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IMPROVING THE THERMAL EFFICIENCY OF LOW COST HOUSING IN SOUTH AFRICA

Study by

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Thanks to Steve Thorne who assisted me, introduced me to people and organisations involved in low cost housing and energy issues. Thanks to EDRC for using their office space and equipment and to all who supported my work in South Africa.

"It is our task to give millions of South Africans an essential piece of dignity in their lives - the dignity that comes from having a solid roof over your head, running water and other services in an established community."

(† Joe Slovo, 1994)

ABSTRACT

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Title: **Improving the Thermal Efficiency of Low Cost Housing in South Africa**

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The rapid delivery of Low Cost Housing is one of the major concerns in the 'New South Africa': One Million houses are promised to be built in the next five years and access to electricity will be provided for 80 % of the population in the next ten years. Thermal energy efficiency in building layout and design has not become part of the housing delivery process yet.

This study examines the potential of low cost passive design technology for housing: Indoor conditions (temperature and humidity) can be improved with resultant decrease in energy used for space heating in winter.

Chapter one and two give an study process outline and introduce the objectives of this document.

Chapter three examines the climatic zones of South Africa and combines these to three major zones. The climate data of Cape Town are summarized and converted to files which are used in the simulation.

Chapter four and five reviews the literature and extracts passive design options which improve the thermal efficiency. Methods of economic analysis are applied.

Chapter six and seven examines a typical low cost housing project in Cape Town: A Computer simulation program calculates hourly indoor temperatures and the yearly energy consumption for space heating of these row houses. The various improvements are studied and analysed with respect to costs and benefits:
It was found that energy consumption and peak demand can be reduced to one third of the existing standard and indoor temperatures reach comfort conditions in summer. The options prove to be cost effective with pay back times of less than two years achievable.

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1 STUDY PROCESS OUTLINE

This chapter describes the process, the objectives and development of the document.

1.1 COOPERATION WITH EDRC

In February 1994 I applied for working at the Research Centre to do my 'Studienarbeit'. Mr Anton Eberhard was asked to cooperate with the TU in Berlin. He recommended me to one of EDRC's researchers, Steve Thorne.
In November, I started working at the Centre. This study contributes to the 'Energy Efficiency and the Environment Programme' coordinated by Steve. Patrick Jochum at TUB has been informed about the progress of the study. (A profile of the Energy for Development Research Centre is added to the Appendix.)

1.2 PROJECT DETERMINATION

In the first two weeks I was introduced to EDRC and had to determine the field of work I have been researching the five months. In discussions about energy efficiency, we found that there are needs for further research on thermal efficiency of housings.

A conference in Johannesburg ('Greening the RDP' 25.11- 27.11.1994) confirmed the importance of energy efficiency and encouraged me to work in the field of low cost housing. I studied the Reconstruction and Development Programme and the subsidy scheme of housing to overview the policy on housing in the New South Africa.

1.3 LITERATURE SURVEY

To overview the literature and projects, I consulted the following databases:

- International Construction and Architecture Index
- Applied Science and Technology Index
- Index of South African Periodicals
- General Science Index
- Global books in print
- Boris (UCT library)
- Pretoria library

The following keywords were used (in combination):

Low cost housing, Architecture, Energy efficiency, Climate, South Africa, Economic analysis, Cost benefit analysis.

Books and journals which have been consulted in this study are listed in the appendix.

1.4 CONTACT RESEARCH INSTITUTES

On a visit to the University of Pretoria, I meet Prof. Edward Mathews (Dept. of mechanical engineering) who is doing research on computer simulation programs for buildings. He has developed the simulation program 'quick', which I am using for simulating temperatures and energy consumption.

1.5 CONTACT BUILDERS AND ARCHITECTS

To obtain information on the design of low cost houses I contacted the local architects office BEYNHAM & THÉRON who are involved in low cost planing.
I will analyse one of their typical low cost housing projects developed for the investor NEWHCO, Western Cape.

1.6 RESEARCH CLIMATE DATA

To overview the climatic conditions in South Africa I collected data of various climate zones. I divided South Africa to climate zones and developed design criteria for each of these zones. This is the base for energy efficient and comfortable housing design. (Hourly climate data of Cape Town were compiled to files)

1.7 STRATEGIES FOR CLIMATICALLY RESPONSIBLE DESIGN

Thermal performance of houses refer to the different climatic zones. I reviewed literature and summarized various passive design options to improve energy consumption and thermal conditions. Various building and insulating materials from South African suppliers were compiled.

1.8 SIMULATION

To verify the improving effects of passive design options I examine a housing project in Cape Town, 'Devon Street'. Improved variations of these were examined in terms of indoor temperatures and energy consumption by using the simulation program 'quick'. The options of attached and detached houses were inspected. The calculation results were illustrated, documented and analysed in terms of economic benefits.

1.9 ECONOMIC ANALYSIS

Economic analysis identifies the monetary benefits of improved building design. Cost benefit analysis indicates the most cost effective option. Dependencies are indicated by sensitivity analysis. Tony Leiman from the School of Economics, UCT was consulting me during my studies.

1.10 CONCLUSION

The study concludes resuming the results of the simulation and the economic analysis. Strategies are drawn and areas of further research are pointed out. The results are reported to the architects as well as to the investors and some insulation material companies.

2 INTRODUCTION

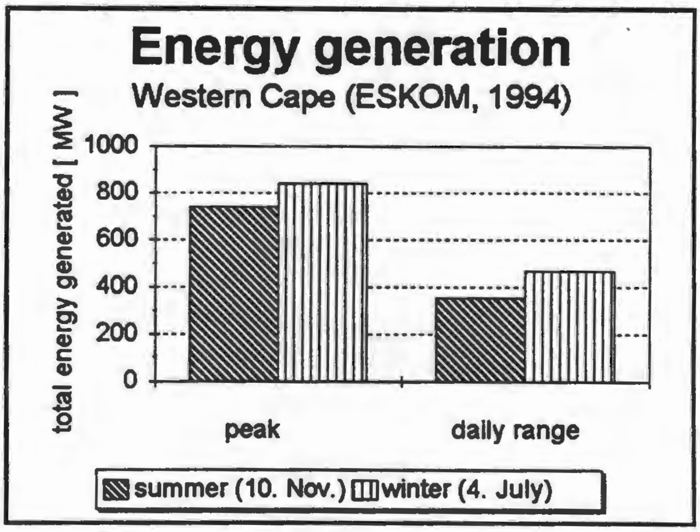
This chapter introduces the general energy situation in South Africa. It describes the national housing policy for low income people and the subsidy scheme for low cost housing.
The importance of energy efficiency in the low cost housing sector is emphasised.

2.1 ENERGY IN SOUTH AFRICA

In South Africa current energy use per unit of GDP is 70 to 100 % higher than in the United States. This is as a result of energy intensive industries as well as inefficient use of energy in all sectors. The 1991 per capita CO_2 emission was 7.81 tons, above the world average, but below the level of most industrialised countries [Enquete 1991, Vol. 2].
In 1991 South Africa produced 276 million and 33,000 metric tons of CO_2 from solid and liquid fuels respectively. This amounted to 1.2 % of world CO_2 being produced by less than 1 % of the world population. These figures are alarming in that 60 % of the population still does not enjoy access to electricity.
The South African total prime energy is comprised of 80 % coal. The majority of the residential sector is reliant on biomass. The 40 % of households enjoying access to electricity consume 30 % of electricity, 30% using coal directly. Households use most of the kerosine and LPG refined.
In 1990 large electrification projects were mooted, to provide electricity for the needs of the poor. Energy efficiency through the management of demand had not been considered until that time.
Little has been done to improve energy efficiency in South Africa. The potential to improve is as yet untapped [Thorne 1994].

2.2 PEAK DEMAND

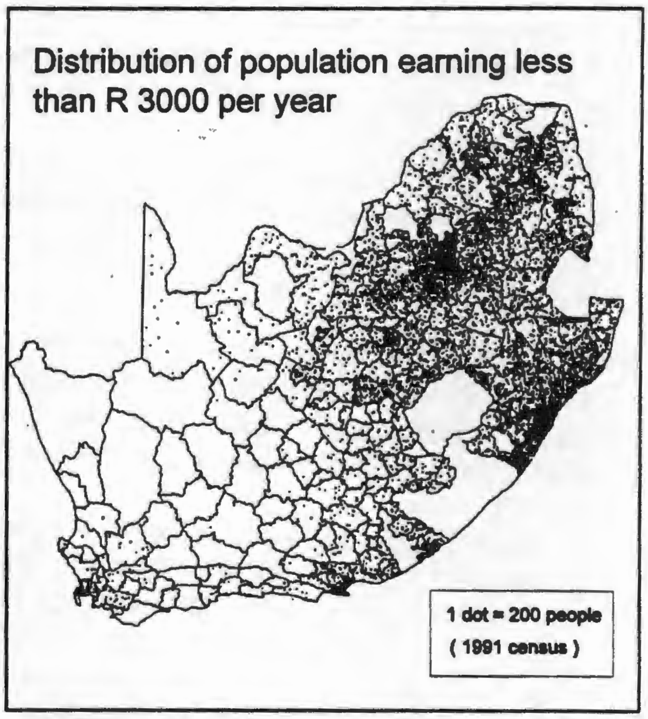
This figure shows the peak electricity demand in the Western Cape, generated by power plants in the Western Cape (Municipalities are not included).
The difference between winter and summer is about 100 MW. There is a daily range of 400 MW at the same day (day/ night). Both peak demand in winter and summer can be reduced by energy efficient design. This will have an impact on the total load and installed power.



The economic perspective of both options, installing peak power and investing in energy savings are studied in the chapter 'economic analysis.

2.3 POPULATION AND INCOME

Economically active people moved to the cities in the late 1980's and early 1990's, when influx control was scrapped and as the drought forced them out of the rural economy. [Development Bank of South Africa]. Migration from the rest of Southern Africa continues and will come increasingly from the rest of Africa as war and economic decline force people south to seek relatively better economic conditions.


Distribution of population earning less than R 3000 per year

population in South Africa

The map beside shows the distribution of people earning less than 3000 Rand per year (equivalent to R 250/ month). In absolute terms, the poorest people are in the rural areas of the poorest provinces, which are those dependant on the primary sector, those with the lowest skills and the least potential for economic growth. The metro and urban areas have huge numbers of poor people living within their limits, in shacks and overcrowded buildings. [Development Overview Conference, July 1994].

2.4 HOUSING

2.4.1 General

It is estimated that South Africa's population will reach 42 million in 1995, consisting of about 7.9 million households with an average of 5- 6 people per household. The population will increase by 970,000 people each year. By 1995 28 million people (66% of the population) will live in towns and cities, while about 15 million people (24%) will live in rural areas.

There are approximately 2.6 million formal housing units in South Africa. At the same time 1.7 million households live in shacks on unserviced land (squatter housing). There are approximately 620,000 shacks on serviced sites, while another 100,000 serviced sites are not occupied. About 2.1 million people live in hostels.
With specific reference to the informal housing situation, 25 % of the population do not have access to piped water, 47 % of households do not have electricity and 48 % do not have access to sanitation system. There are between 7 and 8 million homeless people [National Housing Forum, Development Bank of South Africa].

2.4.2 Low cost housing

In 1979 the South African Government abrogated responsibility for low cost housing to the private sector. The low cost housing which was subsequently built by the private sector was of an unimaginative standard type, that paid little or no attention to thermal performance. Housing standards are in force, but these standards were relaxed on the ground on affordability in black residential areas or 'townships'. These areas were poorly planned far from the cities, which soon became overcrowded and still have no economic heart.

In the past, thermal performance of low cost housing built by the government and private sector were ignored. Indoor conditions of low cost houses are often cold, damp and smoky and are known to be health hazards. Particularly common are illness of the upper respiratory tract which, in South Africa, is the second highest cause of infant mortality. Total Suspended Particulate, associated with the burning of solid fuels, have been measured between 5 and 10 times WHO guidelines. [Thorne, 1994]

2.4.3 The Reconstruction and Development Programme (RDP)

The Programme of the African National Congress points out the housing sector as a major issue:

- Right to housing

The RDP endorses the principle that all South Africans have a right to a secure place in which to live in peace and dignity. Housing is a human right. One of the RDP's first is to provide for the homeless.

- Housing standards

As a minimum, all houses must provide protection from weather, a durable structure, and reasonable living space and privacy. A house must include sanitary facilities, storm- water drainage, a household energy supply (whether linked to grid electricity supply or derived from other sources, such as solar energy), and convenient access to clean water. Moreover, it must provide for secure tenure in a variety of forms. Upgrading of existing housing must be accomplished with these standards in mind. Community organisations and other stakeholder must establish minimum basic standards for housing types, construction, planning and development, for both units and communities. Legislation must also be introduced.

2.4.4 Housing Standards

There were no design standards for thermal insulation for low cost housing in the past. Temperatures are recorded to be over 40°C in summer and around 0°C on cold winter days even in the Cape Province.

Increasing fuel consumption causes air pollution and health problems for people living in low cost housing areas. Often people have to spend about 15% of their income on space heating.

To improve housing standards which require energy efficiency and relays to human comfort needs the acknowledge of the principal climate elements according to a certain climate zone. The frequency, likely duration and nature of any extreme climatic phenomena must be ascertained. From the point of view of human comfort, they must be considered in order to ensure optimal thermal performance.

