do nothing to reduce storm water runoff from a building's roof, or to reduce a building's heat gain through the roof during warm seasons. Green roof technology has demonstrated a positive effect on these as well as other factors, Becker et al, (2003). Becker et al, (2003) lists the benefits of using green roofs as follows:

1. *Reduction of storm water runoff*

Green roofs reduce storm water runoff so there is less water directed into storm drains. A green roof can reduce storm water run off by collecting storm water by the plants' roots as well as through evaporation and transpiration performed by the green roof's components.

2. *Temperature reduction*

Green roof technology can reduce roof temperatures during warmer seasons as compared with conventional roof designs. The evaporation and transpiration that is facilitated through green roof technology causes the sun's heat to be re-radiated efficiently, thus reducing temperatures in and near the green roof (Beattie, 2003).

3. *Extended roof life*

Temperature reduction by green roof technology increases the lifetime of a roof (W.P. Hickman Systems, Inc., 2003). The expected lifetime of a conventional roof is a factor of wide and rapid temperature swings of roofing materials (Beattie, 2003). Beattie, 2003 explains that this phenomenon occurs during warmer seasons, when direct sun exposure causes conventional roof materials to reach temperatures greater than one hundred forty five degrees Fahrenheit during day and alternatively cycle back towards cooler temperatures while radiating heat during the night. (W.P. Hickman Systems, Inc., 2003) explains that under such strain, conventional flat roofs will last for five to twenty years depending on number and type of layers. Green roofs provide a smoothing effect on these temperature swings by reducing roof temperature during the day and thus lengthening lifetime of the roof (Beattie, 2003).

4. *Energy conservation*

The vegetation layer help insulate a building's interior. This reduces the amount of energy required to keep the building warm (Solar Design Strategies presentation at UVM, 2003).

*5. Carbon Sequestration*

Stored carbon is dumped into the atmosphere every day through the exploitation of fossil fuels. The resultant of this phenomenon is global warming. The carbon sequestration inherent in a green roof is a step in mitigating this challenge (Becker, 2003).

*Remarks*

Green roof technology has much to offer to building's occupants and image. Building temperatures are beneficially affected during all seasons through the cooling effects of plants, and insulating effects of the plant media. Roof maintenance and replacement is less frequent due to temperature mediating properties of plants. The reductions in energy consumption and storm water runoff that result from installation of green roof are steps in the direction of curbing overall environmental impact of human population. (Ferrante and Mihalakakou 2001) and (Akbari et al 1997) agree that plants mitigate green house effect, filter pollutants, mask noise, and prevent erosion and calm human observers.

## 3. CLIMATIC COMFORT AND ENERGY EFFICIENCY IN BUILDINGS

Climatic comfort conditions in buildings are important because they make occupants feel comfortable and decide on building's energy consumption Nicol and Humphreys (2002). The envelope thermal characteristics affect both HVAC equipment capacity and energy required for their operation. The challenge for engineers is to provide occupants with comfortable indoor environment while keeping energy cost at a low level. Current designing of buildings does not cater for both comfortable indoor environment and energy efficiency Nicol and Humphreys (2002). Thus buildings today are not sustainable.

Humphreys, (1979) investigated thermal comfort of the human body and defines it as that temperature at which a person feels thermally neutral. Using available data from more than thirty comfort surveys from the world, Humphreys, (1979) proposed a series of correlations for thermal comfort prediction. Humphreys, (1979) showed that 95% of the neutral temperature is associated with the variation of outdoor mean temperature. De Dear and Brager, (2002) found similar results. Humphreys and Nicol, (1998) states that for free running buildings, i.e. not heated or cooled, the regression equation is approximated by:

Nicol and Humphreys (2002) lists variables which influence thermal comfort as temperature, air velocity and humidity. Air temperature and relative humidity have significant impact on thermal comfort. Data from South African building manual, (2005), indicates that relative humidity below 30% cause dry skin, eye irritation and respiratory problems.

Relative humidity above 60% provides an environment conducive to the growth of mold, mildew and dust mites that cause allergic reactions. The South African Residential Building Code (SABC) recommends indoor temperature range of 16-28°C and relative humidity range of 30-60%.

People are not passive in relation to their environment. If a change occurs such as to produce discomfort, they react in ways which tend to restore their comfort, Humphreys (1975) and Auliciems (1981). The adaptive opportunity as described by Baker and Standeven (1996) may be provided by fans or openable windows in summertime or by temperature controls in winter.

Energy efficiency measures are meant to reduce the amount of energy consumed while maintaining or improving the quality of services provided in the building. A report published by United States Department of Energy Solar Building Program states that the main reasons to, building passive climatic comfort energy efficient houses, is as follows:

i. The house uses significantly less energy than a conventional home without energy saving features; consequently it costs less to operate. Reducing building's heating and cooling needs means lower monthly utility bills.
ii. Passive house is more comfortable than a conventional home. Tight construction, improved windows, interior air flow, passive solar gains and proper shading create a comfortable in door environment.
iii. It is more marketable and will have high resale value. Energy performance remains the most important homebuyer considerations in many countries.

