NEW STANDARDS OF THERMAL DESIGN
TO PROVIDE COMFORT AND ENERGY EFFICIENCY
IN SOUTH AFRICAN HOUSING

H.C.HARRIS B.Sc. C.A.(S.A)

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Promoter: Professor E.H.Mathews

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ABSTRACT

The fundamental objective of this thesis is to determine whether the requirements for thermal comfort in housing in South Africa will provide for the necessary levels of energy efficiency. The effectiveness of various thermal design measures in achieving improvements in energy efficiency is evaluated. These measures are developed into a proposed energy efficiency standard. An estimate is made of the reduction in greenhouse gases which might result from the implementation of such a standard. This may constitute a project which might be accredited and traded in terms of United Nations protocols.

Electrical energy consumption in South Africa continues to grow at a rate which may necessitate that new generating capacity is on stream by 2007. It is shown that improvements in the energy efficiency of upper income houses will reduce the demand for electricity during peak hours. It is proposed that the progression of shack dwelling families to energy efficient formal housing, in conjunction with an appliance switch to more fuel efficient energy sources, will generate reductions in non-renewable coal and wood based fuel burning. As a result less localized air pollution will probably occur.

In this study three types of house are analysed for their thermal comfort in hot and cold conditions. The energy efficiency and the affordability of heating these houses in winter is also investigated. The climatic variations between the regions of South Africa have been analysed in terms of the local thermal neutrality and indoor heating and cooling requirements. Criteria for measurement of comfort requirements and energy efficiency are developed. The ability of various thermal design measures necessary to effect thermal comfort and energy efficiency, has been analysed using the Building Toolbox software. The objective of the simulations was to maintain internal temperatures within the confines of local thermal neutrality with a minimum of heating. This methodology has given rise to the proposed intervention standards.

The proposed standards and range of compliance methods will allow designers a high degree of flexibility. Architects will be able to make use of thermal mass, thermal insulation/resistance, variations in window size, etc. to achieve the required levels of energy efficiency. One proposed method of compliance check will be the so called Star Rating System. If properly promoted, the Star Rating System could lead to energy efficiency becoming an important attribute in the housing resale market. The results of an opinion survey among the members of the Thermal Insulation Association of South Africa (TIASA) indicated a high degree of consensus around the proposals. Comparison with the energy codes of foreign jurisdictions shows the proposals to be conservative. Given that power generating capacity will need to be expanded, it must be expected that electrical costs will escalate. This will effectively make such energy efficiency measures cheaper.

In conclusion, it has been demonstrated that substantial reductions in carbon based energy consumption will take place if energy efficiency targets are to be built into the South African National Building Regulations. The standards which are proposed in this thesis will also bring about improvements in thermal comfort, productivity and the well-being of the entire community.

OPSOMMING

Die doel van hierdie studie is om te bevestig dat die vereisters vir termiese behaaglikheid in Suid Afrikaanse huise tot die nodige energie doeltreffendheid sal lei. 'n Ondersoek is gedoen om te bewys hoe verskillende termiese ontwerpe, energie effektiwiteit sal verbeter.
'n Skatting is gemaak van die vermindering in koolstof gas produksie wat deur die Verenigde Nasies se program goedgekeur sal kan word.

Daar is gevind dat die elektriese energie verbruik nog steeds styg en veroorsaak dat nuwe kragstasies voor 2007 in Suid Afrika klaar opgerig moet word. Dit is bewys dat middel en hoër inkomste huise, gedurende spitstye, met verbetering van huishoudelike energie effektiwiteit, minder elektrisiteit sal gebruik. Nog voordele van hierdie verbeteringe is dat minder hout en steenkool deur laer inkomste (informele behuising) families gebruik sal word. Dit sal gebeur wanneer bestande toeristing vervang word met elektriese of gas toeristing vir huishoudelike verhitting, in 'n nuwe energie effektiewe huise. Minder koolstof sal dus geproduseer word en minder lugbesoedeling sal voorkom.

In hierdie studie is die termiese behaaglikheid, energie doeltreffendheid, en die bekostigbaarheid van verhitting van drie tipes huise in somer en winter toestande ondersoek. Die klimaat verskil tussen Suid Afrikaanse streke is bestudeer in terme van plaaslike termiese neutraliteit, sowel as winter verhitting en somer verkoelings vereistes. Die maatstawwe van termiese doeltreffendheid is ontwikkel. Die efektiwiteit van verskillende aspekte van termiese ontwerp is geanaliseer met die 'Building Toolbox' sagteware. Die doel is om die binne lug temperature tussen die beperkings van lokale termiese neutraliteit met minimale verhitting te behou. Dit het tot die voorgestelde aanbevelings en energie effektiwiteits standaarde gelei.

Die voorgestelde standaarde en metodes gee ontwerpers baie vryheid met hulle ontwerpe. Dit sal vir argitekte die opsie gee om gebruik te maak van termiese massa, verskillende boumateriale, vlakke van termiese insulasie, venster grotes ens. om die energie effektiwiteit vlakke te beruik. Een voorgestelde metode van evaluering van die standaard is die Ster Gradering ('Star Rating') stelsel. Indien korrek toegepas, sal die stelsel verseker dat die konsep van energie efektiwiteit 'n belangrike aspek in die tweedehandse eiendomsmaak word.

Die resultate van die opname tussen die lede van TIASA (Thermal Insulation Association of South Africa) dui aan dat die meeste lede met die voorstelle saamstem. Die vergelyking tussen ander lande se energie kodes en hierdie voorstell dui daarop dat die voorstelle konservatief is. Die huidige lae koste van elektrisiteit sal in die toekoms weens uitgawes op nuwe kragstasies, moet styg. Gevolglik sal energie effektiwiteit meer noodsaaklik word.

Ten slotte, blyk dit dat groot verminderings van energie verbruik kan plaasvind, as energie doeltreffendheid in the nasionale bouregulasies vereis word. As die standaarde wat in hierdie tesis ontwikkel is, in die wet vervat word, sal dit tot verbetering in termiese behaaglikheid, produktiwiteit en tot die gesondheid van die algemene bevolking lei.

NOMENCLATURE

The following abbreviations for terms are used:

% P.C.	percentage persons comfortable
E.T.	effective temperature (temperature modified for humidity)
GWh	gigawatt hours (standard unit of electrical consumption x10^6)
°K	absolute temperature [degrees Kelvin]
kWh	kilowatt hours (standard unit of electrical consumption)
L.P.P.C	lowest percentage persons comfortable
p.p.m.	parts per million
R-value	thermal resistance [m^2°C/W]
T_n	thermal neutrality
U-value	thermal transmittance [W/m^2°C]

The following abbreviations may not be specifically detailed

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
CDM	Clean Development Mechanisms
CO_2	carbon dioxide
DSM	Demand Side Management
DME	Department of Minerals and Energy
EPS	expanded polystyrene (foam)
GHG	greenhouse gases
HDD	heating degree days
IECC	International Energy Conservation Code
NDoH	National Department of Housing
NER	National Electricity Regulator
NHBRC	National Home Building Registration Council
NPV	net present value
SAEDES	South African energy and demand efficiency standard
TIASA	Thermal Insulation Association of South Africa
UNFCCC	United Nations Framework Convention on Climate Change
XPS	extruded polystyrene (foam)

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Chapter One

INTRODUCTION AND OVERVIEW

1.1. The need for this research

In order for appropriate housing policy decisions to be taken with regard to energy efficiency, and for legislation, regulations and specifications to be drawn up, the architects of these measures need to be informed as to the effect of suitable thermal design measures.

These measures include the levels of thermal resistance required to achieve acceptable percentages of persons comfortable (% PC) and the resultant necessary energy efficiency. This data is developed for all the major Southern African climatic regions, or population centres, in a format which the Thermal Insulation Association of South Africa (TIASA) can advance for incorporation into a national standard.

Through the United Nations Framework Convention on Climate Change (UNFCCC) multilateral protocols have been negotiated which have as their objective the reduction of global emissions. Projects which reduce such emissions are tradable in terms of the Clean Development Mechanisms (CDM). The World Bank is currently advancing such a project in South Africa, based on emission reductions achievable by way of energy efficiency in low-cost housing.

Due in part to the high levels of coal consumption in South Africa, and also due to the low level of thermal efficiency of South African housing stock and present low standards required in terms of building regulations, the furtherance of the energy efficiency of housing in South Africa may present an opportunity for such a CDM project in South Africa. The TIASA submission to the World Bank was in part be based on this research project.

1.2 Research goals and hypotheses

The first goal of this proposal is the development of suitable standards of comfort and therefore thermal efficiency, for all major climatic regions of South Africa such as may be suitable for incorporation into the building regulations and specifications for housing.

The second goal is to develop the above such as to assist TIASA in promoting a greenhouse gas reduction (CDM) project with the World Bank.

The following hypotheses are advanced:

i. The internal temperature environment of housing stock in South Africa can be significantly improved in terms of comfort and health with the application of higher energy efficiency norms in the building regulations.

ii The improvement of energy efficiency in South African housing may contribute to a significant reduction in greenhouse gas emissions.

1.3 Research methodologies used

1.3.1 Literature review

A literature study in Chapter Two, reveals an energy efficiency problem exists in South African housing and buildings in general. This energy problem manifests in different ways for the various interest groups.

- The poor and under-housed, and occupants of poorly designed houses
- The South African National Department of Housing
- Electricity generators and the National Electricity Regulator
- Greenhouse gas emission protocol signatories

A solution to this multifaceted energy problem may be found, in part, in the improvement of energy efficiency in South African housing in general.

1.3.2 Establishing comfort criteria for housing in six climatic regions in South Africa

In Chapter Three the relationship between percentage persons comfortable (% PC) and temperature, as established in prior research, is reviewed.

The temperature requirements for thermal comfort (thermal neutrality) in both hot and cold conditions, for major climatic regions in South Africa, with adjustment for acclimatization, are assessed using the latest available techniques. An algorithm for % PC variation with temperature is developed which caters for acclimatization.

A rational basis for comfort standards in South Africa will be developed using the performance criteria established hereto.

1.3.3 Computer simulations to build an energy efficiency scale

In Chapter Four, it will be shown that it is possible to bring internal temperatures within the range of comfort neutrality in most South African climatic regions with appropriate thermal design measures. Modifications of the internal temperature environment can be achieved, which will reduce the amplitude ratio or thermal swing within the structure, with the appropriate thermal design measures. It is even possible to achieve a passive design, with very little heating.

1.3.3 Computer simulations to build an energy efficiency scale (continued)

The *'Building Toolbox/NewQuick'* program is used to simulate the internal air temperatures in standard low cost houses and larger middle income designs. This assessment will gauge the effect of various no cost and low cost thermal design measures to bring the structures within the range of thermal neutrality. An energy efficiency measure for the thermal performance of the structures is derived from these simulations.

This energy efficiency measure will be used to construct a Star Rating System which will enable the rating of houses from an extreme of inefficiency through to an energy efficient passive design. An acceptable standard for energy efficiency will be recommended.

1.3.4 The potential of thermal design and insulation to generate greenhouse gas reductions in South Africa

The potential of energy savings or consumption pattern change to generate reductions in carbon usage and greenhouse gas reductions is investigated in Chapter Five. In this chapter a methodology for the estimation of the potential greenhouse gas emission reductions will be developed. An estimate of possible reductions will be made.

1.3.5 Comparison with energy efficiency measures in foreign regulations and codes

Recent and relevant experience with the establishment of energy efficiency in the building sector is to be found in Australian and South East Asian developments. In Chapter Six a comparison will be drawn between the energy efficiency criteria established in this thesis, other proposed local energy efficiency guidelines and foreign regulatory stringency levels.

1.4. Survey of opinions of conference delegates

A survey of the opinions of the delegates to a presentation of the proposals herein, including a peer group of members of TIASA, and representatives of the World Bank, is conducted. The objective of this survey is to assess and record individual company positions on the suitability of the proposals.

The future direction of and action plan of the TIASA Technical Committee is to be determined in part from the responses received.

1.5 Implementing energy efficiency policy in housing in South Africa

In Chapter Seven conclusions are drawn as to the need for and suitability of the proposals herein, for the introduction of energy efficiency in housing in South Africa.
Suggestions are made as to the way forward for the process of introducing an energy efficiency standard into practice and regulation in housing in South Africa.

Chapter Two

THE ENERGY PROBLEM IN HOUSING IN SOUTH AFRICA

2.1 Defining the energy efficiency problem in housing

Much valuable information gathering and analysis has been performed by the Energy Futures Team of the Futures Research Institute commissioned by the Department of Minerals and Energy, up to the final edition of 2000/2001 [9]. This publication reviews the social environment, the natural physical, technological, political and institutional as well as the economic environments, all of which impact on low cost housing.

A review of this publication and others shows that this problem manifests in various forms for different housing interest groups.

2.1.1 International organizations, foreign & local governments;

The global warming problem expressed in physical terms results from in excess of 25 billion tons of carbon dioxide per annum being emitted into the atmosphere. A 50% growth in these emissions is expected to have occurred in the 20 years up to 2010 unless energy savings and efficiencies are developed [9].

The Rio Declaration signed at the Earth Summit in 1992 set out the international agreements on the principles of managing sustainable development, and the United Nations Framework Convention on Climate Change (UNFCCC). The follow-up Kyoto Protocol requires the signatories (at that stage 38 developed and economies in transition – Annexure 1 countries) to commit to legally binding reductions in emissions amounting to 5.2% of 1990 levels. Kyoto also established the flexibility mechanisms of CDM (Clean Development Mechanism), i.e. project driven emission reduction, and Joint Implementation (JI), i.e. credits given for contributions to projects in second countries, with international trading possibilities for these credits [9].

2.1.1 International organizations, foreign & local governments (cont)

The South African government ratified the UNFCCC in 1997, and formed the National Committee on Climate Change. Government policy statements, White Papers, projects, surveys and workshops conducted subsequently, evidence efforts to respond to this challenge in the National Departments of Housing [37] and Minerals and Energy [28].

2.1.2 The energy efficiency problem for the generating industry:

The principal problem for the electricity generation industry is the peak demand problem. Generating capacity is idle for most of each day and utilized more fully mainly between the hours of 18:00 to 22:00 [45]. This peak demand is at its highest in winter, and is caused by home space heating and cooking needs [45] according to Eskom Demand Side Management (DSM) section. Solutions to the demand side management problem from the housing sector have been few according to Basson JA [8] who reports the Compact Fluorescent Lighting project being among a few successes.

Studies which have been commissioned by industry, and carried out by experts in the energy field, point to the potential of thermal insulation to contribute positively to this problem [33] [12]. These examine among other things the efficacy of energy efficiency options and thermal designs. This aspect will be pursued in this thesis.

A second problem for the principal generator, Eskom, is that capacity has been established over many years and the plants have been written down for accounting purposes [14], hence understating the depreciation charge. If a Replacement Cost Valuation is to be accorded the generating industry, and a Current Cost Depreciation charge is accepted in the new tariff determining rules, then generators will set aside sufficient funds for the replacement of capacity and the expansion of the generating plant.

The excess of capacity has enabled an uneconomic tariff to be sustained and a social policy of providing cheap electricity for the poor to be implemented. This policy has been applied by making the first 50kWh of consumption free of charge. The availability of cheap power has exacerbated the peak demand problem as the new consumers tend to have a low consumption and that usage is generally during peak times [44][8][33].

These two problems combine to make a third problem. This is the need for the expansion of electricity generating capacity at considerable capital expense, in order to cope with the growing peak demand. With the construction of new generating stations, or significant load shifting, power shortages can be avoided. Intermediate options to bring in presently moth-balled generating capacity are expected to be able to cope with electricity demand increases, however if decisions are not taken timeously to commence construction on new plants or pump storage schemes, power shortages can be expected in 2007 [45].

2.1.2 The energy efficiency problem for the generating industry (cont)

The consequence of the necessary expansion in capacity is that power generation costs will increase. The result of this will either present as profitability problems for the newly formed generator companies, or as power cost increases for the National Electricity Regulator (NER) to authorize to be passed on to consumers. The NER has shown they will not increase electricity charges at a rate which will allow a build up of cash ahead of the investment. This will possibly cause a sharp escalation of rates to be necessary, as the investment proceeds.

2.1.3 Energy research establishments and renewable energy proponents highlight different energy efficiency problems.

Community energy expenditures have been surveyed against income levels [35]. It has been established that there is a disproportionately high expenditure on energy by the poorer communities. Positive survey responses are reported for projects which assist poor communities [48], pointing to thermal design improvements and education in the benefits of energy conservation [13].

Researchers have studied the inter-relationships of household income levels and household expenditure on energy and fuel usage. Cheaper fuels such as coal burned for space heating contribute much to local pollution problems in South Africa [29].

There is potential for renewable energy sources to contribute to a reduction in the demand for electrical energy and thereby provide a solution to pollution problems [9].

2.1.4 The relationship between community health and energy efficiency

The poor respiratory health of communities in Southern and Western Cape Coastal Region has been linked to deficiencies in the design of housing [13]. In the region children are 270 times as likely to contract respiratory disease as in Western Europe. This respiratory disease is attributed to the damp conditions in low cost housing and condensation on cold roofs or walls. Fungal growth and resultant spore generation is said to be the cause of much of this respiratory disease [40].

2.2 The housing shortage, housing stock designs and energy efficiency thereof.

2.2.1 Housing backlog

The shortage of affordable low cost housing is reported by the Minister of Housing on public radio news as 2.7 million units in May 2003. This is after significant production in recent years. Since April 1994 over 1.2 million houses have been constructed [22].
The rate of construction of low cost housing appears to continue at an average rate of some 100 000 per annum [22].

The affordability of low cost housing is inextricably confined by the limitations of poverty and low levels of family income. The state subsidy will be R23 100 per house for those earning less than R1 500 p.m. in 2003/4, decreasing to R14 200 for those earning less than R2 500p.m.[48].

The provincial housing allocation in 2001/2 was R3.179 billion. This is set to increase in real terms in terms of medium term spending plans [22]. The dilemma facing the National and Provincial Departments of Housing is whether the policy of extensive construction to meet the backlog at the expense of quality of the housing is to be continued [2].

2.2.2 Housing standards

Some 70 % of the 11 million houses in South Africa are classified as formal, 17 % informal (shacks), and 11 % are of traditional materials, occurring mainly in rural areas, according the South African Survey by the Institute of Race Relations [22].

The Energy and Development Research Centre (EDRC) has surveyed the formal housing stock in South Africa, and conducted research into the various housing designs and the construction materials used in each region, concluding that the low income dwellings exhibit poor thermal performance [35].

The National Department of Housing Norms and Standards Document (red book) which serves as a specification for low cost (subsidy) housing makes no reference to ceilings or thermal design [2].

The National Building Regulations require that houses typically have block walls, a lightweight roofing material, but no ceiling is required and thermal insulation is not mandatory [38]. There is little in the way of shading device requirement or consideration of the thermal effects of window design. The reduction in size of subsidy housing in recent years doubles the ratio of surface area to volume, and therefore doubles the energy need [19].