2.4.5 Housing Subsidies

High levels of unemployment, relatively low average wage levels and the costs of housing, are regarded to be the major problems in South Africa.
It is therefore central to Governments approach to the provision of housing to utilise a combination of the provision of subsidies and mobilising individual savings as well as private/ non state credit.

The table below reflects the amount of subsidy per income group, payable under normal circumstances:

Monthly beneficiary income	Subsidy amount	Number of house-holds in million	in %
0 to R 800	R 15000	3.30	39.7
R 801 to R 1500	R 12000	2.41	29.0
R 1501 to R 2500	R 9500	0.98	11.8
R 2501 to R 3500	R 5000	0.46	5.6

[White paper on housing, 1994]

2.4.6 Benefits of improved standards

This document examined the benefits of improving the thermal standards of low cost housing: Advantages do occur for the occupants, the national economy, the energy utility and the environment.

Summary:

- South Africa's CO_2 emissions are above world average
- Energy efficiency in buildings is not taken into consideration yet
- Low cost housing has an enormous potential for thermal energy efficiency

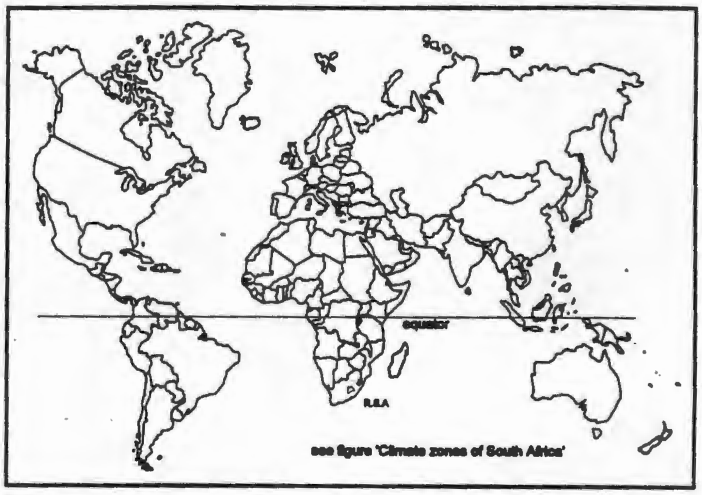
3 CLIMATE OF SOUTH AFRICA

This chapter pictures the location of South Africa and gives an overview of the various climate zones. 13 climatic zones are inspected and summarised to three major zones. The climate of Cape Town is described in detail.

3.1 GENERAL

This map illustrates the location of the Republic of South Africa, in relation to the equator. The distance to the equator is about 3680 km (In comparison Germany: 5700 km).

South Africa has a surface area of 1,123,226 km² with a total population of 31 million (1991).



3.1.1 Location

South Africa is located in the southern Hemisphere:
The country extend from 18°32' E to 31°02' E to 25°45' S to 33°59' S

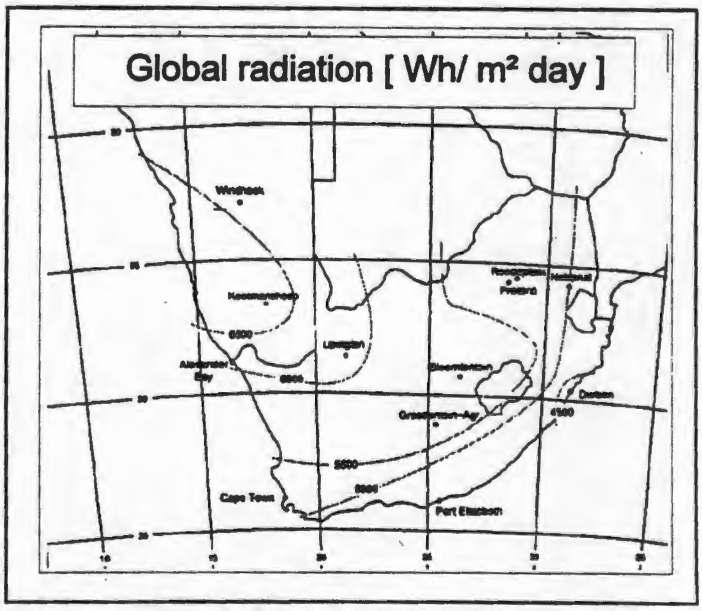
Note:

All solar angles and orientations or directions in this study refer to the southern Hemisphere !

3.1.2 Global radiation

South Africa has a high solar radiation and a large number of sunny days per year. The potential for developing solar energy is therefore high. This diagram display the daily global solar radiation:

It rises to 6000 Wh/ m² per day in the North- West of South Africa. [Eberhard A., 1990]



yearly average of global radiation in South Africa

3.2 CLIMATE ZONES

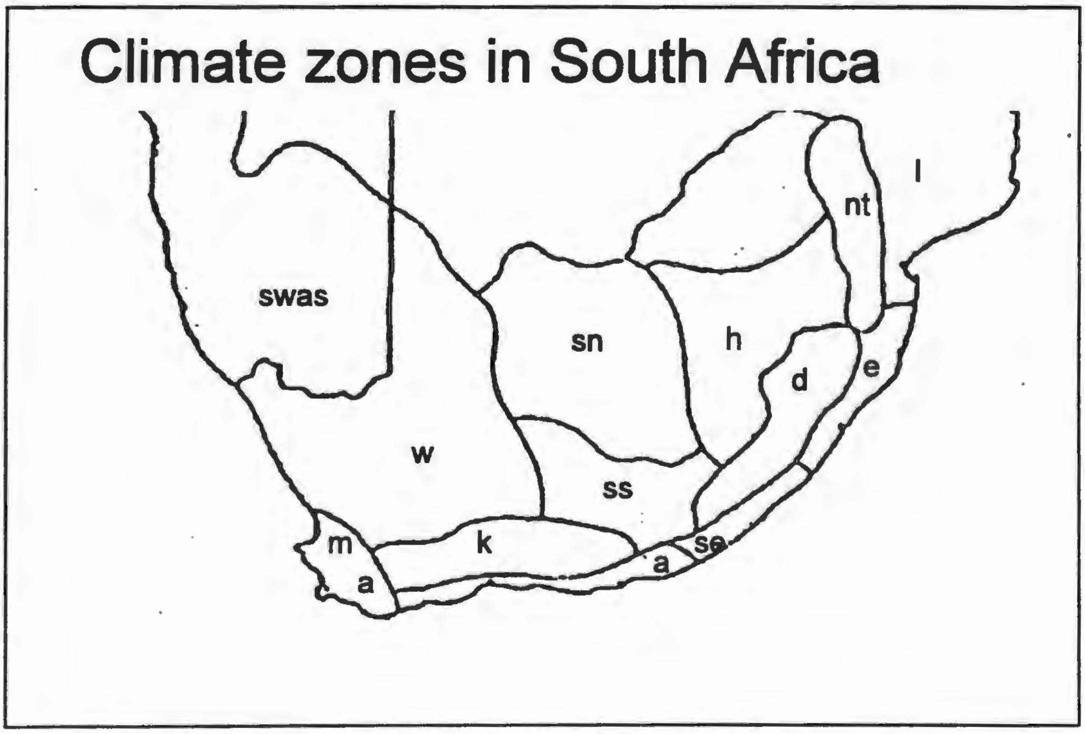
3.2.1 Introduction

By averaging a long series of accurate meteorological observations, the climates of different locations, or various features of them, can be compared with each other. It has been found that whole areas have striking similarities in their climatic patterns, and that the data for certain climatic elements in each area are very similar over a given periode.
Any classification system is a generalization and should be treated with circumspection. Specific climates may derivate considerably from the general climate.

- The boundaries of climate zones are vague.
- Climates are changed by natural and manmade forces.
- These changes are often unpredictable.

3.2.2 Climate zones

This map illustrates South Africa divided to twelve climatic regions (a...w):


Climate zones in South Africa

The climatic regions are:

The letters in bracket (A, B, C) indicates the major climatic zone.

a	Southern Cape Coastal Belt
d	Drakensberg region and Escarpment
e	Eastern Coastal Belt and Zululand
h	Highveld (Southern Transvaal, Eastern Orange Free State)
k	Karoo
l	Lowveld
m	Southwestern Cape
nt	Northern Transvaal
se	Southeastern Coastal Belt
sn	Northern Steppe
ss	Southern Steppe
w	Namaqualand and Northwestern Cape Province
(swas	Southern Part of Namibia)

- Region a

Region a receives rain about equally in all seasons though autumn and spring have a slight advantage over other seasons. On the mountain ranges, especially around George and Knysna, annual amounts may exceed 1100 mm whereas the plains to the south or Riversdale barely receive 400 mm. On the average 8 to 12 rain days per month may be expected. The rain is mainly cyclonic and orographic and thunderstorms are comparatively rare, occurring on about ten occasions per year. Hail does fall but very infrequently.

Frost is practically unknown and the heat of summer is tempered by cool sea breezes. Winds blowing along the coast can sometimes, especially in spring, be unpleasantly strong, whilst in the interior, mainly in late summer, temperatures can occasionally rise above 38°C during hot 'mountain- winds' whose average occurrence is one to three per month. The average daily maximum temperature is about 26°C. In January and 19°C in July; extremes sometimes reach 42°C. The average daily minimum is about 15°C in January and 7°C in July whilst extremes can occasionally drop to 4°C and -4°C respectively.

By South African standards this is a cloudy region, yet the yearly duration or sunshine is about 50% of the possible). (A)

- Region d

This region has a climate very similar to that of regions se and e, except that, due to altitude and distance from the ocean, temperatures show greater fluctuation both seasonally and diurnally. The average daily maximum temperature is about 27°C in January and 19°C in July whilst extremes can reach 40°C and 30°C respectively. Average daily minima are in the neighbourhood of 15°C in January and 3°C in July, whilst extremes can sink to 3°C and -10°C respectively in summer and winter. Depending on topography, the frost period lasts from 90 to 150 days, from April to September.

Winds are mainly southerly and northerly to north- westerly, the latter often very strong especially in autumn. Sunshine duration varies from 50% to 60% of the possible in summer, and in winter from 70% to 80%. The bulk of the rainfalls in summer from November to March when 12 to 13 rain days per month may be expected. In midwinter an average about 12 mm falls on two to three days per month. The rainfall is largely of the thunderstorm type, sometimes of great intensity, and 60 to 90 thunderstorms are experienced per annum. On the mountains of this region snow is more frequent than anywhere else in South Africa probably on account of the great elevation or the Drakensberg. On the average, snow falls on about eight occasions per year, the peak of the 'snow' season being in July. Usually the snowcap melts within a day of two, but on rare occasions the Drakensberg on the Basutoland border has been snow- capped for some weeks on end. (C)

- Region e

This region is one of the best watered regions of South Africa. The average annual rainfall varies from about 760 mm in the northern interior to 1250 mm on parts of the coast and against interior mountains. Rain falls mainly in summer from October to March and the peak of the rainy season changes from February, March along the coast to January in the interior. About 120 to 140 rain days per year may be expected varying from about 15 days per month during the peak of the rainy season to about three or four per month in winter. Most of the rainfall is derived from instability showers and thunder is heard on about 40 to 50 days per year. Occasional heavy showers in short periods of time bring floods, causing extensive damage. Hail at an individual station occurs on about one to three days per year more particularly in the interior. Although the rainfall is fairly reliable, droughts occur about once in seven years.

Cloudily weather during the summer months reduces the sunshine duration to about 45% of the possible, whilst in winter the percentage is about 70%.

Average daily maximum temperature ranges from about 28°C in January to 22°C in July, though extremes can reach 43°C and 34°C respectively. Average daily minima are about 19°C in January and 9°C in July, whilst extremes can sink to 7°C and -1°C respectively. Frost is practically unknown except very occasionally in some interior valleys.

The predominating winds blow from the north- east and south- west in about equal proportions. Gales are very infrequent. During north- easterly winds in summer, sweltering warm to hot days are experienced. Relief comes with south- westerly winds and cloudy weather. Very occasionally (in late winter) hot westerly winds blow off the interior plateau causing the mercury to rise above 38°C. (C)

- Region h

The average annual precipitation in this highveld region varies from about 900 mm on its eastern border to about 650 mm in the west. The rainfall is almost exclusively due to sowers and thunderstorms and falls mainly in summer, from October to March, the maximum fall occurring in January. The winter months are normally dry and about 85% of the annual rainfall falls in the summer months. Heavy falls of 125 to 150 mm occasionally fall in a single day. The annual average number of thunderstorms varies from about 75 in the Transvaal to 100 in Basutoland. These storms are often violent with severe lighting and strong (but shortly) gusty south- westerly winds and are sometimes accompanied by hail. This region has about the highest hail frequency in South Africa. Snow occurs about eight times annually, mainly in midwinter.
Average daily maximum temperature is roughly 27°C in January and 17°C in July but in extreme cases these may rise to 38°C and 26°C respectively. Average daily minima range from about 13°C in January to 0°C in July, whereas extremes can sink to 1°C and -13°C respectively. The period during which frost is likely to form lasts on the average for about 120 days from May to September, though this period is longer in the southern highlands of Basutoland. On the whole winds are light except for short periods during thunderstorms. Very occasionally tornadoes do occur and cause tremendous damage if they happen to strike populated area . Sunshine duration in summer is about 60% and in winter about 80% of the possible. (A)

- Region k

This semi- arid to arid southern interior or the Cape Province receives on the average less than 250 mm of rain per year. Only in certain reaches of the mountain ranges (e.g. the Zwartberg) does the rainfall exceed 750 mm. As in region a, the rainfall is fairly evenly distributed throughout the year, a tendency towards a double maximum in March and November, except in the mountains only about one to three rain days per month can be expected.
About 10 to 20 thunderstorms occur in this region per year and one occasional heavy storm can sometimes account for as much as half the normal annual rainfall.
One or the most outstanding features of the climate of region k is the very large temperature fluctuation, both diurnal and seasonal. Days can be excessively hot and temperatures up to 44°C due to hot winds off the high plateau, are not uncommon; nights can be quite chilly and contrasts of 28 K between day and night are not unusual. The average daily maximum temperature is about 32 °C in January and 18 °C in July whilst extremes of 45°C and 31°C respectively, have been recorded. Average daily minima are about 15°C in January and 5°C in July. Extreme minima can drop to 5°C and -3°C respectively.
Frost occurs from about 1st June to 31st August though in extreme years these dates can be extended by a fortnight either way.