Barriers to energy efficiency in buildings

A report published by the International Energy Agency (IEA) (1997) reports that builders and energy consumers lack information on updated and reliable information regarding energy efficient technologies and the associated costs and benefits. Consumers do not have information on the cost of operating equipment they purchase over its lifetime. They often prefer an appliance with low initial cost irrespective of its energy efficiency. The cost of gathering information and evaluating options in order to make the right decision may be troublesome for end users to adopt.

Most project developers are wary of unfamiliar and innovative designs because they fear that such options will slow down the construction process and increase costs. They fear that any change in regular practice is risky and assume that energy efficient solutions lead to higher costs, greater risks and delays. They want to avoid delays in the completion of the project and any loss in revenue due to delayed occupancy IEA (1997).

Beggs (2002) supports this view and alludes that building designers do not pay energy bills therefore they usually select low capital cost solutions, which often result in higher operating costs.

Energy consumption is taken for granted. Most building occupants and users do not pay energy bills. They are concerned with their own personal comfort and are not particularly interested in how much energy is consumed in achieving a comfortable environment. Most organisations do not have a culture of energy efficiency Beggs (2002).

Policy options for overcoming barriers to energy efficiency

Regulations and legislation

IEA (1997) reports that energy efficiency regulations are important and effective means for national programme aimed at conserving energy. Performance standards can be prescribed to encourage awareness of the importance of energy conscious building design and to provide certain degree of control over building construction and operating practices. If building codes prescribe a minimum level of such practices, builders will focus on the most cost effective way to comply instead of dismissing them as an added cost.

South Africa Energy Policy

South Africa's Department of Minerals and Energy's energy policy contains five key policy objectives (DME, 1998, p.8). These policies form the drivers for increasing access to affordable energy. The policy objectives are outlined below:

i. Increasing access to affordable energy services: government will promote access to affordable energy services for disadvantaged households, small businesses, small farms and community services.
ii. Improving energy governance: stake holders will be consulted in the formulation and implementation of new energy policies.
iii. Stimulating economic development: government encourages energy prices to be as cost reflective as possible.
iv. Managing energy related environmental and health impacts: government will work towards the establishment and acceptance of broad national targets for the reduction of energy related emissions that are harmful to the environment and to human health and will ensure a balance between exploiting fossil fuels and maintenance of acceptable environmental requirements.
v. Securing supply through diversity: government will pursue energy security by encouraging a diversity of both supply sources and primary energy carriers.

The above energy policy clearly alludes to affordable energy for everyone, diversity in terms of supply sources and environmentally friendly energy supply and usage. South Africa has signed the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. These two agreements primarily focus on environmental friendliness and sustainability of energy sources.

## 3.1 Energy management versus energy efficiency

Both energy management and energy efficiency aim at using less energy in a particular application. Southern African Development Community (SADC) Energy Management Project (1994) alludes that energy management process enables best and most cost effective energy efficiency measures to be selected and implemented in proper order. The energy management process also enables energy efficiency results to be monitored thus providing feed back for improving energy consumption. Useful service life of operating systems is extended in addition to facility operating at optimum energy efficiency lowering total operating cost. SADC Energy Management Project (1999) reviews four major steps which are involved in the energy management process.

### Energy data analysis

The energy data analysis involves reviewing energy bills on a monthly and annual basis and comparing them to the previous reference year. In addition, energy use indices (EUI) can be calculated from the collected data such as energy intensity per unit of production (GJ/tonne) or energy intensity per area of floor space ($MJ/m^2$).

### Energy audit

United States of America's Department of Defense Energy Manager's Handbook, (2005), states that energy audits evaluate current energy usage and determine how to reduce energy use and cost. United State of America's Department of Transport Civil Engineering Facilities Energy Manual, define an energy audit as a study that identifies all energy sources i.e. electricity, oil, natural gas, steam etc. The report goes on to explain that an energy audit quantify energy use and costs according to discrete functions such as heating, lighting, air conditioning etc. Energy audits also identify energy conservation opportunities and quantify energy and cost savings potential. (Energy Star, 2006) identifies two types of energy audits which are walk through and detailed energy audit.

Walk through Audit

Walk through audit involves tour of facility with checklist and considering a number of energy efficiency ideas.

A brief review of utility bills is done. Walk through of the facility is done to become familiar with the building operations and identifying glaring areas of energy waste. Bills for a period ranging from 12 to 36 months are collected so that the auditor can evaluate the facility's energy demand rate structure and energy usage profile. Major problem areas are identified. Corrective measures are briefly described and quick estimates of implementation and operational saving costs are noted down. However this level of detail is not sufficient for reaching the final decision on implementation (Energy star, 2006).