National Home Builders Registration Council (NHBRC) Home building manual [29] contains no reference to ceilings or thermal design.

2.2.3 Energy efficiency, comfort and health

The standard of formal housing for the poorer communities does not provide thermal comfort and energy efficiency [35]. In general, designs are reported to have taken little cognizance of orientation, spatial considerations, planting of suitable vegetation for shading in summer, eaves for solar protection, ceilings or thermal insulation for comfort or energy efficiency, ventilation in hot coastal locations or thermal capacity advantages.

The thermal efficiency of informal housing has been studied by Holm [18], and modelled using the *Quick/NewQuick/Building Toolbox* [31] software by Mathews *et al* [39] and Taylor [40]. The thermal efficiency of this housing has been found to be very poor.

This is the principal problem to be addressed. Typical low cost house designs have been modelled by various parties [40] and tested for energy efficiency by various researchers [34][39].

The standard 30m^{2}designs of the National Home Builders Registration Council (NHBRC), as well as the standard 53m^2 Agrément Board houses were examined for their efficacy in meeting the desirable levels of thermal efficiency and comfort by a TIASA Technical Committee. The *Building Toolbox* program was used as the simulation tool [31].

The boundaries of the Southern Cape Condensation Belt have been redefined as result of the work of the Agrement Board who have also made use of modified *NewQuick* software [7][31].This will enable the required building standards necessary for community health purposes to be implemented .

2.3 South African energy policy and future problems for electricity suppliers

2.3.1 Profitability and sustainability of electricity generators

For all energy providers, the three pillars of long term industry viability; that is profitability, environmental sustainability and community need or benefits are fundamental to their survival. This applies to electricity generators as much as to any energy provider.

Government measures to extend electricity supply to previously disadvantaged communities by way of a subsidization policy, has exacerbated the peak demand problem. Electricity generators will endeavor to stimulate consumption by electricity users (in order to improve their profitability). This will also have consequences such as accentuating differentials between peak demand and average consumption of power. If massive energy cost increases or power outages are to be avoided, these effects will need to be countered by the simultaneous advance of energy efficiency. A cost problem will be created for the industry by its regulator or itself, if it fails to act or is not allowed to act to encourage energy efficiency by householders.

2.3.2 Cost of investment in electricity generation capacity will affect householders

In order to encourage investment in new generating capacity and enable the sale of portions of Eskom to new generation companies, these businesses will have to be allowed to charge an economic tariff.

The National Energy Regulator (NER) will have politically difficult decisions to implement to allow electricity producers price increases which are ahead of the rate of inflation. Delayed implementation of tariffs will necessitate higher tariffs in the future.

2.4 Global warming: The South Africa contribution

2.4.1 Global warming

Global warming resulting from excessive combustion emissions threatens the viability of life on the planet, if it continues at the present rate. Atmospheric carbon dioxide levels have risen from 280 p.p.m. to 370 p.p.m. since the start of the Industrial Age, with most of this occurring in recent years [9].

The average atmospheric air temperature is expected to rise by between 1 and 3 °K over the next thirty years, and 6°K over the next century. This is expected to cause the ice caps to melt and ocean levels to rise. These changes to the world ecology could jeopardize the future viability of life on the planet in its present form.

2.4.2 The South African global warming contribution

According to the World Resources Institute South Africa ranks 17 out of 50 countries in its attributable share of global warming gas generation [9]. South Africa is the third [9] or fourth [19] biggest contributor per capita of carbon dioxide in the world. This is as a result of cheap and plentiful coal resources, extensive coal burning power stations and a large metals refining industry. This constitutes some 1.7% of world energy related carbon emission.

The ratios of emissions to size of various national economies are compared in figure 1 below.

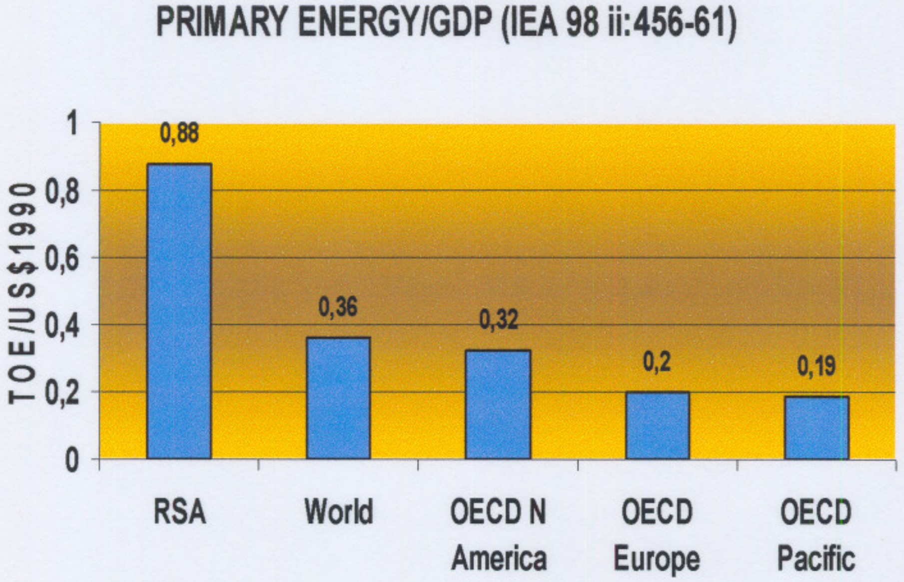

Figure 1. The relative contributions to global warming of various countries as expressed in tons of emissions in relation to Gross Domestic Product (courtesy Holm & TIASA and sourced from the International Energy Agency).

2.4.3 Practices which generate house-hold CO_2 pollution in South Africa

Mixed and multiple energy source homes predominate in South Africa [9]. Wood is the main source of space heating and cooking energy, particularly in rural areas, and mainly by the poor [18].

Coal burning is the dominant method for space heating in use on the urban Highveld regions of South Africa. Because of the low cost of coal in these areas, and also historical practices, a collective/family preference exists for the coal stove. The coal stove is used for food preparation and for space heating. These practices give rise to a predominantly winter air pollution problem in this region [13].

Electrification and the use of more efficient appliances (such as gas hot water geysers and microwave ovens) over less efficient alternative appliances and the use of energy sources with less CO_2 emission, have been identified as part of the solutions to the greenhouse gas problem [9][13]. In 2000 some 70 % of households were supplied with electricity [22].
The energy share is illustrated below by Holm in Figure 2 below.

Energy source shifts will take place by consumers [9], and new electricity consumers are observed to progressively increase consumption over an initial period. If the correct incentives and regulation are in place, this shift will take a direction which is beneficial to society and the planet.

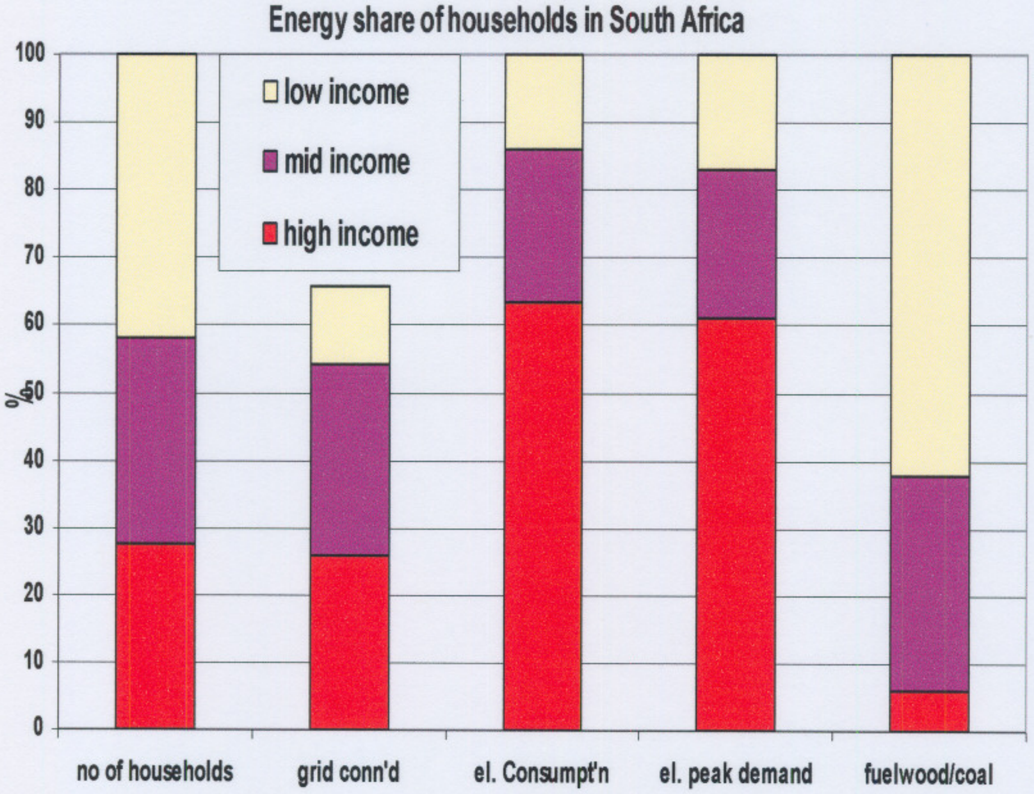

Figure 2.Energy Share of households in South Africa (courtesy Holm and TIASA)

2.5 Conclusions as to actions necessary to ameliorate and correct energy problem

Since the South African government ratified the UNFCCC and with the hosting of the World summit on Sustainable Development in Johannesburg in 2002, the recognition of the need for the state to take steps to regulate and stimulate a reduction in the amount of greenhouse gas (GHG) has probably increased. The government policy statements, white papers, draft reports, & workshops conducted subsequently evidence efforts to respond to this challenge in the Departments of Housing [37] and Mineral & Energy [44]. This effort needs to be driven by these authorities if policy is to be turned to reality.

The planned reorganization of the electricity industry will result in Eskom being split up. The electricity supply industry will then consist of independent generating companies, some of whom will be responsible for bringing previously moth-balled plants into production. Distributing companies will also be created. This process may conflict with the objective of improving energy efficiency and reducing greenhouse gas emissions, if inefficient plants are brought into production. In order to prevent this conflict, the National Energy Regulator will need to ensure that tariff based incentives are in place, and that energy efficiency progress elsewhere initiated [28] is not undermined.

2.5 Conclusions as to actions necessary to ameliorate and correct energy problem (continued)

Other organs of state such as the Standards South Africa and the Department of Trade and Industry need to be engaged by the National Department of Housing to contribute to a review of Building Regulations such as incorporates energy efficiency [37].

Any assistance which can be rendered to government departments to facilitate this process should be given in view of the size and complexity of the energy problem in housing. The reward for TIASA members for this effort is in the long term potential of the business of supplying ceilings and thermal insulation on a scale not yet materializing in South Africa.
This business opportunity for industry and TIASA members, warrants the application of resources.

The willingness of international donor organizations to provide funding for research which will contribute to practical solutions of the energy problem in housing in South Africa has been indicated by the World Bank. Through this office the funding of a pilot project to build energy efficiency into some 250 low cost houses has been pledged from Danida, an agency of the Royal Danish government [2].

Chapter Three

AN OBJECTIVE BASIS FOR IMPROVED COMFORT STANDARDS IN HOUSING FOR SOUTH AFRICA

3.1 Overview of this chapter and the methodology for determining comfort standards

An immediate benefit of good thermal design for house occupants is by way of improved thermal comfort levels. Benefits of improved health and productivity may thereafter be realized [13]. The hypotheses to be developed in this thesis are that improved comfort will generate heating (or cooling) cost savings and further that these savings will generate reductions of greenhouse gas (GHG) emission.

The basis of a comfort standard is to be found in a review of the literature, which is set out in section 3.2 of this chapter. Furthermore the level of energy efficiency corresponding to the comfort level and the extent of the reductions in GHG themselves, are a basis for an energy efficiency standard for housing. This standard will be developed in Chapter Four.

The poor standard of thermal performance of low income and informal housing in South Africa is identified by Simmons and Mammon [35], who report a disproportionate expenditure on energy by the poor as result of low thermal efficiency standards. According to Simmons [34] with better thermal design an opportunity may exist for improvements in comfort and financial wellbeing for this community,

Thermal comfort theory is based on the fundamental work of Fanger [17]. Subsequently, others have developed the understanding of the adaptability of humans to their local climate. These theories have been applied by Holm [20] to develop temperature neutrality maps of South Africa. Zones of common thermal neutrality are shown as isotherms on a map of the sub-continent in Figure 4(a) on pages 21 and 22.

In South Africa energy conscious design has received attention from Holm [21] and others [10]. Holm develops strategies for providing comfort in various climatic regions of South Africa. The performance criteria or objective of the design strategies is to ensure that interior air temperatures are within the range of thermal neutrality, in which 80% of persons are comfortable. In order to develop appropriate thermal performance and energy efficiency standards, the degree of effectiveness of these thermal design measures with respect to human comfort receives further attention in this thesis.

3.1 Chapter overview and methodology for determining comfort standards (cont)

If appropriate thermal design measures are introduced to housing, the fluctuation or swing in temperature within a house can be restricted to the range of thermal neutrality for any region. When this is achieved heating requirements can be minimized. Peak internal temperatures under hot conditions can also be maintained below the upper limits of summer thermal neutralities. The target amplitude ratios to achieve this are developed in Table 1 on pages 18 and 19. These form the basis of the proposed standards for thermal performance as per section 3.3 of this chapter.

3.2 Fundamental research on thermal comfort

3.2.1 Major contributions to theory for predicting thermal comfort

According to Auliciems and Szokolay [3] the definitive work of Professor P.O. Fanger: Thermal Comfort (1970) [17] forms the basis of modern theories linking human response to the thermal environment. Fanger's index of responses to temperature: Predicted mean vote (PMV), and the translation into lowest predicted percentage dissatisfied (LPPD) [17] is incorporated into international standards: e.g. ISO7730; 1994 for air-conditioned environments.

Effective temperature (ET) (dry bulb temperature modified for humidity effects) forms the basis of ASHRAE Standard 55-1992:'Thermal environmental conditions for human occupancy'. A comfort zone can be described on a psychrometric chart in terms of temperature and humidity. Techniques available for predicting comfort neutrality are described by Auliciems and Szokolay in terms of ET on a psychrometric chart.

The adaptability of human beings to climatic temperature variation has been modelled by Humphreys and Auliciems [4] to provide equations which allow for estimation of local comfort neutrality zones based on local climatic data.

3.2.2 Heat balance equation

Fanger [17] compiles a heat balance equation which incorporates (human) internal heat production, heat loss by skin diffusion, evaporation of sweat secretion, latent heat respiratory loss, dry respiratory heat loss, heat conduction through clothing, heat loss by way of radiation and convection. Into this equation variables are introduced which account for the functional dependence of skin temperature and sweat secretion on activity level, which then yields the so called comfort equation. The equation has .been cross checked to population groups in different parts of the world and denies local acclimatization.

The ASHRAE Thermal sensation scale: 'Thermal environmental conditions for human occupancy' has developed from this work and specifies conditions of comfort zones where 80% of sedentary or (s)lightly active persons find the environment acceptable.

3.2.3 Comfort lines

By means of the comfort equation for a particular activity level and clothing norm it is possible to calculate the combinations of air temperature, mean radiant temperature, relative air velocity and air humidity which will create optimal thermal comfort for occupants of a structure, and deviations from optimal thermal comfort.

The comfort equation has been developed into useful graphs which show comfort lines defined in terms of air temperature and mean radiant temperature under various conditions of relative humidity and air movement [17].

3.2.4 Thermal sensation scale

The thermal sensation scale, which indicates the degree to which a particular thermal environment may be providing a **less than optimal** condition gives the predicted mean vote index (PMV). This is used in determining the effect of changes in design, as measured in terms of the vote of the respondents, and is set out in tabular format against air temperature, clothing ensembles and air movement. PMV has been developed to indicate the degree to which a particular thermal environment is not achieving comfort.

The predicted mean vote tables developed show deviations on the following scale:

+3	Hot
+2	Warm
+1	Slightly warm
0	Comfortable
-1	Slightly Cold
-2	Cool
-3	Cold

3.2.5 Percentage persons comfortable

Fanger [17] developed the table of lowest possible percentage dissatisfied (LPPD) which incorporates a normal distribution curve to the probabilities of the vote of respondents. These are developed as graphs in figure 3 below for sedentary persons at various clothing resistance levels (clo) but expressed as percentage persons comfortable:

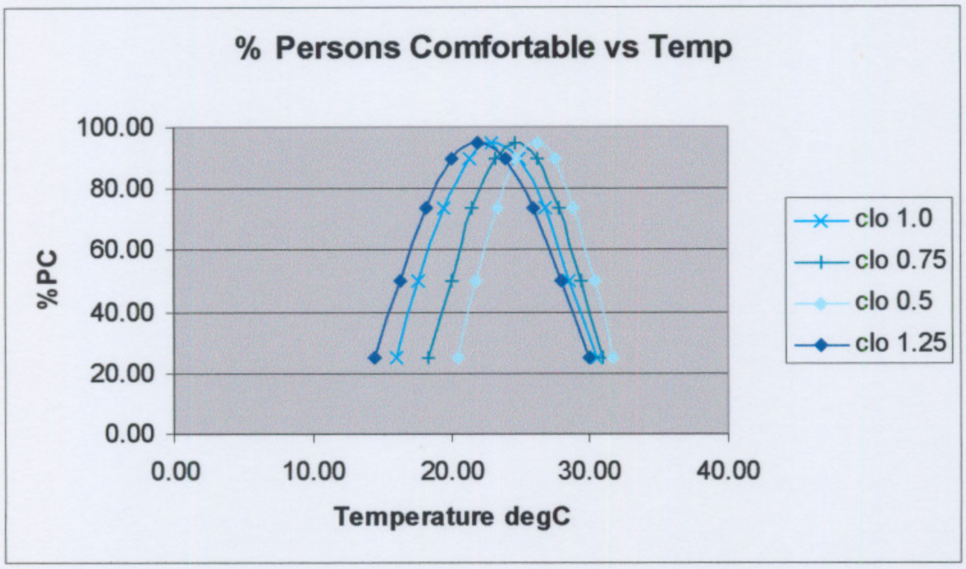

Figure 3: Percentage of persons comfortable versus air temperature for various levels of clothing resistance (clo).

Wentzel & Mathews [40] have provided a simplified version of the relationship between air temperature and the percentage of persons comfortable (% PC) index which is incorporated into the *NewQuick* software. This function was developed out of surveys of factory workers and possibly shows some adaptation to South African inland temperatures which are higher than those for corresponding probabilities as per Fanger. This could be as result of the high altitude and low humidity in inland South African conditions and local acclimatization.

3.2.6 Adaptation and acclimatization

The adaptability of human beings to local climatic temperature variation has been modeled by Humphreys and further demonstrated in research by Auliciems in Australia, Griffiths in Europe and in Pakistan by Nichol and Roaf [3]. These researchers have provided equations which allow for estimation of local comfort zones.