Snow can be seen on the higher mountain ranges on about five occasions per year. Although hail seldom falls it is a distinct hazard to be reckoned with by fruit farmers. Skies are mostly clear resulting in an annual sunshine duration equal to about 70% of the possible. (B)

- Region l

In the low- lying areas of this region the average annual rainfall varies from about 500 mm in the north to about 700 mm in the south. Against the escarpment rainfall increases rapidly with altitude, in places up to 2,000 mm per year. The rainy season lasts from about November to March with a maximum in January. On the average about 65 rain days per year obtain over the Lowveld whilst against the escarpment over 120 may be expected. The rain is mainly due to thunderstorms and heavy showers exceeding 300 mm in one day have been recorded. Against the mountains orographic rain and mists are of frequent occurrence. Hail occurs infrequently, about once or twice per year. The climate is warm to hot and a fairly high humidity makes summer days very oppressive though cooler weather obtains against the escarpment. Average daily maximum temperatures are of the order of 30°C in January and 23°C in July. Extremes in the Lowveld can reach 43°C and 35°C respectively. Average daily minima are about 18°C in summer and 8°C in midwinter, whilst extremes reach 7°C and -2°C respectively. Frost is seldom experienced and is mainly confined to low-lying valleys.
In winter skies are usually clear and sunshine duration is about 75% of the possible. During summer, the duration is around 50% of the possible.
Winds blow mainly from the south- south- east or north- north- west and can reach gale force against the mountains, though very infrequently. (A)

- Region m

Region m enjoys a climate similar to Mediterranean countries, receiving the bulk of its rainfall in the winter from about may to September, and having a warm to hot and dry summer. The rainfall is profoundly influenced by the very pronounced geographical features, resulting in annual amounts of the order of over 3000 mm in some mountain kloofs, as against 400 to 500 mm on the Cape flats and less than 250 mm in the Breed river valley - the latter being a typical 'rain shadow' effect. During the season of maximum rainfall one may normally expect 12 to 15 rain days per month whilst In the dry season Cape Town and environs experience 4 to 5 rain days per month. The rainfall is mainly cyclonic and orographic but very occasionally thunderstorms do occur, on nearly five occasions per year. Hail is a rare phenomenon. The mountains are occasionally snowcapped but the snow layer never persists throughout the winter. On the average snow occurs on about five occasions per year, mainly in winter and early spring. The average daily maximum temperature is about 28°C in midsummer and 17°C in midwinter but extreme maxima can reach 43°C respectively. Average daily minimum temperature is about 15°C in January and 6°C in July though extreme minima can fall to 4°C and -5°C respectively, depending on altitude and situation.

Frost is rare on the coastal flats though minima below freezing point are occasionally recorded. In the higher mountain valleys, frost is quite usual in winter and minima of -5°C have been recorded there. Winds in summer are almost exclusively from the south- east. In winter north- westerly winds are frequent and spell rainy weather. Winds are frequently strong and may reach gale force, making conditions rather unpleasant especially along or near the coast. Sunshine duration varies from about 60% or the possible duration in July to over 70% in January. (A)

- Region nt

The climate is semi- arid and hot in the Limpopo and Olifants river basins but more humid and cooler on the Waterberg plateau and Soutpansberg. The average annual rainfall, mainly occurring as a result of thunderstorms, varies from about 380 mm in the north to just over 700 mm on parts of the Waterberg. The rainy season lasts from about November to March, the peak of the rainy season falling in January about 50 to 80 rain days per year may be expected. Hail is about half as frequent than on the highveld (region h). The rainfall is somewhat unreliable and in about 12% of all years rather severe drought conditions occur. Average daily maximum temperatures are about 32°C in January and 22°C in July. Extremes are of the order of 42°C and 31°C respectively. Average daily minima are about 18°C in January and 4°C in July, whilst extremes can reach 8°C and -7°C respectively. Days are often very oppressive in summer, whereas winter nights can occasionally be decidedly cold. Frost occurs on the average during the months June to August. Winds are mainly light to moderate and blow from the north- easterly sector except for short periods during thunderstorms or weather changes when they have a southerly component. The duration of bright sunshine exceeds 80% of the possible in midwinter and 60% of the possible sunshine in summer. (B)

- Region se

As may be expected, this region is in many respects similar to region a, namely temperate to warm and humid, except that there is a definite summer rainy season which is at a maximum in autumn (March), and at a minimum in June. On the average the summer months each have about 12 rainy days as against about 4 in a midwinter month. Annual average rainfall varies from about 500 mm in the Fish River valley to about 1250 mm or over at Port St. Johns. In July about 25 mm can be expected.

Rainfall is of a showery nature and thunderstorms are quite frequent, about 20 to 30 per annum and are occasionally accompanied by hail, especially in the interior. Winds blow mainly parallel to the coast, namely north- easterly and south- westerly, and occasionally reach gale force. During north- easterly winds the sky is usually cloudless but hazy and south- westerly winds bring cool cloudy weather and rain. Sometimes, mainly during the late winter, very dry and hot mountain winds are experienced though much less frequently than in the southern and Western Cape Province.

In winter the sky is mostly clear and the region receives about 70% of its possible sunshine. In summer it is often cloudy to overcast resulting in only about 50% of the

possible sunshine duration.
Average daily maximum temperature are around 28°C in January and 21°C in July though extremes sometimes reach 43°C and 34°C respectively during hot winds. Average daily minima are around 17°C in January and 8°C in July, whilst extremes reach 12°C and 3°C respectively on the coast, and 5°C and -5°C in valleys in the interior. The frost period in interior valleys lasts on the average about 30 to 40 days during July and August. (C)

- Region sn, ss

This is a semi- arid region receiving on the average about 250 mm of rain in the west to 500 mm on its eastern boundary. The rainfall is largely due to showers and thunderstorms falling in the summer months October to March, the peak of the rainy season being in March or February.
Hail is sometimes associated with the thunderstorms and mainly occurs in early summer (November); Although these storms may sometimes be very severe and cause much damage, they usually cover a relatively small area.
Sunshine hours amount from 70% to 80% of the possible sunshine duration even during the peak of the cloudy (or rainy) season.
Air temperatures are subject to large diurnal and seasonal variation. In January the average daily maximum lies between 30 °C and 33°C and in July it is about 17°C whilst extremes can attain 41°C and 28°C respectively. Average daily minimum temperatures are of the order of 15°C in January and 0°C in July, whilst extremes of 3°C and -11°C respectively have occurred. These extreme minima are of course largely dependent on local topographical features since the nights are usually calm.
The period during which frost can be expected lasts for about 150 days (May to September) in the south of this region and for about 100 days (June to August) in the north.
Winds are usually north- westerly, attaining their maximum speed in the afternoon. During thunderstorms strong and gusty south- westerly winds of short duration are a common feature and occasional cold snaps are accompanied by unpleasantly cold southerly winds for a day or two. In region sn duststorms sometimes occur, depending mainly on denudation of the surface due to prolonged drought. (B)

- Region w, swas

This region occupies about half of the Cape Province, southern South West Africa and the Namib desert further north. The rainfall is unreliable, amounts to about 250 mm per year in the interior and decreases to an insignificant 50 mm or less towards the west coast. In the interior the precipitation is mainly due to convectional showers in summer and autumn occurring on about two days per month, whilst on or near the coast the sparse rainfall occurs mainly in winter. Hail is seldom recorded in this region. Snow occurs about five times per annum on the southern mountain ranges (around Sutherland).
Due to the cold Benguela current the west coast is frequently foggy. Fog advances onto the coastal flats (sometimes as far as 30- 50 km inland) during the night and

recedes seaward in the forenoon; this diurnal motion is connected with the intense heating of the land during the day and cooling at night due to terrestrial radiation. Temperatures are subject to great variation both seasonal and diurnal. The average daily maximum temperature in January is of the order of 35°C and in July 18°C, whilst extremes can reach respectively 46°C and 32°C. Average daily minima are about 17°C in January and 3°C in July. Extremes can reach 5°C and -10°C respectively. On the interior plateau frost is common in winter. One of the hottest areas in south Africa is found in the Orange River Valley around Goodhouse and one of the coldest spots is Sutherland in the Roggeveld. (B)

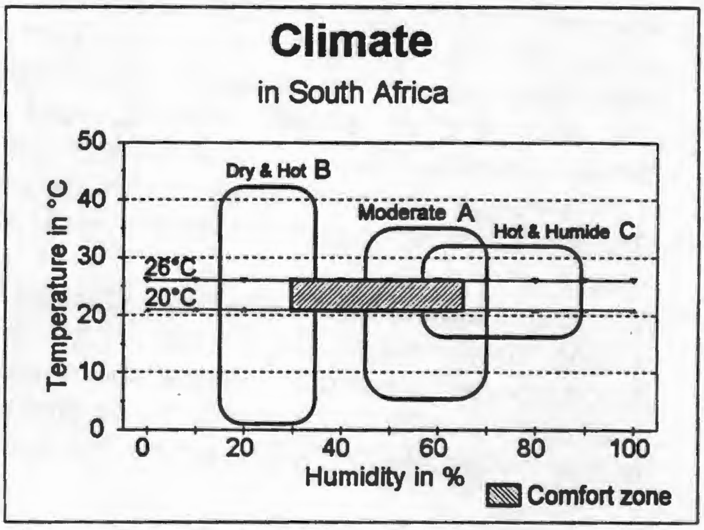
3.2.3 Major climate zones

These 13 zones can be simplified and comprised to three major zones:

Temperate climate	A
Hot and Dry climate	B
Hot and Humid	C

3.2.3.1 T- r diagram

These tree climate zones are displayed in the schematic Temperature- relative humidity diagram.
The comfort zone ranges from 20°C to 26°C and from 30% to 65% relative humidity. No climatic zone satisfy the needs for comfort conditions at all times.
In the table below the main characteristics of these climate zones are mentioned.



climate zones in South Africa

3.2.3.2 Temperate climate (A)

In the south west (Cape Province) and mid east of South Africa.

Temperate climate	
Temperature	Medium annual range of 14°C larger than medium diurnal range of 10°C. Ground temperature slightly lower than air temperature in clear nights
Relative humidity	Winter, wet season 60- 90 %. Vapour pressure 1,2- 1,5 kPa Summer, dry season 40-60 %. Vapour pressure 0,8- 1,2 kPa
Rainfall	Winter rainfall. Often wind- driven. Varies 350- 400 mm/ year, coastal 500 mm/ year
Sky	Clear, bright in summer, diffused in winter. Long days, long twilight. Annual solar radiation at 6 GJ/ m², low sun angles in winter
Wind	Westerly winds during winter rains, equatorward during dry summer
General	Hot summer days, cool nights. Pleasant climate. Condensation problems in buildings

3.2.3.3 Hot and dry (B)

The internal areas of South Africa (Orange Free state, Northern Cape, Northern and Western Transvaal, Karoo)

Hot and dry	
Temperature	Medium annual range 14 °C. Very large diurnal range of 17°C. Ground temperature higher than air temperature. Sky temperature lower than air temperature when clear.
Relative humidity	Average relative humidity 10-55 %. Vapour pressure varies 0,75- 1,5 kPa
Rainfall	Up to 50 mm/ hour. Occasional downpours. Mean less than 250 mm/ year.

Sky	Radiant clear, dark blue (1700-2500 cd/m²). White dust haze before rains (3500- 10000 cd/m²). Dark during rain or duststorms (850 cd/m² and less). Annual solar radiation 8 GJ/m² and more. Predominantly direct radiation. High ground glare. Clear nights permit heat diffusion.
Wind	Local diurnal cycles following the suns path. Occasional whirlwinds. Frequent calms
General	Very cold winter nights due radiation losses. Frost in higher regions. Extreme heating and cooling cause thermal stresses in structures. Dry heat is tolerable due to cooling perspiration. The thermal stress is less than in warm humid climates. Reclamation of areas which have become desert is cost and energy intensive.