Detailed Audit

Detailed audit is a technical analysis and expands on the walk through energy audit by providing a dynamic model of energy usage characteristics for both existing and new energy conservation methods identified (Energy star, 2006). Computer software simulation is used to predict building system performance and the goal is to build a base that is consistent with actual energy use of the facility. The auditor makes changes to improve efficiency of various systems and measure the effects compared to the baseline. A detailed energy audit is done to determine how much energy the processes and equipment are consuming. Detailed energy audits are not done very often because:

I. The equipment for measuring is expensive and recording data is time consuming.
II. Energy management programs can be conducted without them (most managers have an idea of where energy is going without conducting these audits)

**Implementation**

Implementation involves identifying organizations that are responsible for implementing recommended measures identified through the energy audit. The implementation plan is phased over a number of years. Generally no-cost and low-cost measures are undertaken first as these represent rapid paybacks and the savings generated can be used to finance more costly measures.

**Monitoring**

Clarifies what was done, how much was saved and whether the savings met expectations or not. Monitoring an energy management process is essential in order to measure results and to steer the programme with progressive feedback. The simplest monitoring technique involves daily review of energy use data against the driver for energy consumption to spot any sudden deviation from the normal consumption patterns and to take corrective action where necessary.

Remarks

Energy management is much more than simply carrying out an energy study or audit of building. Energy audits are useful in gaining appreciation of where major energy losses are and what kind of solutions is required. To reduce these losses significantly and guarantee that the solutions are permanent, energy managers must go beyond and establish an ongoing energy management process in buildings.

## 4. CONCLUSIONS

Passive thermal comfort energy efficiency interventions have been seen to provide occupants with thermal comfort as well as improve energy efficiency of HVAC systems. Their major shortcoming is their disability to work in all kinds of weather, heating in the winter and cooling in the summer. There is need to optimize passive thermal comfort energy efficiency interventions so that they provide heating in the winter and cooling in the summer.

## 5. REFERENCES

Akbari H., Bretz S., Taha H., Kurn D. and Hanford J. 1997. Peak power and cooling energy savings of high-albedoroofs. Energy and Buildings-Special Issue on Urban Heat Islands and Cool Communities Vol. 25, No. 2, pp. 117126.

Akbari, H., Pomerantz, M., Taha, H., 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar energy , Vol. 70, No. 3, pp. 295-310.

American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). Handbook of Fundamentals, Atlanta, GA, USA, 2001 [Chapter 23].

Comakli K, Yuksel B, 2004. Environmental impact of thermal insulation thickness in buildings. Applied Thermal Engineering, Vol. 24, No.2, pp.3340.

DeWalle, D.R., Heisler, G.M. and Jacobs, R.E. Forest home sites influence heating and cooling energy, J. Forestry, 81 (1981) 84. Department of Minerals and Energy, 1998. White paper on the energy policy of the republic of South Africa, [online], Available at http://www.dme.gov.za/pdfs/energyplanning/wpenergypolicy1998.pdf [accessed 10 April 2008]

Douglas, J.B., 2006. Passive Solar Come Back Ahead: why the hot building technology of the future may be the mature and proven one, [online], Available at: http://www.solartoday.org/2006/septoct06/passivesolarcbs006 [accessed 10 April 2008]

Golden Makakaa,, Edson L. Meyerb, Michael McPhersona Thermal behaviour and ventilation efficiency of a low-cost passive solar energy efficient house Renewable Energy 33 (2008) 19591973

Humphreys MA, Nicol JF. Understanding the adaptive approach to thermal comfort. ASHRAE Trans 1998;104(1):9911004.

Humphreys MA. Field studies of thermal comfort compared and applied. J Inst Heat Vent Eng 1975;44:527.

Humphreys MA. The influence of season and ambient temperature on human clothing behaviour. In: Fanger PO, Valbjorn O, editors. Indoor climate. Copenhagen: Danish Building Research; 1979.

Lee, W., Chen, H., 2008. Benchmarking Hong Kong and China energy codes for residential buildings. Energy and Buildings.

Pasupathy, A., Athanasius, L., Velraj, R., Seeniraj, R., 2008. Experimental investigation and numerical simulation analysis on the thermal performance of a building roof incorporating phase change material (PCM) for thermal management. Applied Thermal Engineering, Vol 28, pp.556-565.

Poel, B., Van Cruchten, G., Balaras, C., 2007. Energy performance assessment of existing dwellings. Energy and Buildings, Vol 39, pp.393-403.

SADIC industrial energy management project, (1994), Seven Steps to energy management awareness.

Yilmaz, Z., Kundakci, A., 2008. An approach for energy conscious renovation of residential buildings in Istanbul by trombe wall system. Building and Environment,Vol 43 , pp.508-517.

Zimmermann, M., Althaus, H., Haas, J., 2005. Benchmarks for sustainable construction. A contribution to develop a standard, Energy and buildings Vol. 37, No. 11, pp. 1147-1157.