Szokolay and Aluciems [3] set out a methodology which entails the calculation of a point of thermal neutrality for the month defined on a psychromatic chart from the mean effective temperature T_n for the region. The median temperature and relative humidity are calculated, the T_n point located on the chart and the relevant effective temperature (ET*) line located. The dry bulb temperature at which the ET* line intersects with the 50% relative humidity curve is substituted into the following equation to determine the temperature of thermal neutrality.

$$T_n = 18.9 + 0.225 \times ET^*$$

The range of neutrality at an 80% level of persons comfortable is given as +/- 3.5°K about T_n for so called free-running buildings, i.e. for naturally ventilated structures.
No formula is provided for the 7.0 °K variation in width of this band, in the methodology, but Szokolay [4] does refer to the rule established by Gagge *et al* at the J.B.Pierce Foundation Laboratories at Yale University who propose that the slope of the extremes of the comfort zone are formed by the slopes of the appropriate Standard Effective Temperature lines (Effective temperature at 50 % relative humidity) and provide an approximation of these slopes as given by $0.025\ (T_n - 14)$. The upper and lower absolute humidity of 12g/kg and 4 g/kg provide the upper and lower limits of the comfort zone.

3.3 Establishing comfort criteria for housing in South Africa

3.3.1 A methodology for establishing comfort criteria

The performance objective for the standard of comfort in housing in South Africa would be that houses at all times are within the limits of thermal neutrality for a particular region. An acceptable standard for comfort in South African housing could be on the basis of an acceptable limited number of hours which the 80% comfort norm might be exceeded in typical hot weather, or a lesser acceptable percentage of persons comfortable at the peak hour. As part of a desirable standard of comfort, houses must also be able to be heated without great expense and must therefore be energy efficient.

Thermal neutrality ranges, for the major climatic regions in South Africa, in both hot and cold seasons, have been calculated using the techniques described above, and are set out below in Table 1 (a) and (b), with adjustment for acclimatization. The effective temperature is determined using the Szokolay method based on psychromatic charts. This procedure accounts for the altitude and local humidity effects and enables a comparison of the thermal neutrality ranges, in terms of dry bulb temperature, for different regions.

Summer conditions **Centre for climatic region**	**Units**	**Johannesburg**	**Pretoria**	**Phalaborwa**
Altitude		1694m	1330m	427m
Summer Mean Maximum	T_{maxs}	25.60	28.60	31.80
Summer Mean Minimum	T_{mins}	14.70	17.40	20.80
Summer Median	T_{means}	20.15	23.00	26.30
Summer Mean Maximum Relative Humidity	%	78.00	72.00	84.00
Summer Mean Minimum Relative Humidity	%	50.00	44.00	20.00
Summer Median Relative Humidity	%	64.00	58.00	52.00
Effective Temperature	ET	21.40	24.70	25.50
Thermal Neutrality	T_{ns}	23.36	24.46	24.64
Upper Bound of Thermoneutral Zone	$T_{nuppers}$	26.86	27.96	28.14
Lower Bound of Thermoneutral Zone	T_{nlows}	19.86	20.96	21.14
Difference between Thermal Neutrality and median temperature	ΔT	3.21	1.46	1.66
Amplitude of Neutrality	α_n	3.50	3.50	3.50
Amplitude of External Air Temperature	α_{as}	5.45	5.60	5.50
Amplitude Ratio	A	0.64	0.63	0.64

Winter conditions **Centre for climatic region**	**Units**	**Johannesburg**	**Pretoria**	**Phalaborwa**
Winter Mean Maximum	T_{maxw}	16.60	19.60	24.50
Winter Mean Minimum	T_{minw}	4.30	4.60	10.20
Winter Median	T_{meanw}	10.50	12.00	17.30
Winter Mean Maximum Relative Humidity	%	67.00	71.00	-
Winter Mean Minimum Relative Humidity	%	30.00	29.00	-
Winter Median Relative Humidity	%	49.00	53.00	40.00
Effective Temperature	ET	10.50	12.00	17.30
Thermal Neutrality	T_{nw}	21.26	21.60	22.79
Upper Bound of Thermoneutral Zone	$T_{nupperw}$	24.76	25.10	26.29
Lower Bound of Thermoneutral Zone	T_{nloww}	17.76	18.10	19.29
Difference between Thermal Neutrality and median temperature	ΔT	10.76	9.60	5.49
Amplitude of Neutrality	α_n	3.50	3.50	3.50
Amplitude of External Air Temperature	α_{aw}	6.20	7.40	7.10
Amplitude Ratio	A	0.56	0.47	0.49
Lower Amplitude Ratio for Region	A	0.56	0.47	0.49

Table 1(a) Thermal neutralities and amplitude ratios for climatic regions 1,2 & 3

Summer conditions **Centre for climatic region**	**Units**	**Cape Town**	**Durban**	**Upington**
Altitude	m	42m	8m	793m
Summer Mean Maximum	T_{maxs}	26.10	27.80	34.30
Summer Mean Minimum	T_{mins}	15.70	21.10	17.40
Summer Median	T_{means}	20.90	24.40	25.80
Summer Mean Maximum Relative Humidity	%	74.00	77.00	63.00
Summer Mean Minimum Relative Humidity	%	42.00	69.00	36.00
Summer Median Relative Humidity	%	58.00	73.00	50.00
Effective Temperature	ET	20.90	25.50	26.20
Thermal Neutrality	T_{ns}	23.60	24.64	24.80
Upper Bound of Thermoneutral Zone	$T_{nuppers}$	27.10	28.14	28.30
Lower Bound of Thermoneutral Zone	T_{nlows}	20.10	21.14	21.30
Difference between Thermal Neutrality & Median	ΔT	2.70	0.24	1.01
Amplitude of Neutrality	α_n	3.50	3.50	3.50
Amplitude of External Air Temperature	α_{as}	5.20	3.30	8.40
Amplitude Ratio	A	0.67	1.06	0.42

Winter conditions **Centre for climatic region**	**Unit**	**CapeTown**	**Durban**	**Upington**
Winter Mean Maximum	T_{maxw}	17.50	22.60	20.80
Winter Mean Minimum	T_{minw}	7.00	10.50	1.70
Winter Median	T_{meanw}	12.20	16.60	11.20
Winter Mean Maximum Relative Humidity	%	89.00	78.00	83.00
Winter Mean Minimum Relative Humidity	%	62.00	53.00	37.00
Winter Median Relative Humidity	%	76.00	66.00	60.00
Effective Temperature	ET	12.20	16.50	11.20
Thermal Neutrality	T_{nw}	21.65	22.61	21.42
Upper Bound of Thermoneutral Zone	$T_{nupperw}$	25.15	26.11	24.92
Lower Bound of Thermoneutral Zone	T_{nloww}	18.15	19.11	17.92
Difference between Thermal Neutrality and median temperature for region	ΔT	9.45	6.01	10.22
Amplitude of Neutrality	α_n	3.50	3.50	3.50
Amplitude of External Air Temperature	α_{aw}	5.20	6.10	9.50
Amplitude Ratio	A	0.67	0.57	0.37
Lower Amplitude Ratio for Region	A	0.67	0.57	0.37

Figure 1(b) Thermal neutralities and amplitudes for climatic regions 4,5 and 6

3.3.2 Relevance of the theory to South African situations

It is evident that under winter conditions, with acclimatization, the range of thermal neutrality for most centres and regions is above the range of diurnal temperature fluctuation. Heating is necessary to bring occupants to comfort in most areas, except for Durban/KwaZulu-Natal coastal belt, and for the Lowveld and Limpopo valley region. By limiting the fluctuation in internal temperature, and by maximizing solar gain benefits, heating can be minimized.

Under hot conditions, the range of thermal neutrality is within the daily range of temperature fluctuation in many temperate South African climates. In these regions interior comfort can be achieved by reducing the amplitude of fluctuation within the structure, and by taking advantage of night cooling. Mechanical cooling is often necessary in these more tropical and coastal regions.

The reduction in internal temperature fluctuation and amplitude ratio can be achieved with judicious thermal design. This will include the use of thermal resistance in the shell of the structure and by making use of elements with high thermal capacity. These design options will be evaluated for their efficacy.

The divergence of local climatic extremes from thermal neutrality at most Southern African locations is clearly set out on psychrometric charts by Holm [21]. He also sets out other design intervention strategies for mitigating the extreme climatic effects for each of nine regions. Some design interventions introduced to achieve passive design, will be looked at more closely in the next section of this chapter. This investigation is conducted for each of the six regions set out above, to assess their efficacy in the various regions.

The variation of thermal neutrality (T_n) across the Southern African sub-continent as indicated by the isotherms map compiled by Holm is set out in Figure 4(a) on page 22 below.

The six climatic regions detailed on a map in the NHBRC Manual [29] are typified in terms of major centres in the region as set out below. The climatic variation evident from a study of the maps provided by Holm, confirms the similarities within the regions:

Region	Major centre	Approximate location
Region 1	Johannesburg	Highveld regions generally over 1300m in elevation
Region 2	Pretoria	Temperate regions between 1000m and 1300m in north and above 500m from coastal regions
Region 3	Phalaborwa	Lowveld and Limpopo valley area below 1000m
Region 4	Cape Town	South, Eastern and Western Cape coastal below 500m
Region 5	Durban	KwaZulu-Natal coastal region below 500m
Region 6	Upington	Northern cape interior regions below 1000m elevation

Studies of electricity demand indicate that at 16 °C homes begin to be heated [44]. This coincides with the percentage persons comfortable (on the Fanger curves in Figure 3) dropping to a level below 25 percent. This same temperature (16 °C) is also that indicated by the modeling of the NHBRC 30m^2 and the 53m^2 Agrement Board reference house between 17:00 and 18:00 for the Highveld Region (Region 1, i.e. for Johannesburg).

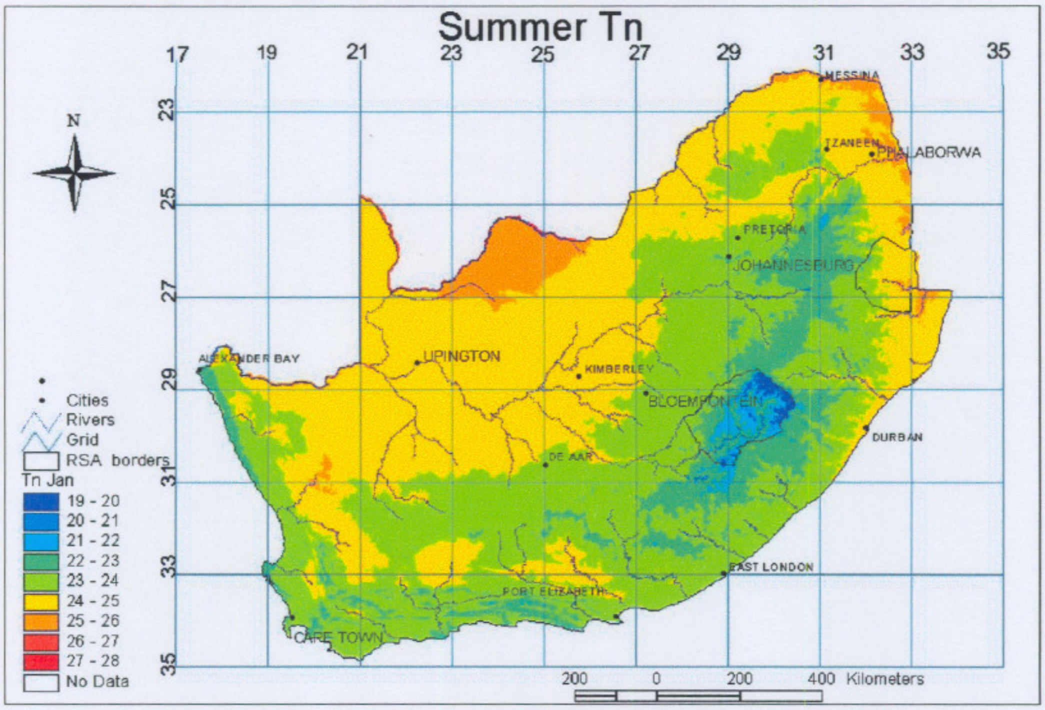

Figure 4(a) Summer thermal neutrality temperatures for South Africa

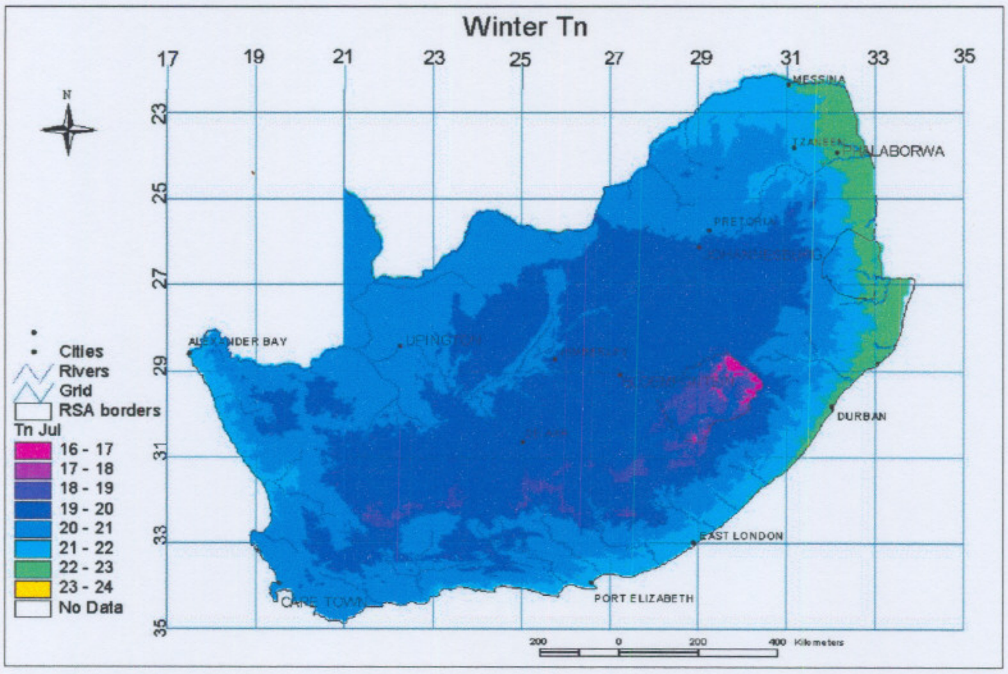

Figure 4(b) Winter thermal neutrality temperatures for South Africa

3.4 Estimated effect of interventions on predicted percentage persons comfortable

3.4.1 Methodology for calculating effect on percentage persons comfortable

By modeling a $30m^2$ NHBRC house design, a $53m^2$ Agrément reference house and a typical $120m^2$ middle income house using the *NewQuick/Building Toolbox* software, we can derive estimated internal temperatures and relative humidity at various times of day, for the various types of housing, with the different thermal design interventions.

The local acclimatized thermal neutrality temperature is derived from the climatic data in Table 1(a) and 1(b) above. Thermal neutrality range indicates the human comfort range allowing for adaptation for local temperature, absolute humidity, and presumably altitude. In order to calculate the number of persons comfortable in each region at the maximum temperature, it is necessary to generate an algorithm to link percentage persons comfortable (% P.C.), to internal air temperature, and adjust for the local neutrality (as per the Aluciems methodology). A new algorithm is proposed and is set out in appendix 1.

The Wentzel & Mathews algorithm is incorporated into the *NewQuick/Building Toolbox* software. The alternative algorithm developed in Appendix 1 is used in the tables below:
This method calculates the % P.C. from the local thermal neutrality temperature and the specific maximum dry air temperature of the day in question. A comparison of the two algorithms over modeling of the NHBRC and Agrément design, shows the Appendix 1 method to be a little more conservative than that provided in the software.

3.4.2 Effect of thermal design interventions on comfort in low cost house designs

The drop off in the percentage persons comfortable from 28 to 32°C is from 80% to 20%. This is shown by the slopes of the graphs in Figure 3 on page 16. A range of thermal design measures which might give a somewhat gradual decrease in thermal comfort performance at a somewhat gradual cost increase, and might give a wide range of comfort versus cost solutions options, is therefore unlikely. Analysis is required to assess whether these low cost comfort solutions are attainable.

The results of modeling of the various house designs with *Building Toolbox* software, to the chosen following criteria are set out below:

- Inside (internal) air temperature
- Percentage persons comfortable
- Capacity of the heating equipment necessary
- Heating efficiency as measured in terms of the energy requirement per square meter.

The six regions are those suggested in the NHBRC Manual [29]. The effect of the various levels of thermal design are set out in Table 2 on page 24 below: The discussion of the results and how these are achieved is developed in Chapter 3.4.3 and Table 3(a).

House design & thermal performance criteria: Section 1 : **NHBRC 30m² unimproved** Climatic region	Highveld	Pretoria	Palaborwa	CapeTown	Durban	Upington
Inside Peak Temp. (°C)	43.40	42.10	48.90	42.60	41.40	48.30
% Persons Comfortable	0.00	0.00	0.00	0.00	0.00	0.00
Heating Equipment (kW)	7.40	5.40	3.00	4.70	3.20	5.70
Energy Efficiency per square meter (kWh/m²)	195.33	114.87	47.83	97.10	53.73	115.93
Section 2						
Agrement Board 53m² unimproved design						
Climatic region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temp. (°C)	32.50	33.40	39.20	33.00	33.20	40.00
% Persons Comfortable	0.00	0.00	0.00	0.00	0.00	0.00
Heating Equipment (kW)	4.50	4.70	2.30	3.70	2.30	4.90
Energy Efficiency per square meter (kWh/m²)	53	52	16	38	17	54
Section 3						
Agrement 53m² basic design intervention						
Climatic region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temp. (°C)	27.20	29.50	34.00	28.50	29.80	35.50
% Persons Comfortable	95.00	55.07	0.00	74.97	49.10	0.00
Heating Equipment (kW)	2.10	3.10	n/a	2.10	n/a	3.00
Energy Efficiency per square meter (kWh/m²)	33	34	21	23	16	33
Section 4						
Agrement 53m² passive design intervention						
Climatic region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temp. (°C)	26.90	28.60	33.20	26.80	28.80	35.20
% Persons Comfortable	95.00	72.98	0.00	95.00	69.00	0.00
Heat/Cooling Equip. (kW)	1.80	1.90	n/a	1.90	1.60	2.00
Energy Efficiency of heat'g ***& Cooling*** (kWh/m²)	29	32	21	24	12	52

Table 2: House designs and thermal performance criteria with various levels of thermal design intervention shown over various climatic regions.

Inside peak temperature is the interior dry bulb temperature, % persons comfortable is as per the methodology set out in Appendix 1, heating equipment is that theoretical capacity required to heat the structure from a set point of 16°C, energy efficiency per square meter is the measure of kWh/m² being necessary to heat such a structure from this set point. Heating is assumed except for Durban and Phalaborwa for which cooling is allowed.