3.2.3.4 Hot and humid (C)

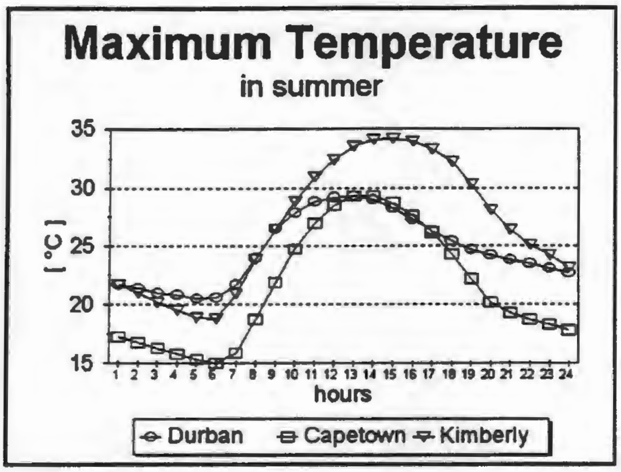
In the south- east coast areas (East-London, Transkei, Natal, Kwazulu, Eastern Transvaal)

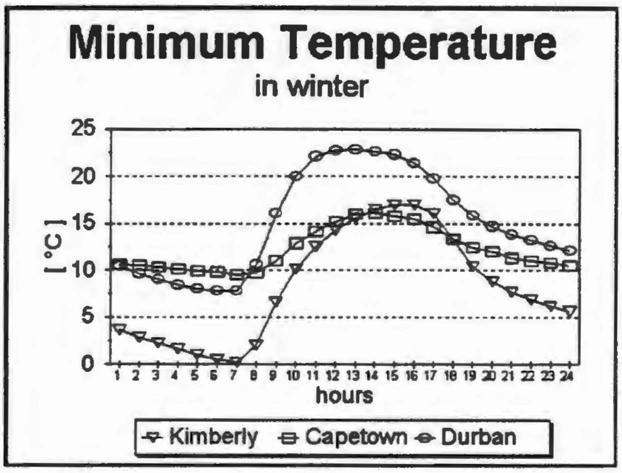
Hot and humid	
Temperature	Small annual range of 9°C equal to small diurnal range of 8,5 °C. The range increases from coastal to inland zones.
Relative humidity	Summer 70 -80 % (wet season) Vapour pressure 2,2 - 2,5 kPa. Winter 40- 70 %. Vapour pressure 1,6 - 1,8 kPa
Rainfall	About 800-1800 mm/ year. Very varied regionally, but generally reliable. East coasts have no distinct dry winters, but inland winters are dry. Usually summer maximum.
Sky	Bright, diffuse radiation at coast. Clearer sky inland. Annual solar radiation 6,5 GJ/ m².
Wind	At coast, land and sea breezes. Inland mountain winds.
General	Oppressive humid summer. No cooling during summer nights. Generally mild winters. Mountain zones above 1500 m have cooler climates, decreasing by 5,5°C / 1000 m altitude above sea level.

3.2.3.5 Temperature and humidity range

These diagrams pictures the mean temperature and relative humidity range of three South African cities during a day. It shows a typical hot summer day and a cold winter day. The cities and their climatic zone are:

- Cape Town, Zone (A)
- Kimberly, Zone (B)
- Durban, Zone (C)

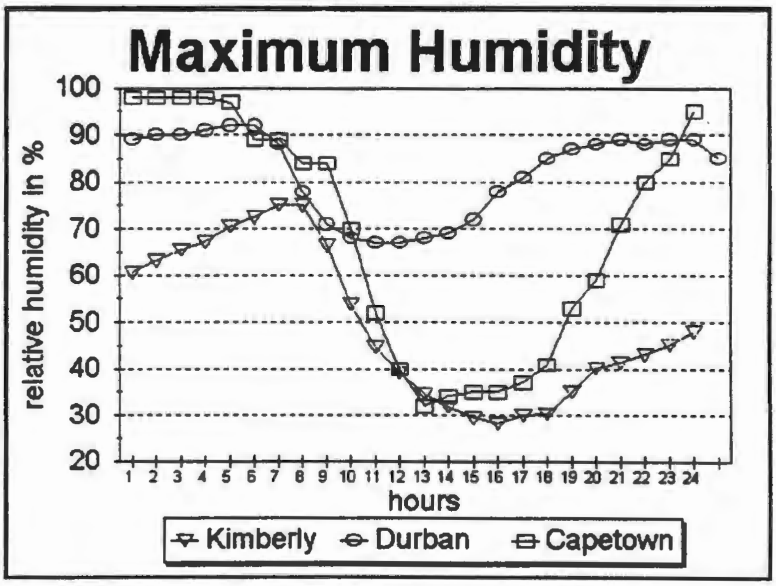




It illustrates both, the diurnal and seasonal temperature range:
A high temperature range is recorded in the zone C. In humid zones the winter and summer temp. do not differ much. Temperate climate shows a seasonal range of about 10 K.

Diurnal range of humidity:

In hot zones the average relative humilities are less than 50 %, while in humid zones the rel. humidity is above 80 % most of the time. Cape Town has high humidity in winter, increasing from 30% to 98%.



3.3 CLIMATE OF CAPE TOWN

In the following subchapters the climatic data of Cape Town are illustrated:
Solar position, solar radiation, temperature range and extrem values, precipitation and wind characteristics.

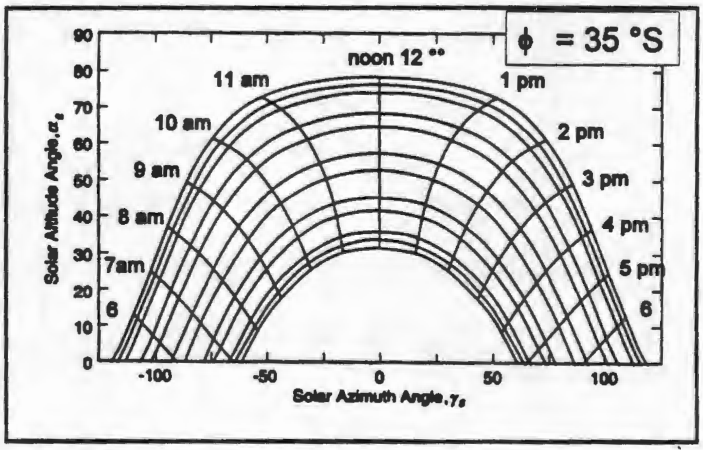
3.3.1 Solar radiation

3.3.1.1 Solar position diagram

This diagram shows the solar azimuth and altitude angle during the day/ year. Solar time is noon for the central time line; lines are shown for each hour before noon (on the left) and after noon (on the right).

The top to bottom order of the month, by the southern hemisphere are the following:

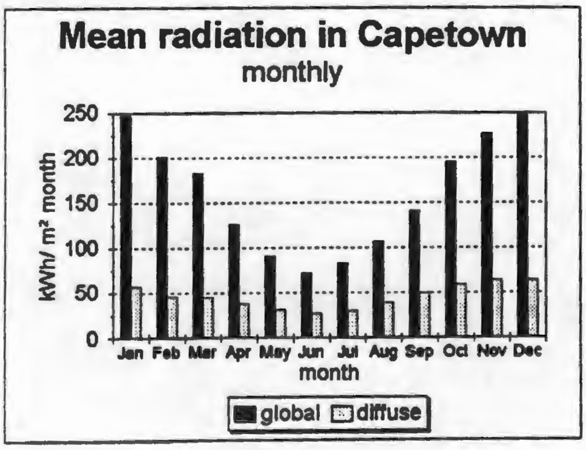
December
January
November
February
October
March
September
April
August
May
July
June

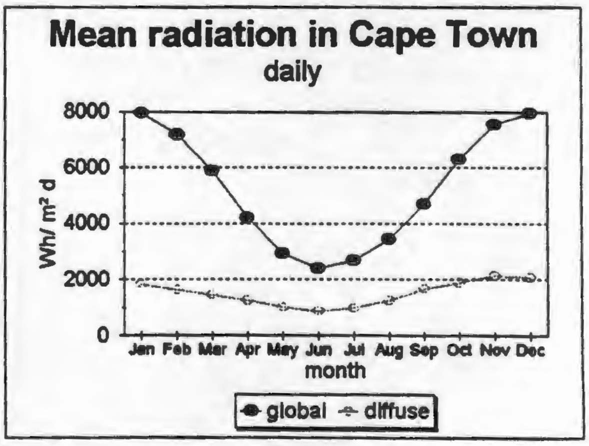


In summer high maximum altitude angles of 60° to 75° do occur. Winter altitude angles are low, between maximum of 30° and 40°.

3.3.1.2 Amount of solar radiation

These diagrams picture the radiation monthly and daily:
Global radiation rises to 8 kWh/ m² per day in summer. In winter it drops to 30% of the summer radiation of 2200 Wh/ m² per day. There is a significant change in the percentage of diffuse radiation from summer to winter.



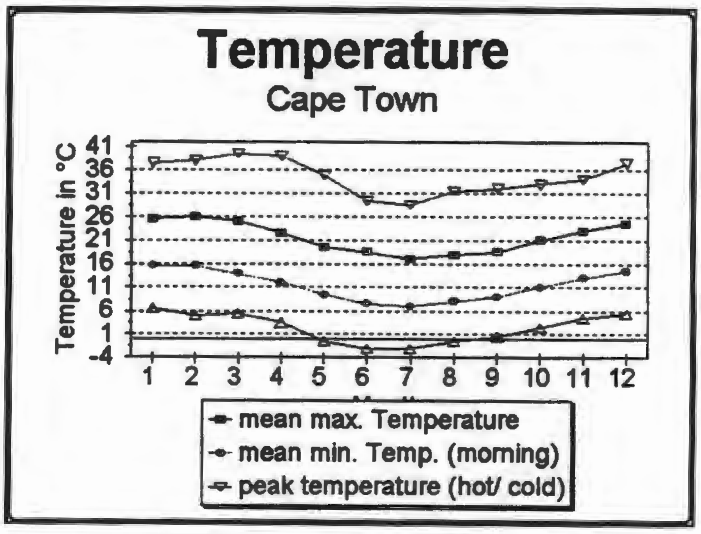


3.3.1.3 sunshine per day

Mean daily sunshine per month / average												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ave
11.5	10.5	9.4	7.7	5.9	5.8	6.2	6.8	7.8	9.0	10.3	11.1	8.5

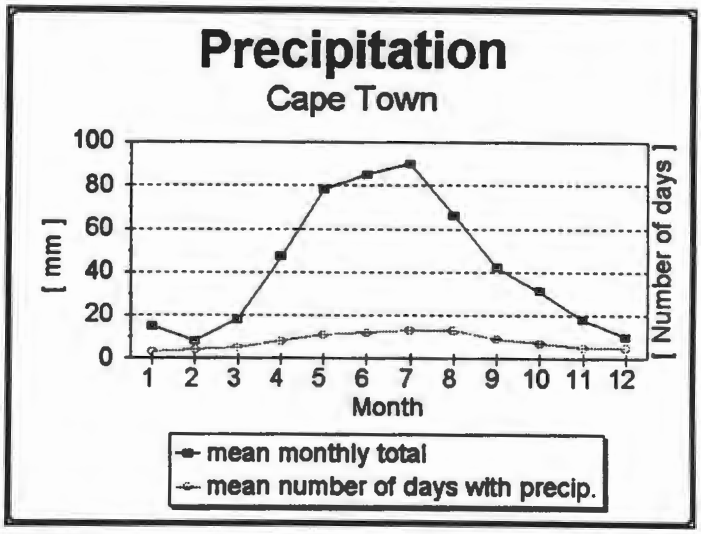
3.3.2 Temperature

This diagram illustrate the mean maximum and minimum temp. during the year.
Peak temperatures are recorded in March (39.5°C) and in June (-2°C). The daily range is about 10 K, typical for temperate climate.



3.3.3 Precipitation

The characteristics of precipitation are shown in this diagram. Cape Town's rainfall rate is very low in the summer months: Below 20 mm per month. During the winter the precipitation rate is above 80 mm per month and reaches maximum rainfall of 218 mm per month and peak rates of 60 mm per day.



3.3.4 Wind characteristics

The region is influenced by the continuous procession of eastward moving high and low pressure cells. Ahead of the cold front associated with the passage of a cyclone a coastal low often develops on the west coast.
Winds are strongly along the coast, where the addition of the land and sea breeze components is felt, and on some exposed mountains slopes.
The mean wind speed during the year is 4.0 m/ s and 9 m/s at Cape Point. [Diab R. 1979]

Data of the weather station at DF Malan airport (1956-1987, height of measure 12m) indicate the following:

The frequency of wind speed is:

< 2 m/s	34 %
2 - 4 m/s	19 %
4 - 6 m/s	17 %
6 - 8 m/s	15 %
> 8 m/s	15 %

Mean wind speeds are highest in summer and below 4 m/s from April to August. During summer the mean wind speed above 4 m/s increases to 60 %. Prevailing winds are from the SE to S with a smaller secondary maximum from W and WNW. The SE sector winds are also the strongest and possess higher power [Diab R. 1990].

Summary:

- South Africa has a variety of climate zones
- These are summarised to three major zones
- Cape Town climate belongs to the temperate climate zone

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4 THERMAL EFFICIENT DESIGN

This chapter examined passive design options for low cost housing and gives the background for thermal energy efficient design. The options for orientation, solar control, thermal capacity, ventilation, openings, surfaces, ground contact are explored.