3.4.3 Commentary on thermal design interventions for low cost housing

The 30m^2 NHBRC design is detailed in appendix 2 .This design is unresponsive to measures which would attempt to attain comfort at the peak hour in terms of either the Wentzel & Mathews algorithm or that set out in Appendix 1. This is due to the large exterior surface area (wall, roof, windows, doors) in relation to the heated volume. The proportionately large windows are favoured for cold weather warming and an absence of any high mass/ high thermal capacity elements prejudice the thermal efficiency of this design. This conclusion is reached after the application of many permutations of thermal design measures in computer simulations. This design is found to be uncomfortable for most of a typical hot day and very difficult to heat to comfort levels.
As this house is likely to constitute a core house which will be added onto at a future time it arguably not worth attempting to design for comfort within the initial dimensions.

The 53m^2 Agrément Board design is the reference house as per detailed specification set out in Appendix 3. This house is representative a large portion of the South African housing stock and is used by Sodelund and Schutte [37] for reference purposes. In its basic format does not achieve comfort at any hour for 11:00 through to 19:00. This house is also relatively energy inefficient with regard to its performance in cold weather. The heating requirement for such a house is so large as to be impractical for electrical heating. The cost of such heating is too expensive to heat to the acceptable level of comfort, except perhaps with a traditional coal stove.

This 53m^2 Agrément Board design is able to provide comfort and energy efficiency at the peak hour in cooler climates with only a basic level of thermal design interventions. The variation in fluctuation of interior temperatures is reduced to a swing of less than 7.0°C and comfort is achieved even in the warm and humid KwaZulu-Natal Coastal belt, and also for Pretoria, for the major part of a typical hot day with the basic interventions set out hereto.

The level of the intervention necessary is different for the various climatic regions due to the climatic variations (and local acclimatization). The more extreme climates require greater levels of intervention.

Basic level of Intervention packages in each Region	**Highveld**	**Pretoria**	**Phalaborwa**	**CapeTown**	**Durban**	**Upington**
Thermal design package	B	C	A	C	C	A
Orientation optimized	Yes	Yes	No	Yes	No	Yes
High surface absorption coefficient/dark colour	Yes	Yes	No	Yes	No	Yes
Shade windows summer	Yes	Yes	Yes	Yes	Yes	Yes
Insulation U-value roof/ceiling (W/m^2°C)	0.4	0.7	0.4	0.7	0.7	0.4
Insulation U-value wall (W/m^2°C)	No	No	0.8	No	No	0.8
Cavity wall	No	No	No	Yes	Yes	No
Extra high mass elements	No	No	No	No	No	No

Table 3(a) Basic thermal design intervention package for the region

3.4.3 Commentary on thermal design interventions for low cost housing (continued)

A further level of thermal design intervention is necessary to achieve the reduction in amplitude ratio (daily temperature swing) to bring internal temperatures to within the extremities of the thermal neutral zone. Within the confines of the 53m^2 Agrément design, it is not possible to achieve a passive design, which would require no heating or cooling, in the more extreme climates.

At the levels of intervention set out below, the thermal design measures contribute towards establishing a passive design which requires the minimum of heating or cooling energy to maintain comfort. The energy efficiency levels set out in section 4 of Table 2 above, with the interventions below are achieved with the assumption of both heating and cooling.

Passive design intervention packages for regions						
Thermal design package	A	A	A	B	B	A
Orientation optimized	yes	yes	yes	yes	yes	Yes
High surface absorption coefficient/dark colour	yes	yes	no	yes	no	Yes
Shade windows in summer	yes	yes	yes	yes	yes	Yes
Insulation U-Value roof/ceiling (W/m^2°C)	0.4	0.4	0.4	0.4	0.4	0.4
Insulation U-value wall (W/m^2°C)	0.8	0.8	0.8	no	no	0.8
Cavity wall	no	no	no	yes	yes	No
Extra high mass elements	no	no	no	no	no	no

Table 3(b) Table of passive design interventions necessary for each climatic region

3.4.4 Effect of Design Interventions for Middle Income Housing

With design interventions as for levels set out in Table 3(a), i.e. a basic level of intervention considered appropriate to the climate for the region, the 120m^2 house performs similarly to the 53m^2 house with the higher intervention levels, as far as comfort is concerned.

CSIR 120m^2 with basic intervention level						
Climatic region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside peak temp. (°C)	26.20	28.60	32.80	27.20	29.10	34.10
% persons comfortable	95.00	72.98	0.00	95.00	63.03	0.00
Heating/cooling equipment (kW)	8.60	10.10	0.00	8.50	0.00	7.30
Energy efficiency of heat & cooling (kWh/m^2)	55	54	16	45	9	41

Table 4: Thermal performance of 120m^2 CSIR design with basic levels of thermal design intervention shown over various climatic regions.

3.4.5 Summary of thermal design interventions

The important outcomes, which are evident from the above analyses are summarized below.

Firstly; thermal comfort is achievable across Southern Africa with a basic intervention comprising of **three packages of thermal design intervention,** incorporating orientation, appropriate colouring and shading of walls and which include the thermal insulation levels set out below, and described as levels A,B and C.

1. In the hot season it is impossible to provide for comfort in the extremes of regions 3 & 6, however a very significant reduction in internal air temperatures is achieved if the **roof/ceiling R-Value of 2.5 m^{2}°C/W** is coupled with **wall insulation of R-Value 0.8 m^{2}°C/W .**
   This could be referred to as the **level A** intervention package.
2. The highveld and southern interior (regions 1) requires a level of **roof or ceiling** thermal insulation with a **U-Value of 0.4 W/m^{2}°C** or **R-Value of 2.5 m^{2}°C/W**.
   This could be referred to as the **level B** intervention package.
3. The milder south & western Cape regions (region 4), the lower altitude interior stations (region 2) and the Kwa-Zulu Natal coastal belt (region 5) require a roof or ceiling **U-Value level of at least 0.7 W/m^{2}°C or R-Value of (say) 1.5 m^{2}°C/W** to achieve comfort.
   This could be referred to as the **level C** intervention package.

Secondly, it is evident from the results of the simulations of the 53m2 Agrément reference house that lower (and perhaps cheaper) thermal insulation or intermediate thermal design solutions **cannot** provide comfort in hot weather and **cannot** provide homes which can be heated to comfort in winter. This implies that all of the no cost measures and plasterboard ceilings are not sufficient to achieve comfort.

If upper-income homes are to be both heated and cooled the need for the houses to be more energy efficient is apparent. This need will be examined in Chapter Four.

Thermal insulation to the R-Values set out above is crucial to the achievement of comfort in both hot and cold conditions.

3.5 Conclusion

The first part of the original hypothesis set out in this thesis is to suggest that comfort is the driver of energy efficiency measures. This is shown by the movement of the comfort index, percentage persons comfortable, in opposition to the index of energy efficiency, i.e. as household measures are taken to improve comfort the energy efficiency of homes is improved. The further link of improved energy efficiency with reductions in generation of greenhouse gases will be established in Chapter Five.

The six climatic regions show much variation in climate around South Africa. It is evident that with the variation of climate comfort standards vary, as a result of acclimatization. The variations in thermal neutrality across the climatic regions, are set out on the charts of Figure 4 on pages 21 and 22. As result of this variability different standards of thermal design are appropriate for different parts of the sub-continent.

Other important conclusions to be drawn are in relation to the levels of design intervention necessary for comfort. The thermal resistance of major elements (R-Values) set out above are crucial to the achievement of thermal comfort in both hot and cold climatic regions.

Chapter Four

STANDARDS OF ENERGY EFFICIENCY FOR SIX CLIMATIC REGIONS OF SOUTH AFRICA.

4.1 The requirements for thermal comfort for housing in South Africa

4.1.1 Climatic variations within South Africa

The winter heating temperature requirements and summer cooling requirements have been set out in map format by Holm [20]. These are copied in Figure 5 and it can be observed that there is much variation in climate around South Africa.

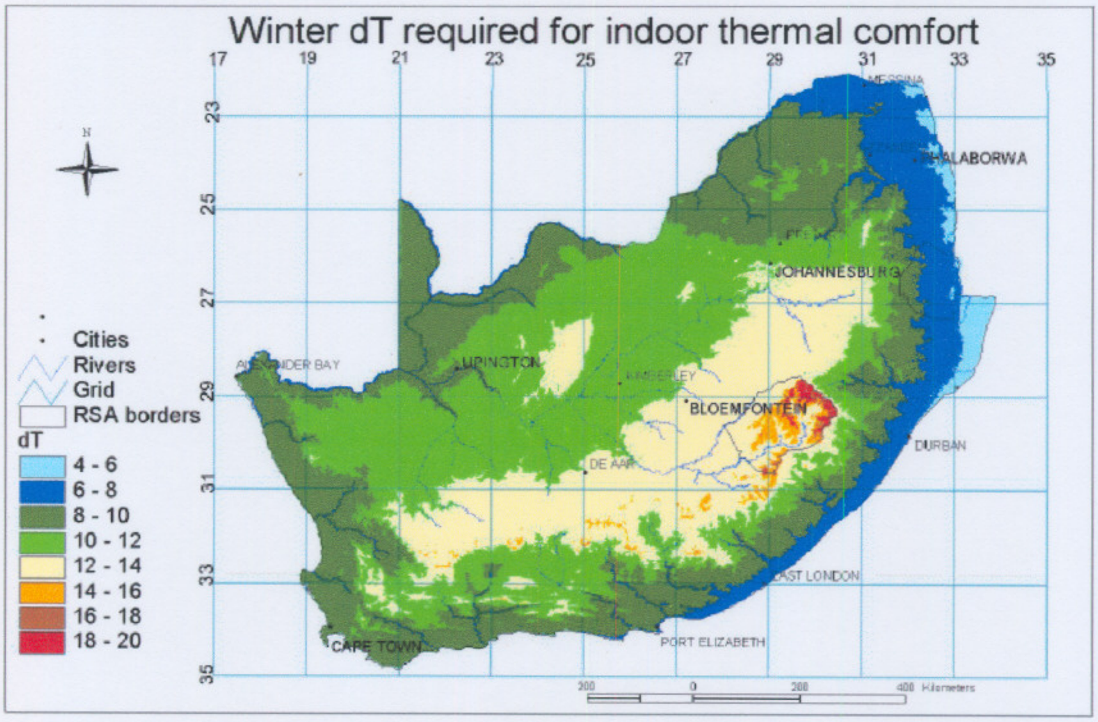

Figure 5(a) Winter heating temperature difference (dT) for indoor thermal comfort

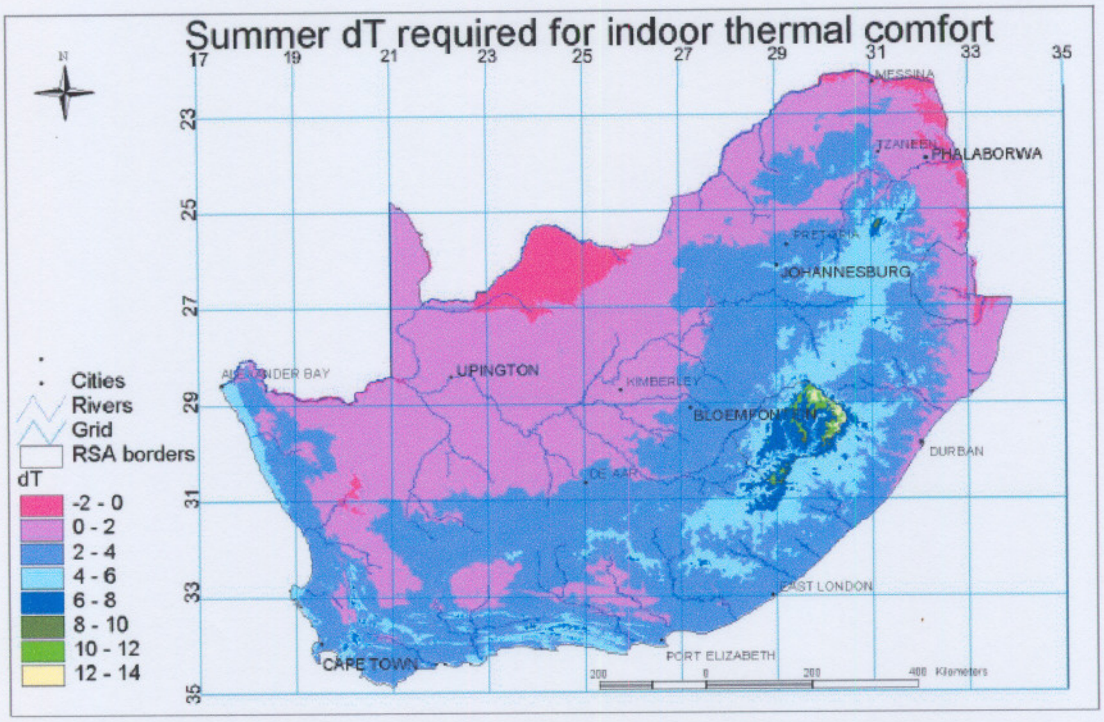

Figure 5(b) Summer cooling temperature difference requirement for comfort

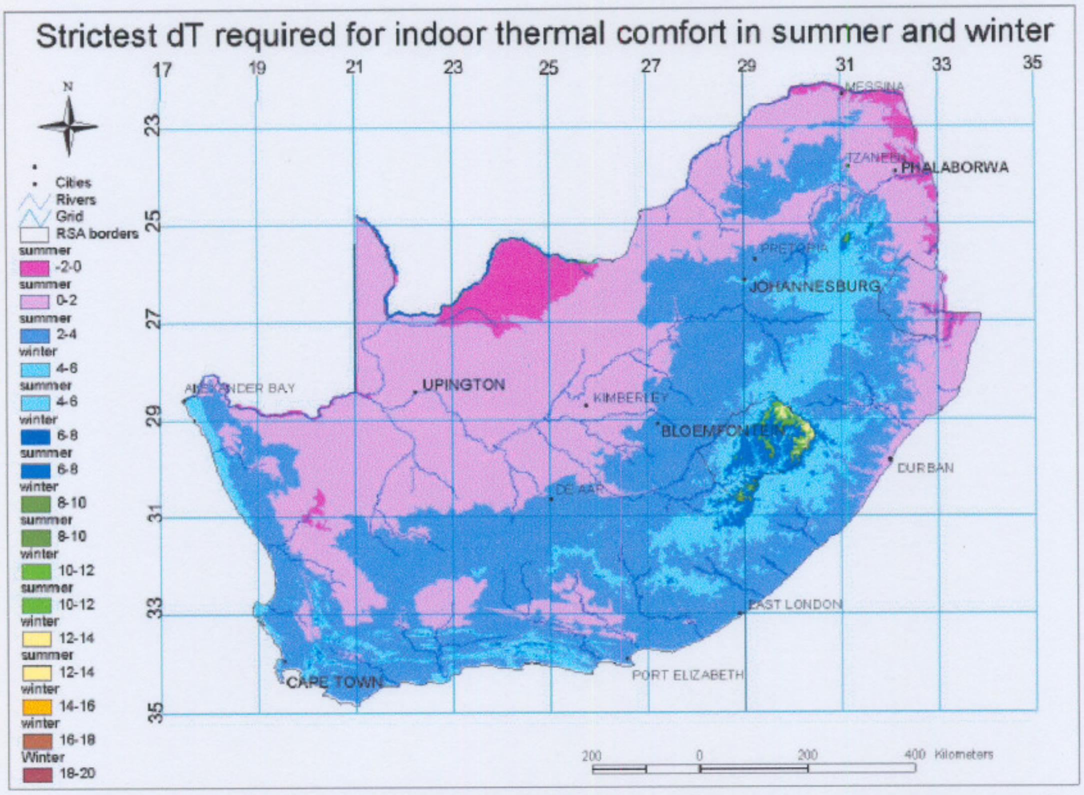

Figure 5(c) Strictest heating or cooling temperature difference for thermal comfort

4.1.2 Comfort requirements define thermal performance criteria

In Chapter Three it was observed that thermal comfort is the driver of energy efficiency measures by home-owners, i.e. as thermal design interventions measures are taken to improve comfort the energy efficiency of homes is improved.

The variations in thermal neutrality across the climatic regions are set out on the maps of Figure 4, and the variations in heating or cooling requirement are set out in Figure 3 above. As result of this variability different standards of thermal design are appropriate for different parts of the sub-continent. In Chapter Three it was concluded that the levels of design intervention necessary for comfort, in both hot and cold seasons, necessarily included minimum thermal transmission (U-values) for the shell of the reference house, in all climatic regions.

In the cooler regions space heating goes hand in hand with a requirement for the thermal efficiency of housing stock, in order for the achievement of thermal comfort. Comfort cannot be reached without one or the other, except with unaffordable energy costs. In warmer climates homes can be constructed to achieve comfort without heating or even cooling. Passive design intervention levels suggested in Table 3(b) on page 26 are appropriate for this objective.

In hot climates mechanical cooling is often necessary to achieve comfort. A heating or cooling requirement generally involves an artificial energy input, and the energy efficiency of the structure will then have cost implications. Other important conclusions drawn in relation to the levels of design intervention necessary for comfort are that the R or U-values set out above are crucial to the achievement of thermal comfort. The achievement of these R or U-values also has cost implications. As costs are a constraint to the achievement of energy efficiency by both society and households, these costs will be evaluated for economic and financial viability in section 4.2.1.

4.2 Establishing energy efficiency criteria for housing in South Africa

4.2.1 A tool for measuring the energy efficiency of housing

In Table 2(a) of Chapter Two the thermal design interventions adopted in an effort to improve the 53m2 Agrement Board reference house such as to provide comfort in the major population areas, are set out. When these interventions are modeled using the *NewQuick* software, with the assumptions previously set out in chapter three, a measure of energy efficiency is one of the outputs. These results have been set out in Table 3 of the previous chapter.

The use of the *NewQuick* software for comparing the energy efficiency of structures is proposed. Subsequent to criticism by Szokolay [?], the *Quick* software has been modified to incorporate a third order equation to handle the effect of mass in the shell which has improved the response of the model for light structures [25]. The *NewQuick/Building Tool-box* program has been extensively verified and is use by the Agrement Board of South Africa [7], in a modified version and many other reputable institutions.

4.2.2 Economic and financial evaluations of energy efficiency

The cash costs of ceilings and roof insulation for low income housing, and the savings to these households as result of reduced energy consumption have been calculated by Winkler, *et al* [47] from both an economic and a financial perspective. The 'total resource cost test' calculates the net economic benefit for the country as a whole, and the 'consumer revenue test' determines the benefits of the householder investment decision to install ceilings or insulation. Both calculations use a discounted cash-flow method to evaluate the decision and the cash implications thereof.