4.0.1 Strategies

4.0.2 Thermal control

Thermal control requirements can be specified as the deviation of outdoor conditions and from the conditions required by humans of their belongings:

outdoor conditions - comfort conditions = required control

The control may be passive or active. For reasons of economy (both in monetary and energy) it is desirable to utilise passive controls to their full potential. Active means of control should be resorted to only if passive means are inadequate.

required controls - passive controls = active controls

4.0.3 Strategy options

There is a hierarchy of different design options to regulate indoor climate:

- No Building System
- Passive Building Systems
- Active Building Systems

The design strategies may be further subdivided into short-, medium- and long-term categories.
(You can ether ignore cold temperatures in winter, put on socks, move into kitchen, make a fire or build an insulated house next year.)

4.0.3.1 No building system means no building at all, living with the climate: Acclimatization and adaptation. Activities are adjusted to the supply of nature and not by individual demand. The seasons are marked by regular activities which are celebrated. The live styles intensionally cyclical. Often it implies mankind do with less, like the normad's tent or a tree which is shading do not need a lots of energy or engineering.

4.0.3.2 Passive building systems affecting the thermal performance of the house by using natural resources: sun, shade, wind, thermal mass, orientation of the building, insolation and others.

4.0.3.3 Active building systems are mechanical, electrical or other thermodynamic systems which are affecting the indoor conditions by using external energy sources.

4.1 BUILDING DESIGN

These tables give a overview of basic characteristics like housing layout, shelter design and building materials. The criteria refer to the moderate, hot and humid climate. (Note: These criteria refer to the southern hemisphere)

4.1.1 Moderate climate

House design	
site selection	Slopes east of north are preferable, similar to orientation requirements. 'Warm slope' area is best, but lower and upper inclined portions are also advantageous if wind sheltering is provided. Breeze utilisation in warm periods is important.
town structure	Open and free layout of buildings which tends to low density.
public spaces	Open lawns with grouped shade trees are desirable. Roads are best planned in SW direction to avoid winter winds and channel summer breezes. Walking distances can be arranged freely.
landscape	Indoor and outdoor relationships in house design should be considered. Use of outdoor living areas can be extended for several month as adjuncts to interior areas, if properly designed.
vegetation	Windbreaks are desirable against winter NW wind directions. Tree layouts should not block prevailing S-SW summer breezes. Evergreen trees are best for wind protection, deciduous for shading purpose. Lawns near structure are useful for radiation absorbtion. Shade trees are preferred on E and W side of residences.
Shelter design	
house type	Most flexible arrangements possible. A close relationship between buildings and nature is desirable and possible.
general arrangements	The large range of thermal conditions requires the utilisation of radiation and wind effects, as well as protection from them. A dual role is required in the structure.
plan	Freedom in plan design is characterized by spatial connections of outdoor and indoor areas. Buildings should be open to N-NE and closed on westerly sides. Bedrooms should be located on easterly sides, open porch on N-NE side (useful 30 % of year, or if glass enclosed 60 % of the year).
form	Cross shaped or free building formations are possible, elongation in E-W axis is preferable, with the optimum shape being 1:1.6. Volume effect is not too important.

orientation	Orientation of 17° East of North secures balanced heat distribution. The orientation of high buildings should be correlated with wind exposure.
interior	Provision for adequate cross ventilation is necessary. Humidity-producing areas should be separated from rest of building. Sun penetration is desirable, depths of interiors should be low.
colour	Medium colours are advantageous. Dark colour only in recessed places protected from the sun. Light colour on roof surfaces.
Building elements	
openings and windows	Window- size is not important for internal heat balance. South exposed glass areas work on seasonal bases. Protection is needed from summer radiation. Openings should be screened. Location of openings should allow cross ventilation. Reduced openings on westerly side is desirable.
wall construction	Avoid absorptive materials, or those which are affected by freeze-thaw action. Rain and moisture penetration is mostly on SW exposures.
roof	Eave and gable ventilation is needed. This might be closed in winter.
materials	Required insulation coefficient to N: E: 1.3, W: 1.3, S: 1.4, Roof: 1.5. West wall material with 6 hour time lag balances internal heat distribution. Vapour barriers on warm side prevents condensation.
shading devices	Deciduous tree on E and W sides, 68° overhang on North exposure protects low structures. Sunshade on E and W. Vertical fins on S side protects higher buildings.
foundation	Summer basement temperature will remain approximately midway between deep ground basement temperatures and average diurnal temperature.
mechanical equipment	Yearly heating requires are (approximate): 2830 hours of low heat 2690 hours medium heat 508 hours high heat and few days of maximum heat output. 2600 hours without heating.

4.1.2 Hot and dry

House design	
site selection	On NE-N slope exposures, lower portions are preferred, where cool air flow effect can be utilized and controlled. High altitudes, and locations with evaporative possibilities, are advantageous.
town structure	The walls of houses should provide shade to outdoor living area, similar to the effect of horizontal devices. Unit dwellings or groups should create patio- like areas: concentration is desirable. The town structure should react against heat with a shaded and dense layout.
public spaces	There should be a close connection between public spaces and residential areas. Half and full shade protection is desirable, paved surfaces should be avoided. Pools of water are beneficial.
landscape	As vegetation is generally sparse, concentration of plant and grass covered areas in the manner of an 'oasis' is desirable.
vegetation	Vegetation is desirable both as a radiant absorbent surface and for its evaporative and shade giving properties.
Shelter design	
house type	Compact 'patio' house type is preferred. Adjoining houses, row houses and group arrangements, which tend to create a volume effect, are advantageous. High massive buildings are preferable.
general arrangements	Heat loss, rather than gain is the objective. Therefore, closed building arrangements around green area are preferable. Utilizing evaporative cooling effects and night out- going radiation losses. Lithosphere arrangements are applicable, subterranean utilization. High ceilings are not necessary. Outdoor or roof sleeping possibilities should be considered.
plan	Inward looking layout can benefit from microclimate advantages. Walled- in house arrangement can benefit from cool air pool advantages. Single flood and a convenient plan with economy of movements avoid heat gains. Evaporative possibilities should be utilized. Heat producing area should be separated from other areas of house. Non- inhabitant spaces should be placed on W side to avoid sun impact.
form	Compact shapes are preferable, elongated on E- W axis. The optimum shape is 1: 1.3. Volume effect is important. Building forms should have minimum solar projection.

orientation	Exposures 25° E of N secure balanced orientation. All exposures from N to 35° E of N are acceptable. For bilateral buildings with cross ventilation, 12° N of W axis is preferred.
interior	Deep room arrangements can be used as a cooling contrast to intense outdoor heat. Use of emissivity cool colours reduce heat reflection on interior surfaces. Connection with patio areas has cooling effect on adequate spaces.
colour	White paint has high reflection ratio on exposed surfaces. Dark adsorptive colours are adaptable where reflections towards interior are expected (such as under areas). Deep- set surfaces can be dark coloured for winter radiation absorbtion. Bright colour contrasts are in agreement with the general character of the region.
Building elements	
openings and windows	Relatively small openings reduce intense radiation. Windows should be shielded from direct radiation and set high to protect from ground radiation. Openings should be tight- closing as protection against high diurnal heat. External shades are preferred. Openings should be located on N, S, and to a lesser degree on E sides.
wall construction	Walls of daytime living area should be of heat- storing materials. Walls of night- use rooms of materials with light heat capacity. E and W walls should be shaded. High reflective qualities are desirable for both thermal and solar radiation.
roof	Generally heat storage insulation is best, which uses the flywheel effect of outgoing radiation for daily heat balance. A shaded and ventilated roof is applicable, primary over night use rooms. Water spray on roof is effective. High solar reflective is a basic requirement. Emissivity is essential for long- wave radiation.
materials	Required insulation coefficient relative to N: E: 1.1, W: 1.2, S: 1.0, Roof: 1.6 High heat capacity are essential. Necessary time lags for internal heat balance are: E: 0 hrs, S: 10 hrs, W: 10 hrs, N: 10 hrs (or no lag), Roof: 12 hrs
shading devices	Shading should be separate from structure and exposed to wind convection.
foundation	Lithosphere type of house are possible in this zone.
mechanical equipment	Equipment should have a high operating efficiency in heat producing devices.

4.1.3 Hot and humid

House design	
site selection	High elevations on windward side. Locations near crest slightly offset from prevailing wind direction receive most air movement. Southern and Northern slope directions rather than E and W sides are preferred because of less radiation.
town structure	Accent should be on detached houses to utilize air movement. A shaded environment becomes an important consideration. The character of the town fabric should be loose and scattered.
public spaces	Minimum walking distances and shaded areas are preferred.
landscape	In the generally flat areas, the integrated of water use is both possible and desirable. Water drainage must be provided away from house. Grading, also, must be provided for run- off of intensive rainstorms.
vegetation	Shading trees should be high branching so they do not interfere with breezes. Low vegetation must be kept away from houses so as not block air movement. Air coming into a structure from across a shaded lawn is desirable.
Shelter design	
house type	Individual, preferable somewhat elevated house types are advantageous. Freely elongated high buildings are preferred, with a loose density.
general arrangements	Buildings should be shaded structures with encourage cooling air movements. Shade protection should be on all sun- exposed sides, mainly on roof and E and W exposures.
plan	As temperatures are not too excessive, free plans can be involved as long as the house in under protective shade. A free air path through interior is important. Plan might be organized into sperate elements, since 75 % of the time outdoor conditions are near comfort, if shaded. Paving should be avoided. Screened areas are necessary to keep out insects. Roll back walls are useful. Heat and moisture- producing areas should be ventilated and separated from the rest of the structure. Vapour, insects and humidity control is necessary in storage places.
form	Strong radiation effects on the E and W sides should dictate the shape of the buildings to a slender elongation. The optimum shape is 1: 1.7, but up to 1:3 on the E-W axis is also acceptable. A volume effect is undesirable.

orientation	Orientation is balanced at 5° E of North, with relatively small deviation from it to remain desirable. Orientation with long side toward differing wind directions acceptable only under shaded conditions.
interior	Interior spaces must be shaded and well ventilated. Flexible spaces, by the use of screened, movable, or low partitions, are desirable. Floor materials must be impervious to moisture. Daytime living areas should allow the flow of E to W winds. An area of safe retreat is necessary during strong storm weather.
colour	Reflective light colour in the pastel range are the best, in order to avoid glare both inside and outside.
Building elements	
openings and windows	Customary distinctions between walls and openings disappears. Ventilation is needed 85 % of the year. E- W cross ventilation is essential. Roll back opening walls are practical. Elements such as screening, louvres, jalousies and grills are useful to admit air flow and to protect from sun. Structure must be sheltered from rain and solar radiation. It must be shielded from sky radiation and glare. Removable shutters are desirable for strong wind pressures protection.
wall construction	Walls have less importance than in any other region. They are used primarily for screening from insects and for their flexible wind penetration qualities, rather than as thermal barriers. Folding window wall solutions are possible.
roof	Strongest thermal impact here. The design emphases changes from wall to roof. A ventilated double roof is desirable, the upper roof function as sun protection. It has to be insulated, water proof and reflective to solar rays. A wide overhang is necessary for rain protection (often comes up to 45°) and for reduction of sky glare.
materials	required insulation coefficient relative to N: E: 1.4, W: 1.5, S: 1.1, Roof: 2.3 Light heat capacity walls are best. Thermal lag may cause night reradiation of heat and morning condensation. Prevention of deterioration of materials by moisture and animate sources is necessary.
shading devices	Sunbrakers are important because of powerful mainly radiation on W and E sides. Note that the S wall gets more radiation impact in summer than N wall.

foundation	Basement is impractical because of constant high humidity. Foundation must be protected from moisture, fungus, termites and other insects and animals. Building on high stilts provides better ventilation and living areas and can create sheltered area below as well.
mechanical equipment	40 hrs of the year needs moderate heating, with approximate thermal differential between indoors and outdoors of 1- 4 K. 1250 hrs require low heating (average daily differential of 5- 10 K). 940 hrs need no special requirements. 6630 hrs of the year, cooling would be desirable.

[Olgyay, 1961]

4.2 ORIENTATION

Orientation is the most cost- effective determinant of the thermal behaviour of a building. As such it should be considered in the most earliest stages of the design process.

It is not always possible to orient the building in the optimal directions for site and other planning considerations may make it difficult and, at times, impossible. It is important to quantify the effects of deviating from the North to be able to predict thermal performance.

Decisions concerning the orientation of a building entail many considerations such as views, sources of noise, topography and the position of the building in relation to nearby roads and climate. Building orientation affects the indoor environment in two ways:

- Solar radiation through it's thermal effect on the 'skin' of a structure.
- Prevailing wind through their impact on wind flow around and through buildings.

Consideration of these two factors may lead to contradictory orientation decisions.

4.2.1 General

4.2.1.1 Sol- air temperature

The heat transfer into the outer surface of building elements exposed to sunlight is higher than that into similar elements not subjected to radiation. Consequently, even under steady-state conditions the heat gain through sunlit elements is not merely determined by multiplying the air- to- air temperature difference with the U-value of the element, but it is also related to the surface temperature of the element or the amount of solar energy absorbed by the surfaces.

To take account of this fact the 'sol-air' concept was introduced. It is defined as that 'temperature of the outdoor air which, in contact with the shaded surfaces of any building material that does not directly transmit solar radiation, would give the same rate of heat transfer and the same temperature distribution through that material as exists with the actual outdoor air temperature and solar radiation incident upon the sunlit surface' [Mackey and Wright, 1940]. In order to arrive at an expression for sol-air temperature, Mackey and Wright expressed the heat entering the outside surface of a sunlit building material, which does not directly transmit solar radiation, in the form:

$$q_{os} = \alpha * I_s + h_o * (\theta_o - \theta_{os}) \qquad \text{(sol-air 1)}$$

q_{os} = heat flow entering the outside surface [W/ m²]
α = absorptivity of surface to solar radiation [-]
I_s = intensity of incident solar radiation [W m²]
h_o = outer surface coefficient of heat transfer [W/ m² K]
$\theta_o - \theta_{os}$ = outdoor air/ surface temperature difference. [K]
θ_{sa} = sol-air temperature [K]

By writing equation (sol-air 1) in the form

$$q_{os} = h_o * \left((\alpha * I_s / h_o) + \theta_o - \theta_{os}\right) \qquad \text{(sol-air 2)}$$

and by defining the sol-air temperature (θ_{sa})

$$\theta_{sa} = (\alpha * I_s / h_o) + \theta_o \qquad \text{(sol-air 3)}$$

the rate of heat flow into the outside surface of the element at any time is given by:

$$q_{os} = h_o * (\theta_{sa} - \theta_{os}) \qquad \text{(sol-air 4)}$$

The sol-air temperature, therefore, combines the effects of air temperature and solar radiation upon the rate of heat entry into the surface and upon the temperature distribution through the element. In this way the problem is not only simplified considerably but it also allows a physical picture of the heat flow. Since all the heat entering a light-weight element with relatively little heat-storing capacity must be passed on to the indoor air, the rate of heat transfer per unit area through sunlit elements is given by:

$$q = U_{sa} * (\theta_{sa} - \theta_i) \qquad \text{(sol-air 5)}$$

$\theta_{sa} - \theta_i$ = sol-air/ indoor air temperature difference [K]
U_{sa} = air to air thermal transmittance value [W/ m² K]

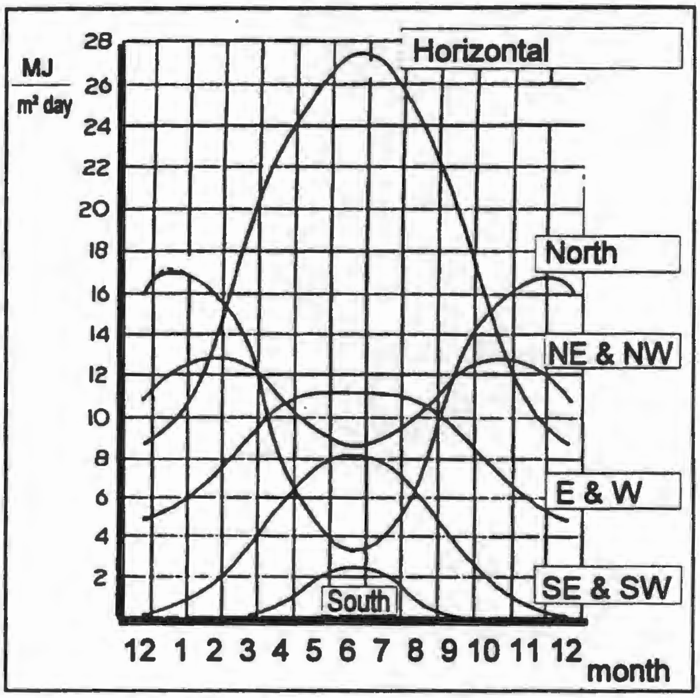
The expression for sol-air, i.e. equation (sol-air 3), is strictly speaking not correct in so far as it does not take account of the low-temperature or long-wave radiation exchange between the surface and its surroundings. The long-wave radiation exchange is generally relatively small in comparison with the direct solar heat absorbed by most surfaces, so that it can be neglected during the day. During the night the effect of long wave radiation can be utilized for cooling (see section cooling).

4.2.2 Radiation on surfaces

General observations applicable for any clear sky radiation considerations are as follows:

- The daily total of direct radiation on a horizontal surface is considerably more than on a vertical surface, especially in the summer months.
  This implies that insulation against solar radiation is more important on the roof than on the walls. It also implies that the radiation per unit floor area of the building reduces with the increase in the number of floors as the ratio of the roof area to the wall area decreases with the increase of the floors.

- At locations near the equator the intensity of solar radiation on walls facing east and west is high throughout the year. It is therefore undesirable to place openings in the east and west walls, except small ones.



Daily total direct solar radiation
35° South

- At latitudes remote from the equator walls facing the equator receive a considerable amount of solar radiation during the winter month but little during the summer month. Where solar radiation is required during winter only, openings in the wall facing the equator are ideal because shading of the glass may be readily achieved during summer by the use of simple sun- screens.

- The vertical surfaces orientated towards the east and west sides receive equal amounts of daily radiation, it is more important to insulate the western walls, because when the sun is shining on the eastern wall, the outdoor air temperature is rather low after a cool night. When the sun shines on the western wall, the air temperature is high. Thus a west- facing wall is subjected to the combined effect of radiation and high outdoor air temperature, while an east- facing wall is subjected only to the former.

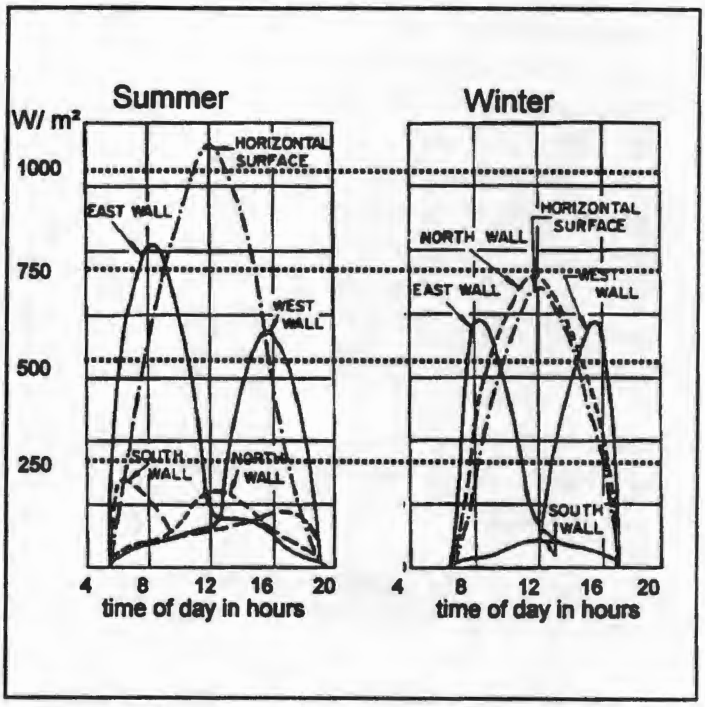
4.2.3 Radiation on façades

In comparing the diurnal solar radiation on building façades of different orientations, the diffuse component from a clear sky will vary from being percentage of the total radiant heat load received to representing the entire solar radiant heat load received. When calculating changing heat loads throughout the day, the diffuse component becomes significant at times when a particular façade receives no direct solar radiation.

The intensity of direct solar radiation varies considerably throughout the year for each façade of a building. The following figure show the variation of different orientations at latitude 25° South at winter and summer condition during the day and the annual daily total radiation for 35° South

(300 dust particles/ cm³, 15 mm precipitable water, 2.5 mm ozone).

In winter the north wall receives more radiation than the horizontal surface.

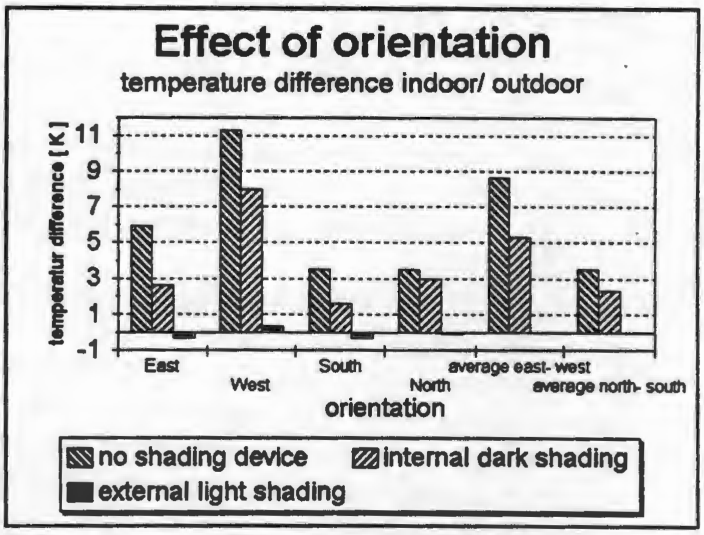


Design solar radiation intensities on different orientated surfaces, Pretoria (25° 45' S)

4.2.4 Temperature range

The effect of orientation on the indoor temperature is largely determined by the ventilation rate and the efficiency of the shading devices. The quantitative effects of orientation and shading of windows has been experimentally studied at the Technion, Haifa, Israel.

(four identical models of 0.15 m Ytong, the front wall contained a window and the rear wall a smaller opening with an insulated shutter- board).



Effect of orientation, [Givoni B. 1969]

The results are shown in the figure beside. In a westward orientated building the temperature rises up to 11.3 K above the outdoor temperature while in a eastward orientated shaded building the temperature drops 0.3 K under the outdoor temperature.

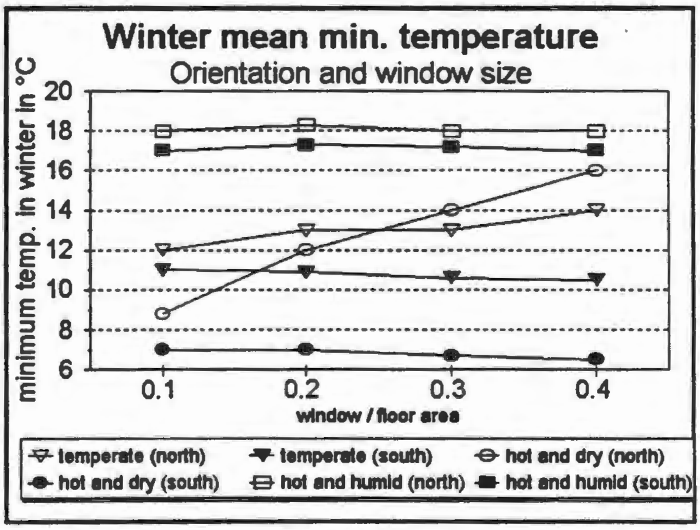
4.2.5 Windows

One main issue is the orientation of the windows. Solar energy penetration through large windows in summer can elevate a buildings indoor temperature high above the outdoor daytime level and thus cause significant thermal stress, as well as increasing the building cooling load. The problems of indirect solar gain through walls, on the other hand, can be minimized effective through the use of a reflective (white) colour or through shading by plants, as well as by adequate thermal resistance (insulation) of the walls and the roof.
The potential of solar penetration through windows in summer, and its effect on the elevation of the indoor temperature, depends greatly on the orientation of the windows:

From an experimental model Givoni, (1968) has found that with an outdoor maximum temperature of about 26°C the indoor maximum in the model with the east window reached about 33°C (elevation of about 9°C above the outdoor temperature at that time). The model with the western window has reached a maximum of about 38°C (12°C above the corresponding outdoor temperature). The maximum temperatures of the models with the south and the north windows were about 30°C, only 4 degrees above the outdoor maximum temperature.(model in Haifa, Israel)

Indoor temperature elevation caused by solar energy penetrating through northern windows in winter is desirable. It is the basis for any 'direct gain' passive solar heating system.

The effect of solar radiation on indoor temperature in winter was examined by Higgs F. and it was found that solar gain has considerable potential in the cold interior of South Africa. Orientation of windows is extremely important.
The following graph illustrate the effect of window size on indoor temperatures:



The mean minimum temperature gives an idea of how cold (and uncomfortable) the room can get during winter. The data are calculated by the simulation program DEROB [Higgs, 1982].
In hot and humid regions the change of window size has little effect on room temperatures in winter. In hot and dry zones the effect of orientation of the window is extreme. South facing windows do not increase the indoor temp. in winter. North facing windows do: Dependant on the window/ floor area ratio W/ F the temp. rises from 9°C to 16°C. In temperate climate the indoor temp. can be improved by 3 K depending on the orientation and window size.

4.2.6 Solar and wind considerations

The main considerations affecting the orientation of the main façades and windows of a building are to some extent different in arid and in humid regions because of the different relative importance of solar and ventilation issues.

- Orientation considerations in hot dry regions

Most of the world hot dry areas are located in subtropical latitudes where the highest intensities of the solar radiation in summer fall on the eastern and western walls in the summer time and on the northern wall during the winter.
This pattern of solar irradiation on the different walls results in a clear preference in subtropical hot dry regions for north-south orientations for the main façades, and especially for the windows. Such orientation enables easy and inexpensive shading of the northern windows in summer, and of the wall in general, by horizontal overhangs. Overhangs can effectively block the rays of the summer sun high in the sky (the solar noon altitude of 70° to 80°) while irradiating the northern wall in winter.

The main objective in hot dry regions is to minimize the impact of the sun on the building in summer and this is the main consideration affecting orientation. Although ventilation in the evening hours is also very important in hot dry regions this factor is secondary to the solar aspect in the choice of orientation.

- Orientation considerations in hot humid regions

In hot humid regions the provision of effective cross ventilation under the local wind direction is the major factor that may affect the building orientation. In view of the importance of natural ventilation in hot humid climates a building relationship to the wind direction should be a major consideration in determining the location of the main rooms, the living and sleeping rooms, during the design stage.