The discount rate is low for the societal calculation and high for the consumer test, reflecting relative capital availability or cash constraints. The merit of ceilings and roof insulation in terms of these calculations for society is economically positive, particularly with externalities included, but not so for poor households. A recommendation flowing from this study was that a subsidy of the order of R1000 using 1999 costs would be necessary for energy efficient ceilings to be installed in such housing.

The 30m2 house design evaluated has a high wall to total shell area ratio and as result the addition of a ceiling and roof insulation is less effective in improving thermal efficiency than might otherwise be. Wall insulation or shared wall options are helpful to this size of house. Furthermore the costs of the ceiling systems indicated in the evaluation appear to be horizontal nailed-up gypsum plaster-board ceilings as opposed to insulated roof-liner systems, which are cheaper to install, if installed over-purlin and under roof-sheeting.

4.2.2 Economic and financial evaluations of energy efficiency (cont)

Taylor [21] has studied the relative efficacy of thermal design measures on both middle income housing and low income houses in South Africa. He establishes the financial viability of the thermal design measures, including the thermal insulation of ceilings, particularly for the more extreme climates of South Africa. The pay-back period for ceiling insulation is found to be less than three years for all inland regions for rooms heated electrically.

The pay-back for insulated ceilings was confirmed more recently by TIASA as being 21 to 24 months, and is set out in an unpublished submission [11] to Sodelund and Schutte (the consultants of the National Department of Housing contracted to compile recommendations on energy efficiency in housing).

In presentations to the consultants to the World Bank in June 2003 an insulated ceiling at a cost of R40/m^2 was targeted and promised for delivery by a number of presenters. This including a 25mm extruded polystyrene insulated ceiling solution [25].

4.3 Proposed Star Rating System for South African housing

In order to compare the energy efficiency of houses in an area, or between areas, an energy efficiency scale is proposed. This is constructed so as to compare houses from an extreme of inefficiency through to an energy efficient passive design. An exponential curve is selected in order to cater for the decreasing benefits of thermal design measures. See Figure 5. The function is selected such as to position a five star rating at the level of passive design and the first half star at the level energy efficiency for which no cost thermal design interventions and a ceiling would impart in the Highveld region for the NHBRC 30 m^2 design i.e. an energy efficiency of 147kWh/ m^2 per annum. For the same region a one star rating can be achieved in the same NHBRC design, if an insulated ceiling with a U-Value of 0.40 W/m^2°C (or R-value of 2.50m^2°C/W), is installed and an annual energy efficiency (EE) of 119 kWh/ m^2 is achieved. In Pretoria this same house with the recommended interventions, including an insulated ceiling with U-Value of 0.4 W/m^2°C, will achieve a two star rating & EE of 58.

The Agrement Board 53 m^2 house with ceiling will achieve a two star rating in both Pretoria and Johannesburg (EE of 56) to the same units. With the recommended basic thermal design intervention the EE is improved to a level of 32 and 33, at which a two and a half star rating is achieved. The U-Value of 0.7 W/m^2°C for the ceiling & roof assembly is necessary in Pretoria, and the 0.4 W/m^2°C level in Johannesburg, in order to achieve the improved EE.

The assumptions made in the Agrement Board calculation method for the energy efficiency are that heating applies when the temperature drops to 16 °C. No cooling energy input is added to this result. It is considered that this omission could result in a misdirection of the effort to save energy and reduce emissions. High consumption households which are cooling as well as heating, hold the potential for larger energy savings and emission reductions, than those homes using little energy, according to Holm [19].

4.3 Proposed Star Rating System for South African Housing (Continued)

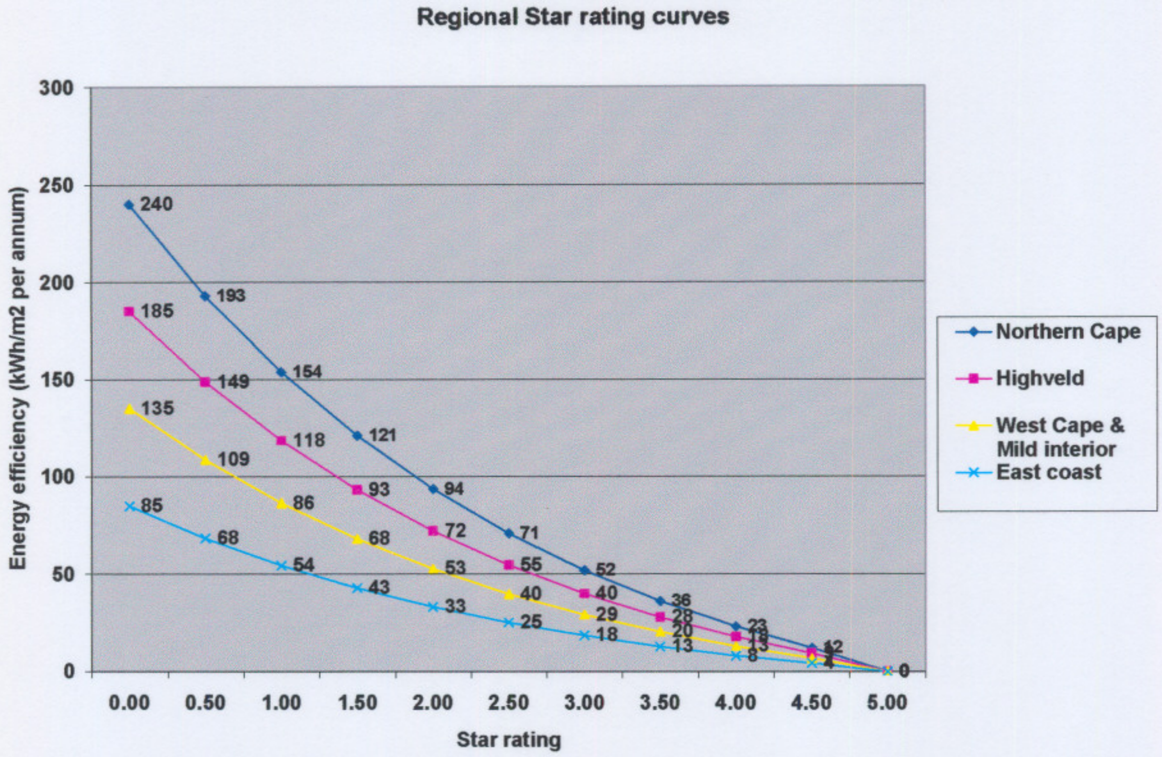

Figure 5 Proposed Five Star Energy Efficiency rating system

In milder climates energy efficiency is more easily achieved, and it is a valid viewpoint that a single scale (graph) should apply. This would better achieve the objective of reducing energy consumption and carbon emissions country wide, as in the more energy intensive regions a more strenuous requirement would pertain. In the interests of similar interventions having similar results in different parts of the country the multi-curve option has been adopted by TIASA.

If the 120m^2 CSIR Reverse Engineered house is used as a basis for examining the thermal performance of the middle/upper income homes, with the *NewQuick* software simulations; a house in Durban with the basic level of thermal design intervention, which is both heated and cooled, will achieve an EE of 20 kWh/m^2 per annum and a star rating of close to three, in contrast its counterpart in Upington which will achieve a 56 EE and similar star rating.

4.4 Achieving passive design

A basic level of thermal design intervention has been proposed in the previous chapter in Table 2 in order to reduce internal temperature to a 7.0 °K swing, with significant improvements in comfort and energy efficiency.

A further level of thermal design intervention is necessary to achieve the reduction in amplitude ratio (daily temperature swing) to bring temperatures to within the extremities of the thermal neutral zone for the region. It is not possible to achieve the passive design performance, which requires no heating or cooling, in some of the more extreme climates, within the confines of the 53m^2 Agrement design. Larger houses are successfully adapted to a passive design with the proposed interventions.

At the levels of intervention set out below in Table 3(b) (repeated but with thermal resistances in place of thermal transmittances) the thermal design measures contribute towards establishing a passive design which requires the minimum of heating or cooling energy to maintain comfort.

Passive design intervention packages for regions						
Thermal design package	A	A	A	B	B	A
Orientation optimized	yes	Yes	yes	yes	yes	Yes
High surface absorption coefficient/dark colour	yes	Yes	no	yes	no	Yes
Shade windows in summer	yes	Yes	yes	yes	yes	Yes
Insulation U-Value roof/ceiling (W/m^2°C)	2.50	2.50	2.50	2.50	2.50	2.50
Insulation U-value wall (W/m^2°C)	1.25	1.25	1.25	1.25	1.25	1.25
Cavity wall	no	no	no	yes	yes	No
Extra high mass elements	no	no	no	no	no	No

Table 3(b) Table of passive design interventions necessary for each climatic region

With the assumption of *both heating and mechanical cooling*, and with design interventions set out in Table 3(b) above, with levels considered appropriate to the climate for the region, the following energy efficiency levels are achieved for a 120 m^2 house. For those regions in which middle income homes are likely to be both heated and cooled the need for the houses to be more energy efficient is apparent.

4.4 Achieving passive design (cont)

CSIR120m2 with thermal interventions for passive design						
Region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temperature	26.4	28.1	33	26.6	28.4	34.3
%Persons Comfortable	100	93	0	100	91	0
Cooling & Heating Equipment capacity kW	2.6&3.4	3.6&3.5	6.5&1.0	3.1&3.8	4.1&1.9	7.1&3.6
Energy Efficiency of Heating & Cooling kWh/m^2 p.a.	25	26	21	24	16	39

Table 5: Thermal performance of 120m^2 CSIR design with passive design interventions shown over various climatic regions.

4.5 Summarised thermal design interventions and conclusions

4.5.1 Design measures for thermal comfort:

Firstly, thermal comfort is achievable across Southern Africa with three packages of thermal design intervention incorporating orientation, appropriate colouring and shading of walls and which include the thermal insulation packages set out below.

(1) In the Hot season it is impossible to provide for comfort in the extremes of Regions 3 & 6, however a very significant reduction in Internal Air Temperatures is achieved if the roof/ceiling R-Value of 2.50 m^2 °C/W is coupled with wall insulation of 1.2 m^2 °C/W.
This could be referred to as the Level A intervention package.

(2) The extremes of the Highveld and Southern Interior climates (Regions 1 & 6) require a level of roof or ceiling thermal insulation corresponding to a R-Value of 2.50 m^2 °C/W.
This could be referred to as the Level B intervention package.

(3) The milder South & Western Cape Regions (Region 4), the lower altitude Interior stations such as Pretoria (Region 2) and the Kwa-Zulu Natal coastal belt (Region 5) require a roof or ceiling R-Value level of at least 1.5m^2 °C/W to achieve comfort. This could be referred to as the Level C intervention package.

Secondly, it is evident from the results of the simulations of the 53m2 Agrément reference house that lower (and perhaps cheaper thermal insulation) or intermediate thermal design solutions cannot provide comfort in hot weather and cannot provide homes which can be heated to comfort in winter. Thermal insulation to the R-values set out above is crucial to the achievement of comfort in both hot and cold conditions. Measures other than thermal resistance have less than 25% of the effect of thermal resistance in the shell [16][40].

4.5.2 Constraints and conclusions

The six climatic regions show much variation in climate around South Africa. It is evident that with the variation of climate comfort standards vary as result of acclimatization. The variation in thermal neutrality across the climatic regions is set out on the charts of Figure 4. As result of this variability different standards of thermal design are appropriate for different parts of the sub-continent.

The modeling has been performed within the constraints of the standard designs. This denies the possible use of thermal capacity, the reduction or increase in window size, as interventions.

The important conclusions to be drawn in relation to the levels of design intervention necessary for comfort and energy efficiency, are that the R-values set out above are crucial to the achievement of thermal comfort in both hot and cold climatic regions. This is to imply that all of the no cost measures and plasterboard ceilings are not sufficient to achieve comfort.

Chapter Five

AN ESTIMATION OF THE POTENTIAL OF THERMAL DESIGN AND INSULATION IN SOUTH AFRICA TO GENERATE GREENHOUSE GAS REDUCTIONS

5.1 Overview of the estimation methodology

5.1.1 Alternative methodologies reviewed

Praetorius and Spalding-Fecher [30] calculate emission reductions for a number of energy efficiency measures in low-income homes. The improvements to the thermal design, with assumptions of a changing fuel mix, are input to the calculation of emission reductions for a one million low cost housing project.

Taylor's analysis of middle income 180m^2 houses [40], and his subsequent chapter on low income housing, uses the NewQuick programme for the calculation of the heating energy savings effects of various design measures. These are converted to various energy sources for the estimation of the effect of upgrading some 3.1 million shacks with insulated ceilings. The ratio of energy sources is assumed constant at the 1996 mix.

Simmons calculates the financial and economic benefits of various ceiling and insulation systems [34] and the emission reductions consequent upon the resultant energy savings.

Holm and Lane [19] calculated an emission reduction, which can be expected from the implementation of the basic interventions similar to those proposed in Chapters 2 and 3 of this thesis, and the heating requirement in terms of temperature differences, calculated for the country, as the difference between the local thermal neutrality and mean temperatures.

In Table 6 the annual impact of the housing energy efficiency interventions, is projected forward to 2025, using only the electrical energy usage of grid-connected houses.
(See Appendix 3 for projection factors.)

Year	Total Consumption (GWh)	CO_2 Pollution (Million metric tons)
Current	32 000	26.2
2025 Business as usual	66 500	54.5
2025 With intervention	60 000	49.2
Reduction	6 500	5.5

Table 6: Projected reductions in electrical energy consumption and CO_2 emissions

5.1.1 Alternative methodologies review (continued)

A review of fuel use for space heating in South Africa shows a differing mix of energy sources for rural and urban communities, and again significant differences between low income and other income homes. This is evident in Figure 2 of section 2.4.3 of this thesis as per Holm [20].
Some 80% of urban households are grid connected [8] and 66% are estimated to use electricity for heating [22], while 51% of rural homes use wood for space heating.
It is submitted therefore that a differentiated approach to the calculation of energy savings and consequent emission reductions, is appropriate.

The possible impact of appropriate policies to advance emission reductions in each of these two income sectors is indicated for detailed calculation by experts in this field.

5.1.2 The methodology used in this thesis to calculate emission reductions

The analysis of potential emission reductions by low-income homes, on the one hand, and then middle and upper-income homes, are calculated separately in view of the differing fuel usage patterns and energy usage. The presumption is based on an analysis of graphs provided by Holm (see Figure 2 of Chapter 2) which show 80% of electricity consumption to be by upper and middle class homes at the present time, constituting the most immediate opportunity for improved thermal efficiency to effect GHG emission reductions.

The provision of formal housing for families, presently housed informally, is the goal of the state [22]. This presents an opportunity for a change of energy source, if desirable. The switching of low income households from carbon burning (principally coal in the Highveld region) to electrical space heating presently implies a switch from one carbon based source to another. Future generating plants with low emissions (possibly hydro or nuclear), and the correct planning and controls over the emissions of electricity generating capacity, will provide GHG reductions.

This market constitutes the second part of the identified energy and emission reduction project. It will be shown that if the appropriate interventions are applied by government to both sets of housing, substantial positive effects will flow and presently experienced undesirable effects will be avoided.

The heating requirements for various regions of South Africa are detailed in section 4.2.
A model of the 'standard home' for the two sections i.e. low cost and the middle/upper income sections, is developed in section 5.3. An estimation of annual energy consumption is provided in the NewQuick software which yields a relative efficiency measure. The potential of the proposed set of intervention measures to result in energy savings, and as a result to generate reductions in carbon usage, which will give rise to reductions in greenhouse gas generation, is investigated for each group in section 5.4.

5.2 Winter heating and summer cooling requirements in South Africa.

The winter heating temperature requirements and summer cooling requirements for the major centres have been set out in Table 1 of page 18 and 19 and on the maps provided by Holm in Figures 5(a),(b) and (c) on pages 29 and 30. The maps of temperature difference provide the basis for combining climatic regions, primarily in terms of the heating requirement, and secondly in terms of a cooling requirement.

The regions are identified as follows:

Firstly, as the mild coastal areas stretching from east of Port Elizabeth northwards, in which area the heating requirement is less than 8 °K, including Durban and East London, Richards Bay, i.e. Region 5;

Secondly, the cooler Western Cape coast and inland areas below 1000m in altitude, in which the heating requirement is less than 10 °K , and including, Cape Town, George, Port Elizabeth, Bisho, Umtata and Pietermaritzburg, i.e. Regions 4 and 2;

Thirdly, the inland areas which are mostly over 1000m in altitude where significant heating is necessary, and including Gauteng, Free State, most of the North West Province, towns such as Ladysmith in the KwaZulu-Natal Midlands, Kimberley, Queenstown, De Aar, Pretoria and Polokwane, in which the heating requirement is over 10°K , and rising to 14°K in towns such as Bloemfontein and Sutherland, i.e. Region 1;

and Fourthly, those areas where cooling is necessary in summer, that is; the Northern KwaZulu-Natal, Mpumulanga and Limpopo Province lowveld areas, and the central and northern interior, including the towns Phalaborwa, Upington, Gaborone, i.e. Region 3.

This classification, and a comparison of the ΔT for winter as per Table 1 enables realistic grouping of the heating requirement in the major centres of South Africa, and points towards an approximation of 10°K average winter heating requirement for all major population centres, with towns in milder climates compensating for those in the more extreme areas.

5.3 Housing stock and heating energy efficiency

5.3.1 Low-income housing

The quality of low income housing being produced in 2003, with respect to thermal design has been determined to be very poor, as per the review in Chapter 2. The basic unit 30m^2 NHBRC design is representative of the current standard of low income house if a 'business as usual' assumption is made. Although it is not possible to introduce thermal design measures which will bring the house into the comfort zone or range of thermal neutrality for any climatic region, this design of house is considerably improved in terms of absolute temperature reduction, in the hot condition, by the basic thermal design interventions proposed in Chapter 3.

The level of energy efficiency is greatly superior to that of the shacks from which it is assumed these families will move. The heating of 36.2m^2 average size informal homes in Pretoria was investigated by Holm for Eskom [18]. A coal stove is used for cooking from 18:00 to the time the stove extinguishes at 22:00, consuming 5.8kg of coal per night, over 120 heating days per annum and provides some 480kWh/m^2 of energy per annum. Adjustment needs to be made to the above data for application on the Highveld. The temperature difference data in Table 1 is used to gross up the Pretoria data by 12%.

The efficiency of a new 30 m^2 house with proposed interventions is as set out below:

NHBRC 30m^2 Thermal performance without design intervention						
Region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temp.(C)	43.40	42.10	48.90	42.60	41.40	48.30
%Persons Comfortable	0.00	0.00	0.00	0.00	0.00	0.00
Heat Equipment (kW)	7.40	5.40	3.00	4.70	3.20	5.70
Energy Efficiency per Annum (kWh/m^2)	195.33	114.87	47.83	97.10	53.73	115.93
NHBRC 30m^2 Thermal performance with basic intervention						
Region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside peak temp.(C)	35.70	35.50	41.70	34.30	34.60	41.60
% Persons comfortable	0.00	0.00	0.00	0.00	0.00	0.00
Heat equipment (kW)	4.60	5.40	3.00	2.60	1.70	3.30
Energy efficiency per Annum (kWh/m^2)	119.30	61.00	19.30	45.60	23.67	59.30
Decrease annual heating energy (kWh/m^2)	76.03	53.87	28.53	51.50	30.07	56.63

Table 7: Decrease in annual heating energy for NHBRC 30m^2 design with basic intervention

5.3.1 Low Income Housing (cont)

The $30m^2$ house design is the 'business as usual' point of departure for analysis. It is thermally inefficient due to the large surface to volume ratio. It can however be regarded as a starter house around which other rooms will be constructed over time as funds allow. It will begin to perform thermally, after these additions, only if the suggested thermal design interventions are in place. With these additions and with the introduction of roof/ceiling insulation the house will be brought into the comfort zone.

The methodology used to develop the necessary thermal design interventions was to make used the $53m^2$ Agrément Board design house as a starting point. However it is no longer built in any number and it can be safely assumed that it will not be built in the near future. This assumption is based on the present backlog of houses, and shortage of funds on the part of Government.

The use of electricity for space heating in informal homes is very low [34]. An emission reduction programme in this sector of the housing market may need to be based on an appliance change, as well as an energy efficient design, which brings about a change in energy source for space heating.

Simmons presents the Eskom residential survey of consumption patterns for space heating and calculates a time-weighted proportion of house-hold fuel type usage over the 20 year expected life of a ceiling. This calculation builds in a fuel switching from coal and paraffin to electricity [34].

It may be a fair generalization that the space heating practice of the average informally housed family is presently such that the living rooms of the homes are heated either by a wood, or coal stove or paraffin heater [35]. If the family moves into a well-insulated low-income home, the heating energy required to raise the temperatures in the dwelling to the lower limit of comfort is less than previously. The size of appliance necessary to heat the entire house is reduced (1.9kW) given the improved thermal design of the structure and is now affordable. The main living room can now be economically heated with a smaller clean burning (gas or electric) appliance, and the temperature in the reminder of the house is raised by heat spillage into other rooms, (which are used for sleeping), and a higher level of comfort generally is experienced. The area of house heated to normal comfort levels will be approximately $20m^2$.

The reduction in emissions will be the difference between that given off by the old wood or coal stove, and that emitted by the new gas appliance or the emission resulting from the use of an electrical space heater. (As the Simmons research was done in 1997 it may now be possible to verify whether the switching of appliances has actually occurred.) If the average informal house was originally heated with coal, the heating energy supplied to heat the structure may have been adequate, albeit concentrated in one room. This area is assumed to be provided in the $20m^2$ living area, and the full savings in energy is considered to be realized over this same area when the household converts to gas or electricity for space heating.

5.3.1 Low Income Housing (cont)

The base case household considered will make a transition from a shack to a formal house. In the process they will save the heating fuel used in the informal house/shack, i.e. they will save some 784kg of coal and 1089litre of paraffin per annum, with an emission reduction of 2494kg of CO_2, and enjoy a cost saving of R1 425 in 1997 Rand terms (R2 024 - 2003)[18].

If the recommended level of thermal insulation has been installed in the ceilings or roof of the new house, the new household space heating energy consumption will be 743kWh per annum over the approximate 20m^2 heated area. This estimate is derived from modeling the 3.250m x 4.250m living room as the only room in house actually heated, with expected variable occupancy, and spillage into a kitchen and bedroom. The duration of the heating period is from 16:00 up to 22:00 in the evening, and from 05:00 in the morning for three hours, similar to that of Simmons [34]. Actual measured data/evidence is necessary to normalize this energy consumption assumption. However the reasonability of these assumptions is cross-checked against present household consumption of 1333kWh per annum (thermally inefficient houses) in Appendix 5.

The electricity used for lighting could contribute a further 1000kWh per annum to the 743 kWh of heating energy. The amount of coal used at the generating station to provide this 1743kWh of energy to heat and light up this house is 889kg. This generates some 1797kg of CO_2 emission. If the cooking energy is now provided by a gas ring, this appliance will add 441kg of CO_2 [30]. A total of 2238 kg of CO_2 is therefore emitted by the new house.
The effect on emission reductions of these energy efficiency measures, with these assumptions is 256kg of CO_2 per annum.

If the actual unit cost of the electricity to the consumer at 0.35c/kWh, and the free 50kWh per month subsidy is ignored, the cost to the consumer for the electricity is R610 per annum.
The cost of gas for cooking purposes corresponding with the gas ring is R450 per annum.
The net cash benefit to the households appears favourable in the amount of a R964 saving.

If the performance requirement for all houses is to achieve the same level of heating energy efficiency (for heating below 16°C) corresponding to the Agrément 53m^2 reference house, with the basic level of intervention, i.e. 33kWh/m^2 per annum, and designs are developed to achieve this a significant emission reduction would be realized.

By reference to Table 6 on page above it is noted that the saving of energy in the 30 m^2 insulated house over the insulated house, in Gauteng, over a year is in excess of 2 280kWh, which point to a insulation retrofit project as being productive in terms of generating emission reductions.

5.3.2 Middle and upper-income housing

The consumption of energy in this category of house-hold is significantly higher than the low income housing category, possibly as high as 621kWh per month. The proportion of houses in the sector making use of electricity for space heating is high at 66%. The average annual consumption of electricity is 328kWh per month. Average electrical consumption is some three times that of a low income household and the economic level is 450kWh [45], indicating a huge cross-subsidization by this sector of the lower income sector.

Taylor uses the NewQuick software to estimate the reduction in heating energy usage which occurs as result of improved thermal design [40]. He makes careful estimates of appliance usage and examines the relative value of aspects such as orientation, wall colour, window area and the benefits of ceiling insulation. This house is 192m^2 in footprint area, has double brick plastered walls and a tiled roof, with plasterboard ceiling.

Taylor's findings on the financial benefits of ceiling insulation are that families can achieve a payback within a period of three years, in some climatic regions, for an insulation level of 50mm Fibreglass, if the house is electrically heated. The return on investment is better when based on those areas of the homes which are actually heated.

These figures have been confirmed by simulations run by the TIASA Technical Committee for submissions to Sodelund and Schutte, the consultants to the National Department of Housing. It is important to note that the payback on insulated ceilings was as low as 21 months [11] if the whole house is electrically heated.

The issue of fuel switching is not as crucial to the middle/upper income standard house, although fuel usage is also mixed. The use of electricity for space heating is standard for 48 % of housing around South Africa [22] and this can probably be assumed to be constant in the absence of any obvious drivers to direct or incentives in place to encourage otherwise. An electricity tariff which differentiated between off-peak and on-peak usage (time-of-use) might direct towards a greater use of gas for space heating. This does not appear to be on the National Energy Regulator agenda at present, but Eskom DSM have expressed interest in the concept [28][33].

The electrical power capacity of the heating equipment in the average mid/upper income home was said to have been surveyed and found to by Taylor to be 6.0kW. The heating capacity requirement to heat a house of this size which is not insulated is 11.6kW. According to the reported heating patterns only 33% of the house is being heated to comfort level i.e. some 60m^2. With intermittent use of heating in the bedrooms, and the rest of the house being allowed to drift, the area heated to comfort levels is only 50m^2.
The average size of the mid/upper income homes, ignoring out-house and garaging space is possibly nearer 120m^2. The heating equipment required to maintain comfort temperature in this size of house on the Highveld is 8.6 kW if poorly insulated. If a conservative assumption is to be made on the area to be heated, such as to maintain comfort, it is perhaps 50m^2.

5.3.2 Middle and upper-income housing (cont)

It is quite likely that the standard house is cooled in summer, and this assumption has been built into the energy efficiency estimates calculated below:

See Table 8 below for energy efficiency differences between the un-insulated house, and that with the proposed basic level of intervention, in each area.

CSIR 120 m^2 with Gypsum ceiling						
Region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temp (°C)	32.2	33.0	38.9	32.4	33.1	39.3
%Persons Comfortable	0.00	0.00	0.00	0.00	0.00	0.00
Heating or Cooling Equipment kW	8.20	8.60	15.7	6.80	10.2	8.80
Energy Efficiency of Heating & Cooling kWh/m^2 p.a.	69	70	58	56	41	91

CSIR 120 m^2 with proposed basic interventions						
Thickness of Fibre Insulation in ceiling	100mm	100mm	100mm	50mm	50mm	100mm
Region	Highveld	Pretoria	Phalaborwa	CapeTown	Durban	Upington
Inside Peak Temp. °C	26.1	27.9	32.7	27.6	29.2	34.0
%Persons Comfortable	100.00	95.00	0.00	98.00	78.00	0.00
Heating or Cooling Equipment kW	4.90	5.0/3.8	7.4	4.30	4.10	5.00
Energy Efficiency of Heating & Cooling kWh/m^2 p.a.	35	35	25	28	20	50

Difference in energy efficiency as result of interventions kWh/m^2 p.a.	34	35	33	28	21	41

Table 8: Regional differences in energy efficiency with thermal design interventions

The arithmetic average of the differences in each region is 32kWh per annum. The split of urban coastal to urban inland housing is presently in the ratio of 42:58 [22]. The theoretical energy saving resulting from the proposed basic intervention level is approximated at a 30kWh/ m^2 consumption reduction per annum across all regions.

If the estimated effective area of space heating for each residence is 50m^2 the saving in energy consumption with the basic thermal design interventions will be 1500 kWh per annum. The reduction in emissions is estimated at 1551kg of CO_2 per household per annum.

5.4 Green-house gas reductions calculated

5.4.1 Low income households

The potential for greenhouse gas reductions from this quarter will be determined primarily by the design of energy efficient houses. This may mean moving to a slightly bigger shared unit design, either in rows or clusters. If the government subsidy could be increased by some R40 per square metre to provide for energy efficiency improvements to the level of 33kWh/m^2 per annum, the energy saving by a portion of households could generate as much as 1720kWh/m^2 per household. With a shift to cleaner heating appliances this potential will be reached sooner.

The second determinant of the extent of emission reduction is the rate of delivery of these units. If 200 000 continue to be produced each year, the backlog will still be reality, with migration and HIV/AIDS influencing the demand for such houses. At this rate 4.4 million houses could be built by 2025.

It is possible therefore to foresee an average emission reduction of the order of 3.9 million tons of CO_2 per annum being effected from interventions in this sector over the period.

5.4.2 Middle and upper-income households

If the number of middle/upper income homes to be constructed in the period 2003–2025 is some 2.2 million houses the average annual emission reduction is estimated to amount to 3.4 million tons of CO_2.

5.5 Conclusions

The probability of a fuel switch to electrical power for space heating by low income households depends on the probability of the marginal cost of electrical energy (and concomitant appliances) being lower than that of coal or wood (plus the traditional low cost appliances) at some time in the future. At 1997 costs this looked to be a beneficial decision for households [34].

If regulation and legislation is put in place for energy efficiency in houses for the middle and upper income level homes a significant reduction in greenhouse gasses will accrue.

If government is prepared to increase the low income housing subsidy by some R40/m^2 and make thermal design mandatory to achieve a level of energy efficiency of 33kWh/m^2 significant emission reductions can be anticipated from this sector.

The combined reductions in emissions over the 22 year period to 2025 might amount to 160 million tons of carbon dioxide emission.

Chapter Six

COMPARISONS BETWEEN ENERGY EFFICIENCY MEASURES IN FOREIGN REGULATIONS & RESULTS OF SURVEY

6.1 Reviews of energy efficiency regulatory systems

6.1.1 International housing energy code reviews

The International Survey of Building Energy Codes [5] performed by the Australian Greenhouse Office reviews the housing energy codes of Australia, The United Kingdom, The United States, California, Canada, Singapore and New Zealand. This document contains much useful analysis relevant to the South African position and covers the types of codes in use in other countries, which can indicate options for a South African energy code.

The PA Consulting Group reviews the Energy Codes of Guam, Sri Lanka, Jamaica, the International Energy Conservation Code and the ASHRAE 90.1-1999 codes, in the process of recommending an energy code for Vietnam [36]. The Jamaican code is based on the codes of many other Association of South East Asian Nations (ASEAN) countries, and as these are predominantly developing countries and are in a similar per capita income category as South Africa, their structure and stringency is relevant.

The Soderlund and Schutte draft report on standards for Energy Efficient Housing in South Africa for the National Department of Housing presented in April 2003 [37] provides a review of a number of foreign energy codes. This document suggests a way forward for energy efficiency in South African housing and is a logical point of departure for further developments in this field.

6.1.2 Review of elements of an energy code

6.1.2.1 Objectives

More recent energy codes have as their objective the reduction of greenhouse gases. Some of these codes have been developed in response to the Kyoto protocol. The imperative need for reduction of energy usage has driven developments in California and the spectre of power shortages in South Africa in the near future (chapter 1 references) could drive a similar programme. The New Zealand energy code is driven by the economic justification (payback period).

Secondary objectives have surfaced in the South African context. The need to upgrade the housing stock in South Africa for comfort is apparent from chapter 3. Comfort has been identified as the driver of energy consumption in chapter 4. These improvements will enable public health improvement objectives to be met.

6.1.2.2 Regulatory frameworks for energy codes

The principle of introducing a hierarchy of performance objectives (Nordic approach) has been proposed by Watermeyer [37] for the South African energy efficiency standard for housing. This is similar to the Australian approach.

This will be to place the stated objective of the standard or regulations at the apex, from which the functional statement level follows, and which in turn lead to the performance requirements level.

The Nordic structure is in common with other standards, and the South African Building Regulations are presently framed in such a structure. The structure envisaged is described as a four level regulatory system with the further levels comprising a verification (method) level to which four alternative compliance or performance based methods are subservient.

The frameworks for most national energy codes usually include two or three methods and further procedures or rules within these methods, which contain tabulated alternatives or trade-offs within the procedures.

A performance approach is proposed for many jurisdictions. The justification for the level of stringency within the performance approach is not detailed in the Australian standards themselves [6], or the reviews described above. The methodology used to arrive at the proposed interventions for a South African energy code, should therefore be set out in any standard which is developed. If the rationale for the proposed interventions is explained the precise performance objectives may be met, and the level of stringency understood.

6.1.2.2 Regulatory frameworks for energy codes (cont)

A prescriptive approach (deemed to satisfy) is usually embodied in various multi-tabular formats which are simple and therefore suitable for application to the majority of (more simple) structures.

A trade-off approach is allowed in most jurisdictions. This compares a notional or reference building which complies with the prescriptive approach or that of an energy code (e.g. International Energy Conservation Code in the United States) with that of the proposed building. These are achieved by elemental calculation of average U-value or by computer modeling.

An energy rating approach is part of many codes. The energy usage, consumption or cost is compared to a reference building which has been found to perform in accordance with the prescribed approach.

Most energy codes have a geographic basis for differentiating between climatic zones, which require a different design approach or level of stringency. The variation in climate warrants that this is also applied in South Africa.

6.1.2.3 Philosophy and scope

The voluntary application of energy efficiency in buildings has proved to be a failure in South Africa for low income housing, leading to a state where highly uncomfortable and unhealthy houses are being provided (see Chapters 1 and 2 detailing).
The reported absence of ceiling insulation in some 4 million houses in South Africa [32] points to a lack of success of the present voluntary approach to energy efficiency in the upper and middle income housing market.

There is also evidence of disfunctionalism in commercial and retail markets [27] in the numerous thermally inefficient structures. Efforts to form a consensus around the necessity for an approach such as is proposed by the South African Energy and Demand Efficiency guidelines project (SAEDES) [16], for non-residential structures in South Africa, have met with limited success [44].

A prescriptive approach for this market is therefore being favoured (by the state), as is evidenced by the support of the Department of Minerals and Energy for the SAEDES Guideline and the development of draft SANS 204 Energy Efficiency and Command.

The size and occupancy types or classes has to be decided in the scoping of an energy code. Most codes differentiate of the basis of residential as opposed to other types of occupancy or use. A size differentiation has been used in some countries, with New Zealand using a 300 square metre size limit for application of the residential and small building category [5].

6.1.2.3 Philosophy and scope (cont.)

Aspects covered in various codes include; windows and building envelope thermal performances (R-values), shading, window to wall ratios, air tightness, lighting, heating, ventilation and air-conditioning aspects and equipment, hot water heating, pipe-insulation, metering and system controls and financial criteria.

6.1.2.4 Performance measures – qualitative & quantitative

The performance measures selected in countries such as the United Kingdom and New Zealand which have a performance based energy code are not strictly performance measures in the context of the envisaged Australian energy efficiency standard (Building Code of Australia), in that the policy of having a qualitative performance criteria still requires subjective intervention, in the establishment of the level of stringency of quantitative parameters.

For example, in New Zealand the Building Code Index (BCI) is constructed by reference to a standard house, which is built up with 'deemed to satisfy' elements.

It is presumed that the Australian standard of energy efficiency is reached via a process of reverse engineering to a target of carbon emission reduction applied to a standard house. The financial cost constraints of micro-level viability, and societal constraint of economic viability probably limit intervention measures, as detailed in section 5.1.2.5 on Stringency details.

The range of thermo-neutrality in South Africa lies within the range of temperature fluctuation for major population centres for the major period of each year. The unique methodology herein employed, which targets a limiting of the fluctuation within a structure, to determine the required intervention measures proposed for South Africa, it is submitted, is therefore valid. The effort to achieve a passive design for each of the major population centres is set out in Chapter 2 and 3 herein. The requirement for comfort could therefore provide the functional requirement in a South African context.

The Building Code of Australia uses the phrase 'capable of efficiently using energy'. The performance criteria consequent on this functional requirement is the package of intervention measures and thermal insulation level necessary to meet the proposed passive design functional requirement. The components of the thermal design combine to result in a level of thermal efficiency as measured in section 4.2.1.

6.1.2.5 Stringency

The level of stringency adopted is dependant largely on economics and political will.

In Australia the original commitment to reduction in greenhouse gas emissions is tempered with the rider of 'to the extent reasonable'. The commitment of the then government to a 'beyond no regrets' level, that is beyond what would be cost effective at a micro or household level, has not been matched by a more conservative new government. A decision on a level of stringency of energy efficiency measures for Australia has as result been delayed. The consideration of cost externalities, such as cost to the environment, community health, etc. presently not with standing a short term approach.

In South Africa the constraint of the affordability of the further subsidization of low income housing is the major barrier to energy efficiency. If the cost of an insulated ceiling, plus the costs of shading on north facing windows and cavity walls in some areas, is to be added to the subsidy, this will be the major obstacle to progress towards the provision of reasonable comfort and energy efficiency.

Indoor and local outdoor air pollution reduction, and health and welfare improvement efforts in the townships, would dictate that improvements are pushed through such as to benefit low income housing. The cost of these pollution externalities have been estimated and can be evaluated with the direct cost savings [30] against the increase in subsidy.

As a matter of principle and in terms of the constitutional rights of home-owners, the level of stringency applied (and therefore the level of comfort) should be the same for low income homes as for upper income homes. An economic approach may be valid for this later market segment as is reviewed below.