Of course, minimizing solar penetration through the windows and solar absorption at the surfaces of the walls and the roof also is very important in humid regions, but when wind and solar considerations conflict while decisions about building orientations are made, ventilation should be the primary factor. The issues of orientation with respect to the sun can be taken care of through such measures as shading devices and the colour of the envelope. Plants around the building can be very effective in regions in providing shading both for windows and walls [Givoni 1991, Akbari 1992].

Orientation for ventilation does not imply that the building should be perpendicular to the wind direction. Oblique winds at angles between 30 and 120 degrees to the wall can provide effective cross ventilation if openings are provided in the windward and leeward walls. However, the wind must be able to flow inside the building from the inlet to the outlet opening, there should be as few obstacles as possible in its path.

Solar radiation on a building can be controlled by effective shading of the openings and by the colour of the opaque walls. A white wall, or a wall shaded by vegetation is effectively exposed to a low level of radiation even when it faces east or west. Similarly eastern and western windows if equipped with appropriate operable shutters, can be protected from the sun while the building takes advantage of an easterly or westerly wind for ventilation.

4.3 SOLAR CONTROL

The dominating power that determines the thermal environment in a building is the sun. The amount of solar radiation received indoors by direct penetration of sunlight through the window is usually the greatest source of solar heat gain. In the case of glazed windows, the sunlight penetration can raise the indoor temperature well beyond the outdoor. The sunlight comprises, mainly, short wave heat radiation to which a window glass is almost transparent. The incoming radiation is absorbed by the wall surfaces and the ground inside the building, which, in turn emit long wave radiation, characteristic for low- temperature radiators.

Even in temperate regions the solar heat gain through windows can be excessive during summer, while in the tropics it is a constant source of discomfort. The following methods are usually available for reducing solar heat gains through the windows:

- orientating the building in such a way that the façades with large openings face towards the directions which receive less sunlight
- using special glasses which act as heat filters (expensive) and
- using shading devices such as screens, overhangs, louvre systems, blinds, etc. in front of window

Carefully designed shading devices can be used to manage the utilisation of daylight illumination, control of glare and solar heat gain. Fixed louvres or shades are often more economical and practical than the movable ones and are appropriate for climates which have continuous periods of sunshine. The adjustable devices can provide flexible control in most climates. If well employed, they may eliminate the need for further temperature control in mild climates, and in a severe one greatly reduce the peak temperature inside a building.

The primary data required for the design of shading devices are the values of solar altitude and azimuth.

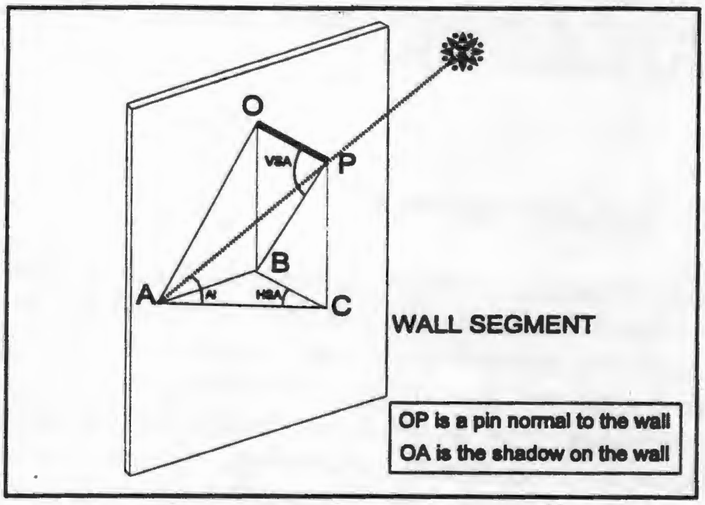
4.3.1 General

4.3.1.1 Shadow angles

A solar chart gives the values of solar altitude and azimuth. In designing a shading system, the optimal form of a building and/ or its orientation, the use of the values of the values of solar altitude and azimuth is not convenient.

Of greater convenience are the angles of the sun position as measured from a normal to the wall in the horizontal plane and in the vertical plane; referred to as the horizontal shadow angle and the vertical shadow angle.

The geometric definition of the shadow angles is as the follows:



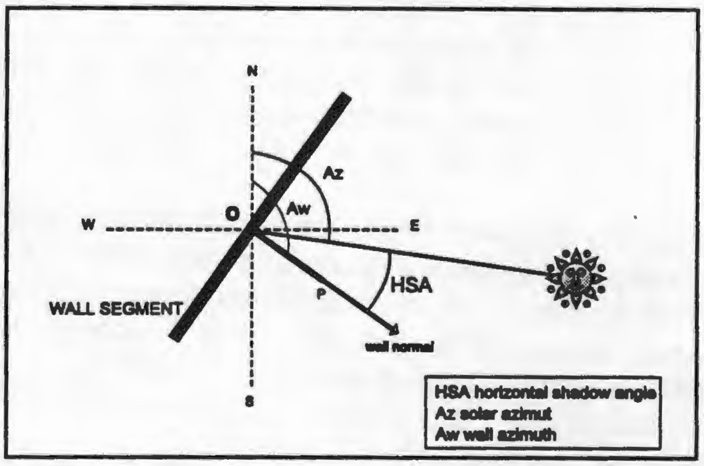
Shadow 1

Consider a pin OP fixed at a normal to the vertical wall shown in the figure 'Shadow 1' let the shadow of the pin on the wall be OA. In figure 'Shadow 2' let the angle between north direction and a normal to the wall, called the wall azimuth angle, be Aw.

The horizontal shadow angle HSA is defined as the angle between solar azimuth Az and the wall azimuth Aw. East azimuths are taken positive and west negative.

HSA = $\measuredangle$BCA or

HSA = Aw - Az



Shadow 2

The vertical shadow angle VSA is the angle between the pin OP and the projection BP of its shadow in the vertical plane containing the pin. Thus in figure 'shadow 1'

VSA = $\measuredangle$ OPB

From the application of trigonometry it may be seen that

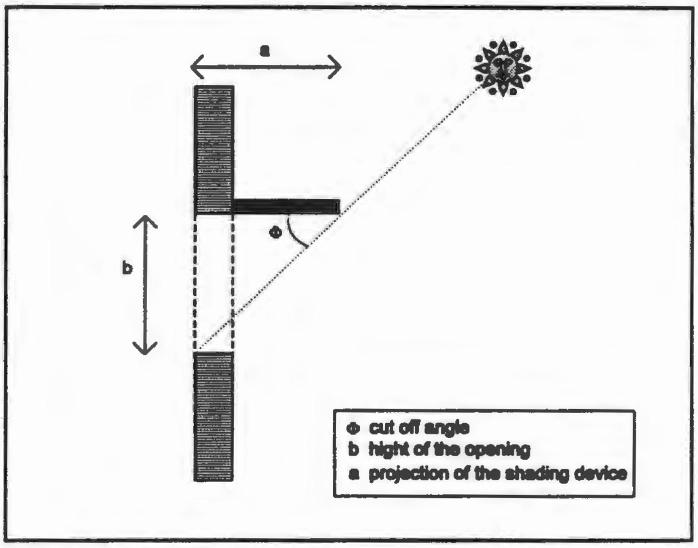
$$\tan(VSA) = \frac{OB}{OP} = \frac{PC}{BC} = \frac{PC\ AC}{AC\ BC} = \tan(Al)\ \cos^{-1}(HSA)$$

4.3.2 Shadow cast on a vertical wall

Since a plane projection may be considered as a continuum of pins, it is possible to predict the shape and extent of its shadow on a vertical wall with the help of horizontal and vertical shadow angles.
A negative sign of the horizontal component indicates that the shadow of the overhang is towards the right. If the horizontal component is positive, the shadow is towards the left.

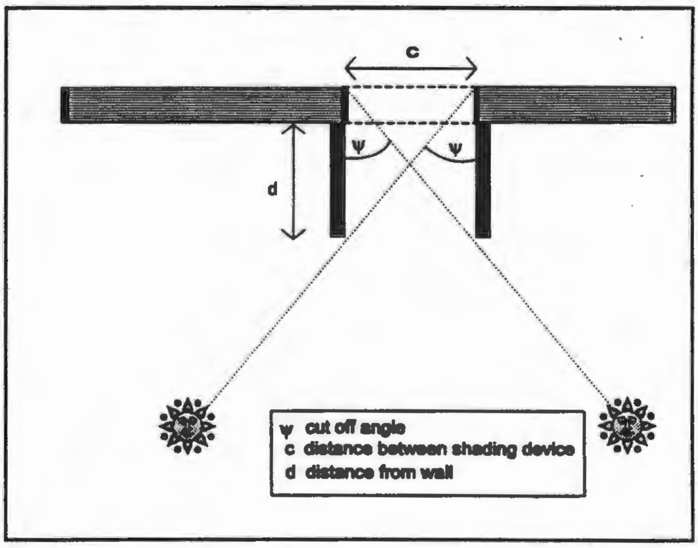
4.3.2.1 Cut- off angle

For a horizontal shading device, the cut- off angle, ϕ, is the vertical shadow angle which gives complete shading on the opening. Thus, in figure 'shadow 5'
$\tan\phi = b/a$, where a is the projection of the shading device and b is the height of the opening requiring protection. The opening will be completely screened by the shading device during the period when the sun lies in the portion between the base line of the protractor and the arc of the vertical shadow angle equal to the cut- off angle.



Shadow 5

For a vertical shading device the cut- off angle, ψ, is defined in a similar manner.
Thus in figure 'shadow 6':
$\tan\psi = c/d$, where c is the clear distance between the shading devices, and d is the distance that the shading devices project from the wall. The cut- off angle, ψ, is the horizontal shadow angle which gives complete shading on the opening.



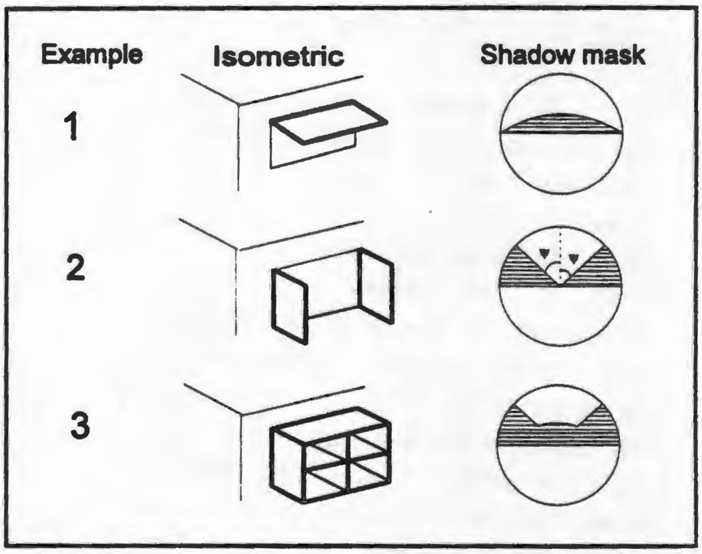
Shadow 6

4.3.3 End treatment of shading devices

If a horizontal shading device does not extend laterally beyond the window opening, the sunlight will bypass the shading device. The amount of lateral extension of the horizontal device will depend on the value of HSA. Similarly, a vertical shading device should extend beyond the window from top. The amount of vertical extension required will depend on the value of VSA.

4.3.4 Shading masks

The shading mask provide by three different types of shading devices.



Simple overhangs like 'example 1' are useful for façades facing the equator.

At latitudes remote from the equator the sun's altitude is low during the winter month and the horizontal overhangs when used on openings facing the equator permit sunlight to enter the openings during those winter months.

During the summer months the solar altitudes are higher in these latitudes and, hence, a simple horizontal overhang on a façade facing the equator can provide effective screening if care is taken to provide effective end treatment.

From the point of daylighting, tiered horizontal devices might be found to be preferable because the inter- reflection of light between their surfaces reduces contrast glare for the occupant of the room behind.

For permitting air movement between the devices and the openings it is useful to have perforated devices. These prevent temperature rising in excess of the air temperature. Inclined louvres permit wider spacing than the vertical ones. The vertical sun-breakers, 'example 2', with their radical masking characteristics, are generally effective on east or west directions.
Used in conjunction with horizontal sun- breakers, 'example 3', these can provide protection to the opening in any orientation with varying degrees of efficiency and redundancy.

4.4 THERMAL CAPACITY

In passive heating and cooling systems, storage of thermal energy is provided in the wall, the ground floor and the roof of a building. The temperature increases as energy is absorbed, and time dependent temperature gradients are established in the building elements. Most of the time the required heat is not available at that times of the day where it is necessary. On the other side solar gains increase the temperature inside a building at times where coolness is needed.
Building elements can play a compensating role in that case. The important factors which determine the thermal behaviour are the thermal capacity and thermal conductivity.