For South Africa the proposed basic level of intervention in Table 3(a) of section 3.4.3 on page 25 is intended to be a 'no regrets' approach. That is that the net present value to householders, of the cash benefits, is positive. In the middle and upper income households the cost of the interventions will be carried by householders themselves. In the process of evaluation of stringency measures, energy costs also need to be extrapolated forward to costs post 2007, i.e. after construction of new electricity generating capacity. These households are anticipated to have the cash available for investment. The decision is a rational one, even at present costs. See net present value cash effect calculation in Appendix 5.

The basis for the stringency levels established in New Zealand is presently on a return on investment basis. It is expected that standards in New Zealand will be increased in response to the Kyoto protocol [5].

6.1.2.5 Stringency (continued)

The passive design elements of Table 3(b) on page 36 can form the basis of a more effective future level of stringency to the energy efficiency code i.e. 'beyond no regrets'. Some form of subsidy by way of a rebate of electricity billing or tax concession will be necessary for a 'beyond no regrets' level of stringency.

The use of the time period for compliance for South Africa to meet the deadline for implementation of energy efficiency in terms of Kyoto protocol, to delay implementation of energy efficiency is considered not to be acceptable. This is on the basis of a consideration of current costs against the long term cost penalty for not acting immediately or soon (that is the damage suffered nationally and individually by not acting). The additional concern is that retrofitting poor thermal design after the event is more and very costly.

The level of stringency proposed in the SAEDES (South African Energy and Demand Efficiency Standard) proposal of 1999 for commercial buildings, has relevance for the South African housing energy standard. If the levels of thermal transmittance proposed for roof and ceilings in Figure 6 of Section 8.5.1 of the SAEDES are reviewed and compared with the thermal resistances of Table 3(a) the SAEDES (16) figures are found to be similar, as set out below.

	Thermal resistance (m^2°C/W)	
City	SAEDES	TIASA
Johannesburg	2.12	2.50
Cape Town	2.00	1.50
Durban	1.75	1.50

Table 9: Comparative levels of thermal resistance

6.1.2.6 A standard building, verification methods and modeling software

A reference building which complies with the prescriptive provisions of an energy code, and which is modeled with an approved software package, such as might conform to ISO 16389 [24], can provide a verification or assessment method.

The assumptions to be made as to heating temperature, hours of heating and ventilation rates need to be standardized. The verification or assessment can be performed by manual calculation, however in order to make the exercise reasonably simple to use it is usually confined to a weighted average U-value calculation for the shell of a structure.

6.1.2.6 A standard building, verification methods and modeling software (cont)

The Agrément Board of South Africa has made use of the NewQuick software to assess the energy usage of houses, for space heating purposes, and has proposed the $53m^2$ design detailed in Appendix 3 as a reference house.

Further modeling of this house indicates that the thermal performance can be improved with the basic thermal design interventions proposed. The comfort levels in smaller houses such as the $30m^2$ are not responsive to the interventions.

6.1.2.7 Prescriptive methodologies and provisions

Early energy codes were prescriptive, e.g. The United Kingdom, Singapore etc. and probably had as their objective the protection of tenants and purchasers of houses from poor quality (poor thermal performance) accommodation. Across-the-board mandatory R-value standards have subsequently been raised in order to affect greater energy efficiency in most countries.

6.1.2.8 Application and limitations, building types

The application of energy codes in many jurisdictions is to regulate commercial, institutional, and government buildings ahead of residential buildings [36].

The SAEDES Guideline [16] is proposed for buildings other than free standing houses and multi-family building units of three or less floors, manufactured/mobile homes and buildings which do not use electricity, fossil fuels or renewable energies.

The ASHRAE (American Society of Heating, Refrigeration, Air-conditioning Engineers) or IECC (International Energy Council Code) standards have been applied in many jurisdictions to commercial buildings. The SAEDES Guideline is similar and is applied in practice for some members of the SAIME (South African Institute of Mechanical Engineers)[44]. SAIME, SAIRAC (South African Institute of Refrigeration & Air-conditioning) and other role players should be brought into a process of developing an energy code and possible adoption of the SAEDES Guideline as an appropriate basis for the commercial side of an energy code for South Africa. The proposals for thermal design in housing could be scoped so as to compliment the SAEDES proposals.

6.1.2.9 Naturally ventilated structure treatment

The methodology by which the proposed thermal design interventions for housing are reached, is based on naturally ventilated structures (as discussed in 6.1.2.4).

6.1.2.10 Climatic zoning

Most jurisdictions differentiate on a climatic basis. The proposal for South Africa is based on the heating (and cooling) requirements of four zones:

Firstly, as the mild coastal areas stretching from east of Port Elizabeth northwards, in which area the heating requirement is less than 8 °K., including Durban, East London,and Richards Bay, i.e. mainly Region 5;

Secondly the cooler Western Cape coast and inland areas below 1000m in altitude, in which the heating requirement is less than 10 °K, and including, Cape Town, George, Port Elizabeth, Bisho, Umtata, and Pietermaritzburg, i.e. mainly Regions 4 & 2;

Thirdly the inland areas which are mostly over 1000m in altitude where significant heating is necessary, and including Gauteng, Free State, most of the North West Province, towns such as Ladismith in the KwaZulu-Natal Midlands, Kimberley, Queenstown, Pretoria and Polokwane, in which the heating requirement is over 10°K, i.e. Region 1;

Fourthly, those areas where cooling is necessary in summer, that is; the coastal and northern KwaZulu-Natal, the Mpumulanga and Limpopo Province lowveld areas, and the central and northern interior; including the towns of Durban, Richards Bay, Phalaborwa, Upington, (Gaberone), i.e. mainly Region 3.

There is probably a case for a further region for which colder areas with a heating requirement of over 12 °K and rising to 14 °K in towns such as Bloemfontein, Sutherland, Harrismith, and Kokstad.

6.1.2.11 Fenestration

The prescriptive packages of thermal resistances for the building shell should include tables for maximum percentages of window area for the floor area or per unit façade area. Trade-off strategies which compensate for high heat loss through windows should be allowed. This can be achieved with tabular listing of roof, wall and floor thermal resistances for each percent of glassing in the shell. (The IECC figure 14 is illustrative.)

In the South African context it may be instructive to detail roof and wall overhangs necessary for maximization of winter solar gain and minimization of summer gains through windows.

Tables for the calculation of total heat gains through window assemblies, including gains through frames should be provided.

6.1.2.12 Fuel type considerations

In California electrically heated houses require an R-49 (15inches of fibre) ceiling insulation level, due to power generating constraints.

The main fuel types for a South African energy code generally involve a form of carbon. Credits for the calculation of the energy efficiency for solar power may be considered in order to stimulate this industry.

6.1.2.13 Construction costs

In order to assess the costs of subsidy increase necessary it will be necessary for government to survey the available solutions which industry is able to offer.

The TIASA member presentations to the consultants to the World Bank, for the pilot project to provide insulated ceilings to a number of low income houses, has provided much of this cost information.

6.1.2.14 Modeling software

The *NewQuick/Building Toolbox* software can be cross checked against other modeling software, if the software is to be used beyond comparisons or referencing to a standard house. The software could also be tailored to specifically to this task, for general use, in the housing construction industry.

If the software can be shown to conform to ISO13790 Thermal performance of buildings – calculation of energy use for space heating [23], this will improve the confidence levels and increase the likelihood of adoption into a national standard.

6.2 Similar climatic regions in other national jurisdictions

6.2.1 Methods of comparing climatic regions

In Table 10, below, climatic parameters for many cities around the world, which could have similar climates to South African cities, are set out. A comparison of the parameters leads to conclusions as to the uniqueness of the South African cities, as result of the warm current influence to the coastal cities and the altitude of inland cities in relation to their latitudes.

A widely used technique for comparing climatic regions is to compare the heating degree days (HDD) or cooling degree days (CDD). The ASHRAE Fundamentals Handbook [42] details the principles behind this tool, and provides climatic design information for many centres around the world. After establishing the climatic regions which are similar to those in South Africa the stringency of the prescriptive components of the energy code can be compared.

6.2.2 Cities of similar climate to South African cities

It is evident that the winter climates of cities such as Adelaide and Perth (Australia) and Los Angeles (HDD of 692) are similar to that of Cape Town (HDD of 936). The winter climate of Miami (HDD of 114), Brisbane (Australia), and Kowloon (Hong Kong) are similar to Durban (HDD of 117).

The climates of the high altitude of cities in the South African interior, such as Johannesburg, Pretoria and Bloemfontein are not replicated by cities in Australia. Phoenix and Tuscon in Arizona are of slightly higher latitude and lower altitude, are comparable to the highveld region in winter but are very hot in summer. The heating requirements of Dallas (HDD of 1272) are not dissimilar to that of Bloemfontein (HDD of 1309 and Johannesburg (HDD of 1066).

The summer climates of Adelaide and Perth are hotter than that of Cape Town. The Los Angeles cooling requirement compares with Cape Town. The Durban summer is similar to that of Brisbane and Miami. The highveld summer cooling requirement is less than that of the compared cities of higher latitudes and buildings therefore do not require an equivalent stringency.

In view of the climatic similarities the stringency of energy efficiency standards of these foreign jurisdictions are relevant to the levels of stringency to be set in South Africa.

6.2.2 Cities of similar climate to South African cities (cont)

Table 10								
Comparative Climatic Data								
Per ASHRAE Fundamentals								
City/town	Altitude	Latitude	Heating Design	Cold Month	Mean min	Cooling Design	Cooling Design	Mean max
	m	Degrees	Dry Bulb	Mean Dry	Dry Bulb	Dry Bulb	Wet Bulb	Dry Bulb
			Min	Bulb				
Johannesburg	1700	28.23	2.80	12.70	-1.60	27.90	15.60	31.60
Bloemfontein	1348	29.10	-2.20	12.70	-5.60	32.80	15.40	36.60
Tuscon (Arizona)	779	32.12	1.10	13.10	-3.90	39.00	18.00	42.20
Phoenix (Ariz.)	337	33.43	3.00	14.50	-1.20	42.00	21.00	45.40
Albuquerque(N.M)	1620	35.05	-7.60	2.70	-14.70	34.00	16.00	37.50
Mendosa (Arg)	704	32.83	0.60	11.70	-3.50	34.00	19.40	39.00
Pretoria	1322	25.73	5.10	15.90	1.60	30.90	17.10	34.70
Dallas/Fort Worth	182	32.90	-4.40	10.00	-5.60	36.00	24.00	39.40
Cape Town	42	33.98	4.90	14.10	1.30	28.60	19.30	34.50
Port Elizabeth	60	33.98	7.50	14.70	3.50	27.30	19.80	35.90
Los Angeles	32	33.93	7.40	13.30	3.50	27.00	18.00	35.90
Adelaide	4	34.93	5.20	12.40	1.80	33.10	17.80	39.80
Perth	29	31.93	4.80	14.40	2.20	35.10	19.00	41.50
Sydney	3	33.95	5.80	13.40	3.10	29.50	19.70	39.30
Durban	8	30.95	11.10	21.00	7.60	29.30	23.70	34.00
Cape Canaveral	7	28.62	5.30	15.80	-1.60	32.00	25.00	35.60
Corpus Christi	13	27.77	2.10	14.40	-3.70	34.00	25.00	36.80
Brisbane	5	27.38	7.80	16.00	3.80	30.00	22.40	35.00
Porto Alegre(Br.)	3	30.00	6.10	13.00	2.80	33.50	24.00	37.90
Kowloon(China)	24	22.00	10.80	17.10	7.10	32.80	26.10	35.40

Table 10: Comparative temperature data for jurisdictions with climates similar to South African cities

6.3 A comparison of international energy code stringency standards

The thermal resistance of the roof or ceiling assembly is selected as the benchmark parameter to compare the level of stringency between regimes. This is based on the presumption that the roof and ceiling thermal resistance has greater influence over the comfort and energy efficiency of a house, than any other parameter [40].

Table 11
Comparative roof or ceiling insulation levels for housing

City		R-value m^2°C/W		Heating degree days to 18.3°C base temp. (ASHRAE)	Cooling deg.days (SAEDES)
Johannesburg		2.5		1066	2362
Dallas/Fort Worth	Note(2)	6.8	3.4	1272	
Pretoria		2.5		639	3238
Cape Town		1.5		936	2474
Perth		2.7			
Adelaide		2.7			
Auckland		1.9			
Los Angeles	Note(1)	8.75	5.4	692	
Durban		1.5		117	
Brisbane		2.2			
Miami	Note(2)	6.8	3.4	114	

Note: (1)Depends on power source - LPG space heating requires a lesser R-value than electric heating
(2) Dept of Energy recommendation & IIECcode

Table 11: Comparative roof or ceiling insulation levels for housing

The states of Texas and Arizona do not have residential energy codes [5], and the figures for non California USA stations are as provided by Owens Corning Fibreglass in the USA [1]. These correspond to the Department of Energy levels.

Had the IECC provisions been applied to the South African locations the roof or ceiling R-19 value would be required, i.e. SI units an R-value of 3.38 m^2degC/W. (All stations having a HHD of between 500 – 2499.) The basis of the code stringency is thought to be an economic one. A discounted cash flow of escalating energy costs being compared to first costs of the intervention. Cheap electricity costs in South Africa [9] would give the appearance of a high level of stringency in the United States of America.

6.4 Results of survey of opinion as to suitability of proposed intervention

6.4.1 Methodology of survey

A Power-point presentation of the package of proposed thermal design interventions was given on 3 June 2003 by a TIASA Technical team with the author as primary presenter, and accompanied by Professor D.Holm, and Mr. L de Beer.
Present were World Bank Energy Efficiency and Housing representatives, various Canadian and Indian consultants to the Bank, eleven members of the Thermal Insulation Association of South Africa, and representatives of the Department of National Housing,

The presentation was followed up with an e-mailing of a questionnaire, (See Appendix 4) to the TIASA membership.

6.4.2 Results of survey

An analysis of the results of the survey is given below

Responses to questionnaire	Yes	No	Uncertain
1.Was the explanation of the methodology used comprehensible?	100%		
2.Do you regard the methodology used as reliable?	85%	15%	
3.Is 80% persons comfortable performance requirement reasonable?	100%		
4.Is the heating performance requirement reasonable?	85%	15%	
5.Do you regard the deemed to satisfy levels above as reasonable?	85%	15%	
6.Is this proposal simple enough for incorporation into regulation?	85%		15%
7.Do you believe the Star Rating System will assist in promoting sound thermal design in housing?	85%	15%	

Table 10: Analysis of survey responses

The majority of comments received are in the positive for the proposals. A response level of 64% was received.

6.5 Conclusions

The proposed packages of interventions appear to be modest in relation to the levels of stringency proposed in the compared jurisdictions.

This is in view of the following factors: a relatively mild climates prevailing in South Africa, greater cost constraints on interventions as compared to developed economies such as the United States, Australia and New Zealand, and the present low cost of energy in South Africa [9].

New standards of thermal design to provide comfort and energy efficiency in South African housing

7.2.3 Alternative energy sources and greenhouse gas issues for government

The local air pollution in the Highveld townships in winter is caused by the burning of coal and wood for home cooking and heating. Large scale acid rainfall pollution in the eastern Highveld is caused by coal burning power-stations. The resource based industries: aluminum and steel making, pulp & paper manufacture, mineral refining, are all based on the coal energy source. These combine to take a toll on the Southern African environment.

As a result of economic forces the coal based economy of South Africa is likely to be a fixture. The adverse effects of this huge reliance need to be mitigated against, by all the players; government, industry and consumers. Government influence in the processes can be significant. Diverse alternative sources of energy are being encouraged. This is evidenced by the growth of natural gas supply (Sasol/Pande field) , the approval process for a pebble-bed nuclear reactor at Koeberg, and the Nepad process which may deliver more hydro-generating capacity in Southern Africa. The penetration of renewable energy sources such as solar (both domestic hot-water and electricity) and wind generation (Darling) appears to have much potential [9].

7.2.4 Health improvements in housing

The over-whelming housing problem is a shortage of funds to provide housing efficiently to low income families. The containment of state expenditures on community health (as result of respiratory disease caused by household air pollution) will follow the improvements in thermal design of buildings thus improving long term sustainability.

7.3 Comfort and energy efficiency

7.3.1 Establishing comfort criteria for housing

The relationship between percentage persons comfortable and temperature (% PC) for Southern African regions has been found to be a complex one. The temperature requirements for thermal comfort (neutrality) for both hot and cold seasons in South African conditions, has been assessed, with allowance for acclimatization, using the latest available techniques.

An algorithm for %PC variation with temperature is developed which caters for this acclimatization.

A rational basis for comfort standards in South Africa has been proposed which can serve as one of the performance criteria for incorporation into the National Building Regulations.

7.3.2 Designing for energy efficiency

It has been demonstrated that with the appropriate design measures, a modification of internal temperature environment can be achieved which will influence the amplitude ratio or thermal swing within the structure, such as to bring the internal temperature to within the range of comfort neutrality, and even such as to achieve passive design.

The South African climate is relatively mild in comparison with climates of similar latitudes. This mildness enables the above methodology to be employed to devise a level of interventions which will achieve comfort with minimal energy input.

Performance standards for the thermal resistance of the shell of the structures are proposed. These measures and other design measures, are proposed which will meet comfort standards, and provide houses which can be heated effectively, with a reasonably low energy cost.

The performance requirement necessitates different levels of stringency for the various regions of South Africa. The maps of heating requirements in winter and cooling requirements in summer provided by Holm are clearly illustrative of the need for this differentiation.

7.3.3 Building and promoting an energy efficiency scale

A Star Rating Scale has been proposed which will enable the rating of houses from an extreme of inefficiency through to an energy efficient passive design, using a software package approach. The software used in South Africa is *Building Toolbox or NewQuick.*

A standard for energy efficiency can be recommended which is based on the comfort standards achieved. The Star Rating System will result in energy efficiency being introduced as a criterion for the valuation of houses. This will have the effect of introducing energy efficiency to the resale market. With the appropriate publicity the advantages of thermal efficiency can be popularized.

The prolific habits of a society can be changed. If the efficacy of energy efficiency is popularized by a promotional programme, along with measures such as the introduction of a time-of-use tariff by electricity suppliers, conservation of energy can become part of peoples' lifestyles. This will offer consumers a cheaper way of living and the perception of a more virtuous lifestyle.

7.4 A residentially based carbon reduction programme

The potential of residential energy savings or consumption pattern change, to generate reductions in carbon usage and greenhouse gas reductions in South Africa has been investigated. It has been estimated as averaging 7.3 million tons per annum through to the year 2025.

A means of achieving the successful implementation of a greenhouse gas reduction programme, can be to introduce DSM measures and energy efficiency in housing, in conjunction with one another.

An appliance switch from inefficient coal or wood based space heating to electricity or gas, is also part of the solution towards the reduction of greenhouse gasses.

7.5 Appropriate levels of stringency in a SA energy code

The establishment of energy efficiency in the building sector in other foreign regulatory systems, has set an example for the South African energy efficiency standard and the building regulations.

The Nordic framework proposed for the implementation of energy efficiency in housing will require performance requirements to be established, from which performance criteria can be established. The intervention package devised herein is entirely performance related and because of its similarity can possibly be extended to the stringency levels recommended in the SAEDES Guideline for commercial buildings.

The logic of the SAEDES relationship between the Heating Degree Days of any climate, to a U-value requirement, has attractions, although its linkage mechanism is not detailed. In order to marry the logic of the SAEDES U-value proposals with those of this study, a compromise may be necessary to match the varying regional heating requirements as per the Holm maps of section 4.1.1 with compensating deemed to satisfy U-values or R-values (thermal resistances) for ceilings. The following table is illustrative.

Heating requirement	Ceiling U-value (W/m2degC)	Ceiling R-value (m^{2}°C/W)
Less than 10°K	0.67	1.50
10 to 12°K	0.56	1.79
12 to 14°K	0.47	2.13
over 14°K	0.42	2.40

Table 11: Table of thermal resistances for regional average heating requirements

The level of stringency of the proposals is conservative in terms of foreign energy code intervention levels, mainly as result of the cheap electricity in South Africa.
The survey of opinion among insulation manufacturers and acceptance by the World Bank consultants as to the suitability of the design intervention proposals herein, indicates that a consensus in favour of the proposed measures has been developed in this group.

7.6 Proposals for successfully implementing energy efficiency policy in housing in South Africa

For all South Africans, and the world community at large, the threat of global warming resulting mainly from excessive carbon combustion emissions, hangs like the sword of Damocles over the viability of humanity, if continuing on the present course.

As to how or whether governments can influence this course of events, without destroying economic growth is the challenge. If governments do not act the sustainability of society is jeopardized. To this end energy efficiency is built into the policies of the various South African government agencies and departments [28][37]. The detail of as to how to implement these policies and the political will to press on with programmes of implementation remain the challenge.

In the South African context, if comfort and energy efficiency standards are to be built into low-cost housing, a reduction in state expenditures on community health (in respect of respiratory diseases) may be achieved. Absenteeism and productivity in the work-place will be similarly improved if in-door air quality in homes is improved [30].

If comfort and energy efficiency are to be built into middle and upper income homes, and other targeted DSM measures are successfully implemented, it is anticipated that reductions in peak hour electricity demand will result. The continued provision of affordable energy for poorer households in the community will then remain an economic possibility.

In order for appropriate housing policy decisions to be taken with regard to energy efficiency, the state of know-how on the subject, both local and international needs to be collated. For legislation, regulations and specifications to be drawn up, the know-how and expertise on the subject needs to be presented or disseminated to those who can use the information. The process of developing and collating this know-how, and the process of discussing and debating the options, needs to be in the public arena for reasons of transparency and in the interests of a better end result.

It has been suggested by Watermeyer [37] that a national standards committee is the logical forum for such processes to take place. The adoption of an energy efficiency standard in housing, in the National Building Regulations, and in the subsidy housing specification is then possible in terms of agreed functional requirements.

CONCLUSIONS

The need for an improvement in the standards of energy efficiency in buildings in South Africa has been highlighted by the hosting of the World Summit on Sustainable Development in 2002. The South African government has endorsed the need for action, to reduce greenhouse gas emissions, in the building sector, but little progress on implementation has been made in the housing sector [31].

Which what local energy efficiency standards are relevant to housing in South Africa has not yet been agreed. The standards of thermal design developed in this thesis are therefore proposed as input to a new South African National Standard in comfort and energy efficiency in housing.

In this thesis performance criteria have been developed, which enable an assessment of the efficacy of proposed thermal design measures. The ability of these measures to meet the functional requirement of energy efficiency, can now be gauged. Local objectives of comfort and health improvement are also introduced.

The methodology which has been used to develop the standards of thermal performance is suited to the unique climate of the sub-continent. This is in respect to the coincidence of thermal neutrality range and diurnal temperature fluctuation in many centres and regions.

The proposed compliance mechanisms allow for a wide range of solutions to be developed which allow a freedom of design and the exploitation of thermal mass, thermal resistance and other factors such as window size. Narrow prescriptive (deemed to satisfy) alternative routes will provide simple solutions for use in a majority of cases. Compliance methods such as the Star Rating or energy efficiency rating system, will facilitate the assessment of performance requirements. The Star Rating system, will if adequately promoted, ensure an adoption of energy efficiency into the housing resale market.

The results of the survey conducted among TIASA membership indicates that a consensus around the proposals has been formed. The comparison of stringency versus other local and international energy codes and the net present value calculations indicate that the proposals are a conservative first step, and are suitable with regard to present energy costs and levels of affordability.

To conclude, it has been shown that designing for comfort in housing can bring about significant improvements in energy efficiency and greenhouse gas emission reductions. It has also been demonstrated that high standards of thermal resistance in the shell of residential structures are essential to the provision of comfort and energy efficiency.

Appendix One

An algorithm for percentage persons comfortable (%PC) for hot conditions

Assuming following:

1.Normal distribution of Percentage Persons Comfortable (%PC) about the Auliciems Thermal Neutrality as about the 95% Fanger level.

2.Local Allowances for clothing adjustment are between clo 0.5 and 1.25, These are wider than the Auliciems figures of 0.7 to 0.9 clo.and these in part account for the 4.0 – 4.5 °K comfort band width variation difference between 95 & 80 % P.C. levels of +/- 3.5 °K

3.Temp. vs %PC is 2.90 °K over 49% from ref. 74% to 25% & is aprox.linear

4.Temp. vs %PC is 1.30 °K over 16% from ref. 90% to 74% & is aprox. Linear

5.Slopes of these two lines are 12.31 and 16.9 %/degC respectively

6.The 80% PC figure is 90% figure of 27.50 plus 10 times slope 1/12.31 i.e. 28.3 °C

7.The 80% PC figure requires adjustment for local acclimatization for any region where the Thermal Neutrality temperature exceeds 23.8 °C.

8.Thereafter the slope of the line is taken from 3. above

Function for the %PC in range of 80>%PC>20 is set out below for 28.3 to 32.0 °C								
Thermal Neutrality is input:	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8
Actual Temperature is input:	28.3	28.5	29	29.5	30	30.5	31	31.5
% Person Comfortable	80	76.02	66.07	56.12	46.2	36.22	26.27	16.32
Thermal Neutrality is input:	24	24	24	24	24	24	24	24
Actual Temperature	28.3	28.5	29	29.5	30	30.5	31	31.5
% Person Comfortable	82.46	78.48	68.53	58.58	48.6	38.68	28.73	18.78
Thermal Neutrality is input:	25	25	25	25	25	25	25	25
Actual Temperature	28.3	28.5	29	29.5	30	30.5	31	31.5
% Person Comfortable	94.77	90.79	80.84	70.89	60.9	50.99	41.04	31.09
Thermal Neutrality is input:	26	26	26	26	26	26	26	26
Actual Temperature	28.3	28.5	29	29.5	30	30.5	31	31.5
% Person Comfortable	95.00	95.00	95.00	95.00	73.25	63.30	53.35	43.40

Appendix 2

NHBRC Reference House

Base-line comparison discussed with Mr. Fred Wassenaar of NHBRC

Orientation:
Arbitrary in respect of north.

Floor:
Area: 30m^2 overall and external dimension of 5.000m x 6.000m
75mm concrete surface bed on grade.

Roof:
Cape and KwaZulu-Natal coastal Area:
6mm corrugated fibre cement sheets with no mandatory overhang.
150mm used where possible on North elevation.
Dark, matt colour. No insulation, no ceiling, no gutters.
11 degree minimum pitch but in practice 17 - 20 degree pitch on plan.
Inland Areas:
As above but mild steel sheet, 11 degree minimum pitch.

Walls:
Cape and KwaZulu-Natal coastal area:
190mm hollow concrete density 1120 kg/m^3 block in Cape,
140mm hollow concrete density 1210 kg/m^3 block in Natal with cement wash both faces.
Pastel colour outside. DPC. No airbricks.
Required wall height 2.400m at eave from Internal Floor, 2.250m as per plan
Height at apex of roof 3.15m as per plan.
All other areas:
140mm solid concrete clinker block of density 1800kg/m^3.

Interior partitions:
90mm hollow block to roof height, density 1260 kg/m^3 enclosing
Bathroom of 1.750m x 1.750m bagged finish.
Interior walls are required on most designs in order to support roof in which case
90 mm width block of density 1540 kg/m^3 used

Windows:
Daylight area: 25% not 15% of floor area as per plans supplied.
Openable section: 5% of floor area.
North Elevation: 2 off 1.500m x 1.350m
South Elevation: 1 off 1.500m x 1.800m and 1 off 1.000m x 0.600m
Glazing: 3mm clear drawn sheet.

Appendix 2 continued

Exterior doors:
2.050m x 0.900m 0,6mm pressed steel in steel jamb. Dark exterior colour.

Details below assumed and not verified with Fred Wassenaar.

Interior loads:

Convective

Hour	1	2	3	4	5	6	7	8	9	10	11	12
kW	0,30	0,30	0,30	0,30	0,35	0,35	0,38	0,41	0,42	0,42	0,52	0,52

Hour	13	14	15	16	17	18	19	20	21	22	23	24
kW	0,53	0,64	0,65	0,74	0,83	0,90	0,76	0,61	0,51	0,41	0,35	0,30

Radiant

Hour	1	2	3	4	5	6	7	8	9	10	11	12
kW	0,10	0,10	0,10	0,10	0,15	0,15	0,12	0,09	0,08	0,08	0,08	0,08

Hour	13	14	15	16	17	18	19	20	21	22	23	24
kW	0,07	0,06	0,05	0,06	0,07	0,10	0,14	0,19	0,19	0,19	0,15	0,10

Air infiltration:
"very leaky" for Summer.

Occupancy:
Two adults: 07:00-17:00
Five adults: 18:00-06:00

Activity:
Sitting/sleeping: 1,2 met. (metabolic rate)

Clothing:
Appropriate for season and activity: 0,77 summer and 0,96 winter.

Appendix 3

Agrement Board 53m^2 Reference House

Assumptions for modelling checked with Mr. Kevin Bramwell of Agrément Board

Orientation:
Arbitrary in respect of north.

Floor:
Area: 53m^2 overall and external dimension 6.335m x 8.275m
75mm concrete surface bed on grade.

Roof:
0.5mm mild steel with 300mmm overhang over all outside walls. Dark, matt colour.
No gutters. 17.5 degree pitch.

Ceilings:
6.4 mm plasterboard ceiling mandatory.
No insulation presently specified.

Walls:
230mm solid clay brick with plaster to interior face. DPC. No airbricks.
Wall height 2.500 at eave from internal floor.
No cavity in wall.

Interior partitions:
110mm brick & plastered with 13mm both sides to roof height,
enclosing bathroom of 1.750m x 1.750m and setting out internal design of three rooms.
i.e. 39.6 m2. of walling.

Windows:
Daylight area: 15% of floor area. Openable section: 5% of floor area.
North Elevation: 2 off 1.800m x 1.200m.
South Elevation: 1 off 1.500m x 1.800m and 1 off 1.000m x 0.600m.
Glazing: 3mm clear drawn sheet.

Exterior doors:
Two doors, one on North Elevation and on the West side
2.050m x 0.900m Plywood Timber with 40mm air-space in steel jamb.
Dark exterior colour.

Appendix 3 (continued)

Agrement 53m^2 reference house (continued)

Interior loads:
Convective

Hour	1	2	3	4	5	6	7	8	9	10	11	12
kW	0,0	0,0	0,0	0,0	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Hour	13	14	15	16	17	18	19	20	21	22	23	24
kW	0,00	0,00	0,00	0,00	0,.47	0,47	0,47	0,47	0,47	0,00	0,00	0,00

Latent

Hour	1	2	3	4	5	6	7	8	9	10	11	12
kW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Hour	13	14	15	16	17	18	19	20	21	22	23	24
kW	0,00	0,00	0,00	0,00	0,35	0,35	0,35	0,35	0,00	0,00	0,00	0,00

Air infiltration:
"very leaky" for Summer.

Occupancy:
Five adults: 01:00-05:00
Four adults: 06:00
Two adults: 07:00-18:00
Six adults: 19:00-24:00

Activity:
Sitting/sleeping: 1,3 met (metabolic rate)

Clothing:
All seasons: 0,77

Appendix 4:

Statistics and sources: Number of households & electrical consumption

Household Estimates from SA Survey: Institute of Race Relations

Total number of households	11 000 000
% Formal on separate stand	57
% Flats, town-houses	12
% Formal Rooms	6
% Formal Total	75
Number of formal homes	7 700 000
% Traditional homes	11
% Informal/Shacks	14
Number of traditional & informal homes	2 750 000

Number of low & middle/upper income formal homes

Split supplied by:		DoH	IRR*
	Low Income:	42 %	39.2 i.e. 52.3%
	Mid/Upper Income:	58 %	35.8 i.e. 47.7%

Number of low-income formal homes	4 027 000
Number of mid/upper-income formal homes	3 673 000

* Assuming R2 500 and above in 1999 is middle income.

Number of electricity grid connections & consumption rates

% Homes electrified	70.0%
% Formal Homes electrified	88.6%
Number of grid connections	9 744 000
Households total consumption (energy Futures)	30 187 GWh per annum
(Holm)	32 000 GWh per annum
Average consumption per connection	328 kWh per month
Average low cost consumption (Basson)	95 kWh per month
Ratio average to low cost	3.45
Calculated middle & upper consumption	621 kWh

Costs of electricity

Cost of electricity 1999 (EDRC)	26 c/kWh
Inflator for period 1999-2002	128%
Current cost of power (Electrical)	33 c/kWh
Average electricity bill per household – first estimate	R108
Expenditures by households on domestic power sources	
Fuel and power expended in 1999	11.0 Billion R (1995 Rands)
Fuel and power expended in 2003 inflated by159% to 2002	Rands
Current expenditure	17.5 Billion Rand
Average electricity bill for household – second estimate	R150

Appendix 5

Projection of Carbon di-oxide emission reductions using Holm & Lane Method

Current Electricity consumption by households (Holm)	32 000GWh	
Current CO_2 pollution estimate (Holm)	26.2	Mt
Projected Electricity consumption households 2025 (Holm)	66 500GWh	
Current portion of energy applied to space heating:		
Inflation adjustment 1995- 1999	131.08	%
Portion of earnings expended on space heating (Winkler)		
Income less than R1800 in 1995 (+/-R2500 in 1999)	5.0	%
Income over R1800 in 1995	4.0	%
Expenditure by lower income home on heating 1995 (Winkler)	262	R p.a.
Expenditure by lower income home on heating 2003 Rand	440	R p.a.
Energy consumption on heating lower income homes	1 333	kWh/a
Expenditure by middle/upper income 2003 Rand on heating	2 483	R p.a.
Total average electrical consumption lower income homes	95	kWh/month
Total average electrical consumption lower income homes	1 140	kWh/annum
Total average electrical consumption middle and upper income	627	kWh/month
Total average electrical consumption middle and upper income	7 524	kWh/annum
Average earnings lower income home	8 800	R p.a.
Average earnings middle and upper income	62 075	R p.a.

Portion of average consumption directed to space heating:

Lower income - electricity	low	
Middle & Upper income - electricity	33	%
Reduction in av. energy consumption per Table 7 with interventions 30sqm homes		
Mainly coal - Highveld	39	%
Mainly coal - Pretoria	50	%
Mainly paraffin-Cape Town	53	%
Reduction in av. consumption per Table 8 with interventions 120sqm homes		
Highveld/Pretoria/Cape Town	50	%
Share of heating to electrical consumption (du Toit)	15.7	%
Share of heating to electrical consumption (Praetorius)	15-20	%
Expected reduction in electrical consumption mid/upper income	16.5	%
Expected reduction in energy consumption lower incomes	low	
Split of electricity consumption mid/upper income vs. total (Holm)	86	%
Expected reduction in total domestic electrical consumption (Harris)	10	%

Appendix 6

TIASA Technical Committee Feed-back request on thermal design proposals

Proposals were tabled on 23 April 2003 to the Dept.of Housing & on 3 June 2003 to the World Bank

The theoretical basis has been developed under the guidance of Prof. Dieter Holm, by our committee.
Copies of the proposal and the powerpoint presentation are supplied on CD herewith.
The suggestions are far reaching, in that they will need to be followed up with changes to legislation, the Building Regulations, Housing specifications, and the housing subsidy.
The performance objective is stated that energy efficiency and comfort are introduced to housing
The performance requirements are:

(1) that 80% of persons are comfortable at the hottest hour, without cooling
(2) that houses can be heated without undue expense in cold weather

The deemed to satisfy requirements which we propose as follows:

Region	Intervention - Rc R-Value	Intervention - Walls	Low cost measures
Coastal Regions east of Port Elizabeth and including Richards Bay (Heating requirement less than 8 degC)	1.5 $m^2C°/W$	n/a	Cavity Walls Shading of windows Orientation to breeze Light color
West & Southern Cape coast & other areas below 1000m altitude (Heating requirement less than 10 degC)	1.5 $m^2C°/W$	n/a	Cavity Walls Light color at coast Orientation to North Summer shading of windows
Inland areas above 1000m (Heating requirement greater than 10 degC)	2.5 $m^2C°/W$	n/a	Solid walls Dark walls Orientation North
Lowveld, Limpopo Valley & Northern Kwa-Zulu Natal below 1000m (Cooling requirement in summer)	2.5 $m^2C°/W$	1.2 $m^2C°/W$	Shading of windows

Questions to be answered by delegates to the presentation or those reading the proposals:

	Yes	No	Comment Below
1.Was the explanation of the methodology used comprehensible?			
2.Do you regard the methodology used as reliable?			
3.Is 80% persons comfortable performance requirement reasonable?			
4.Is the heating performance requirement reasonable?			
5.Do you regard the deemed to satisfy levels above as reasonable?			
6.Is this proposal simple enough for incorporation into regulation?			
7.Do you believe the Star Rating System will assist in promoting sound thermal design in housing?			

Your responses to be e-mailed to Elize Botha at AAAMSA please
Thank you for your responses
TAISA Technical Committee

Appendix 7

Net present value of thermal design investment decision

Assumptions as to size and materials:	
House size (m^2)	120
Region	One
City	Johannesburg
Wall quality	230mm Brick
Roof quality	Clay tile
Ceiling	6mm gypsum
Window area as % of shell	20%
Orientation	North
Investment:	R
120 m^2 of 100mm thermal insulation to existing ceiling:	2 400
Contractor installation cost:	600
Total	3 000
Cost savings:	
Energy saving (kWh/m^2 p.a.)per *NewQuick* model	34
Cost of electricity – 2003 (R/kWh)	0.33
Electricity inflation escalator %	8.0
Discount rate = long term government bond rate %	11.0
Present value of savings	R3 586
Net present value	R 565

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