4.4.1 General

4.4.1.1 Time lag

Mackey C. and Wright L. have developed a formulae to determine the decrement factor and time lag under natural external conditions, as functions of the thermal diffusivity and thickness of the building component and of the cycle period. Their method is applicable to homogeneous and to multi layer walls. The indoor temperature is assumed to be constant. The difference between the maximum and minimum sol air temperature is the external amplitude

$$\theta_{sa,max} - \theta_{sa,min} = \Delta\theta_{sa}$$

The internal surface temperature is assumed to follow a cycle of amplitude $\Delta\theta_{int}$ which is related to the external amplitude by the decrement factor.

$$\Delta\theta_{int} = \mu * \Delta\theta_{sa}$$

The time lag τ, is defined as:
delay of the heat flow peak, in a given construction, behind the heat flow peak that would occur in a wall of zero thermal mass, ie, behind the time of maximum input- side temperature, causing that heat flow instantaneously.
The equations given by Mackey and Wright are

$$\mu = e^{-L\sqrt{\frac{\pi}{\alpha_{dif} T}}} \qquad \tau = 0.5\, L \sqrt{\frac{T}{\pi\, \alpha_{dif}}}$$

with α_{dif} = k / ρ c

τ	= time lag	[h]
k	= conductivity	[W/ mK]
c	= specific heat	[J/ kg K]
σ	= density	[kg/ m^3]
L	= thickens	[m]
α_{dif}	= thermal diffusivity	[m^2/ h]
T	= cycle period	[h]

The time lag of a temperature wave when passing from the front to the back of a thick wall amounts to:

$$\tau = \frac{t_0 \cdot d}{2\pi \cdot d_e} \qquad with \quad d_{e,\,ass} = \sqrt{\frac{k \cdot t_0}{\sigma \cdot c \cdot \pi}}$$

t_0 = time period of the variation [s]
d = thickness of the wall [m]
d_e = effective thickness [m]
$d_{e,\,ass}$ = effective thickness (asymptote value) [m]

The storage effect of a well insulated wall for a sinusoidal temperature variation with a given period can be equated to the effect of a hypothetical isothermal wall (infinite conductivity) with the same density and specific heat capacity but with a smaller thickness. This thickness is called the effective thickness d_e.

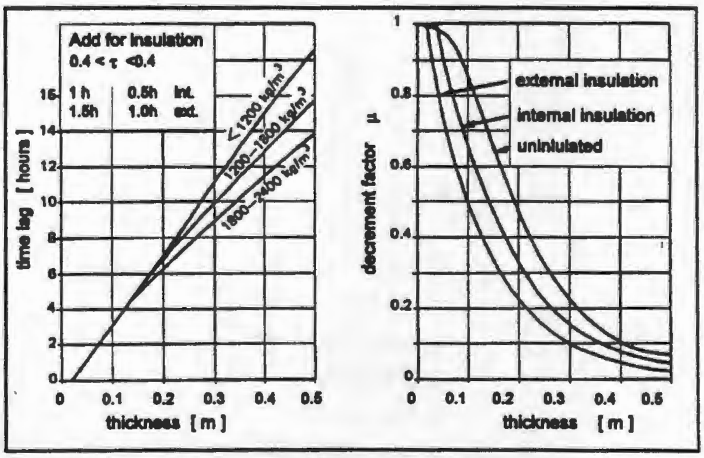
4.4.1.2 Decrement factor

The decrement factor, μ, relates to the maximum heat flow deviation from the daily mean in a given construction to that which would occur with zero thermal mass.

$$\mu = \frac{Q}{Q_0}$$

μ = decrement factor [-]
Q = actual heat flow through wall [W]
Q_0 = instantaneous heat flow with zero thermal capacity [W]

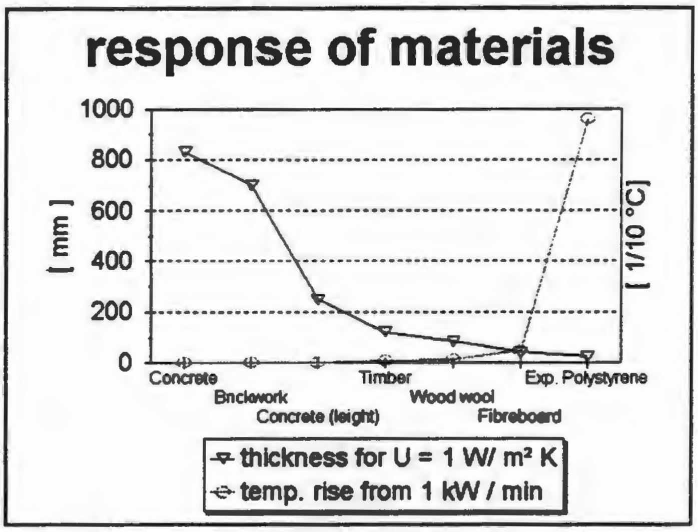
The decrement factor varies with the insulation and the thickness of the building elements.
Time lag is a function of the thickness, density and insulation.



time lag and decrement factor graphs

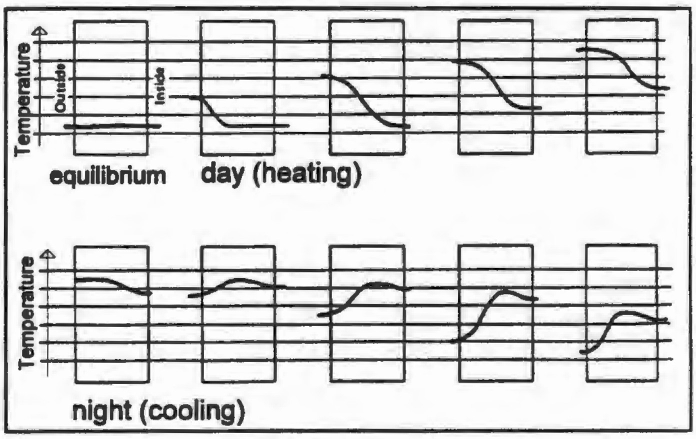
4.4.2 Respond of material

Building materials respond to heat differently seen from the diagram beside. On the left side is the required thickness for a U- value of 1 W/ m² K, on the right side the scale for the temperature rise from 1 kW per minute in 1/ 10 °C. This shows that materials have contrary thermal behaviour in terms of insulation and thermal capacity.



In the figure below displays an idealised time sequences of temperature gradients in a massive wall during day and night time.

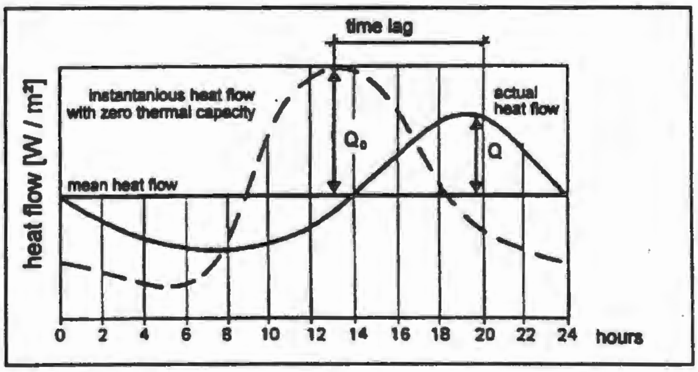
An important factor which determines the thermal function of building elements is the product of specific mass and the heat capacity, so called thermal capacity.
The thermal capacity does not influence the heat flow under steady state conditions, so there is no capacitive insulation effect. Most important is the effect on the daily temperature cycle which can be described as periodic heat flow.



temperature gradients for day and night

The seasonal influence is negotiable in case of walls and roofs but ground contact has to be taken into consideration.

The figure beside shows a schematic 24- hour heat flow cycle through a building element.



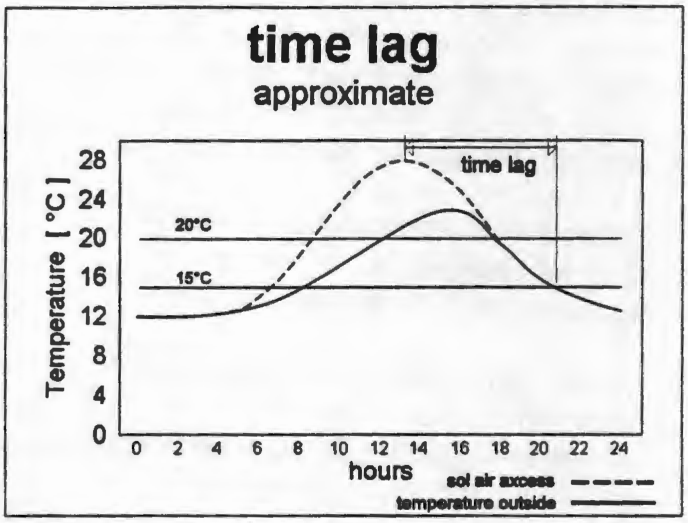
24 hour heat flow cycle

4.4.3 Desirable time lag

Insulation can be optimised, but there is no precise method for the determination of thermal capacity. Criteria for the desirability of massive construction have been discussed in qualitative terms.

In case of a massive construction the time lag for the roof and each wall orientation has to be determined. A graphical method gives some aid to design the thermal capacity and to approximate the time lag of a certain structure.

The time distance between the intersection where the outdoor temperature curve and the lower comfort level meet, and the maximum of the sol air temperature curve is the approximate desirable time lag. If the occupation of a room is earlier than this point, a time lag up to this point is adequate.



4.4.4 Table of building elements

This table gives examples of values of the time lag and decrement factors for various types of composite building elements.

The placement of insulation has a pronounced effect on the thermal behaviour. The time lag increases from 3 to 12 hours when the insolation is fixed outside of the roof.

Component	composition (from exterior to interior)	dimension [m]	decrement factor [-]	time lag [h : min]
roof 1	rockwool concrete	0.04 0.1	0.046	11:50
roof 2	concrete rockwool	0.1 0.04	0.45	3
wall 1	plaster concrete air space concrete plaster	0.15 0.1 0.01 0.1 0.15	0.073	10
wall 2	plaster hollow concrete blocks air space hollow concrete blocks plaster	0.015 0.1 0.01 0.1 0.015	0.056	10:50

wall 3	plaster hollow bricks air space hollow bricks plaster	0.015 0.1 0.01 0.1 0.015	0.1	8:45
wall 4	concrete ventilated air space concrete	0.15 0.03 0.15	0.073	10

[Givoni 1969]

4.4.5 Internal heating

When heat enters directly or is generated within a building, by heating appliances, lightning, sunlight penetration and heat from people, the indoor temperature rise immediately without the time lag characteristics of heat flow through the walls and roof. The temperature elevation depends on the rate of heat absorption of the materials surrounding the heated space.

4.4.6 Ground contact

Thermal capacity of the soil has an impact on the thermal response of the building: Increasing the buildings contact with the ground can provide additional cooling or heating. Throughout the year temperatures below the surface are more constant than air temperatures, varying negligibly several meters deep where they are significantly cooler than the surface or air temperature in summer and warmer in winter.
From experimental studies the upper boundary range of the soil temperature can be expressed by the formula:

$$dT_{(z)} = dT_{(0)} * e^{-0.3\,z} \qquad \text{for humid places}$$
$$dT_{(z)} = dT_{(0)} * e^{-0.5\,z} \qquad \text{for arid regions}$$

$dT_{(z)}$ = temperature range at depth z [K]
$dT_{(0)}$ = earth face temperature range [K]
z = depth [m]

Different types of soil have different conductivities. Soil with a high loam and clay content can have a higher water content than sandy soil. On the basis of different experimental studies, which were conducted in regions with different climatic characteristics, the table below gives the annual relative temperature ranges.

depth [m] climate	0	0.5	1	2	3	4	5
desert	1	0.78	0.61	0.37	0.22	0.14	0.08
arid	1	0.80	0.64	0.41	0.26	0.17	0.11
intermediate	1	0.82	0.67	0.45	0.30	0.20	0.14
humid	1	0.84	0.70	0.50	0.35	0.25	0.17
wet	1	0.86	0.74	0.55	0.41	0.30	0.22

[Givioni, 1969]

Combining the formulae for the range damping factor and the time lag, a generalized formula estimating the soil temperature for any time and depth can be written as [Givioni, 1969]:

$$T_{(s,z,N)} = T_{(s)} + A_0 * e^{(-F*z)} * \mathrm{SIN}\,(0.986 * N - 125 - \tau_z * z)$$

$T_{(s,z,N)}$ = soil temperature on the day N at depth z [°C]
$T_{(s)}$ = annual average of soil temperature [°C]
A_0 = annual amplitude of $T_{(s)}$ $(T_{(s)}/ 2)$ [°C]
F = damping factor [-]
N = day number (January 1st = 1) [-]
τ_z = time lag per meter depth [d/ m]
0.986 = number of days of the year in degree (360/ 365) [-]
125 = April 25th, according to the exp. observation [-]

The table show the time lag τ_L and damping factor F for different climate:

soil type/	loam/ clay		mixed		sandy	
climate	F [-]	τ_z [d]	F [-]	τ_z [d]	F [-]	τ_z [d]
desert	0.45	24	0.50	25	0.55	26
arid	0.40	22.5	0.45	23.5	0.50	24.5
intermediate	0.35	21	0.40	22	0.45	23
humid	0.25	19.5	0.35	20.5	0.40	21.5
wet	0.20	18	0.30	19	0.35	20

4.4.7 Trombe Michel wall

The effect of high capacity can be used to store solar heat gains for space heating in winter. A collector storage wall is essentially a high capacitance solar collector coupled to the room to be heated.

Trombe F. used a wall of concrete to store heat. This can serve both structural and thermal purposes. An analysis of a low cost house in Botswana shows that Trombe walls may not be an economical element of design and should not be used without careful cost benefit analysis.

It is important to use removable shades to prevent overheating in summer.

4.5 INSULATION

4.5.1 General

The term 'thermal insulation' is often regarded as referring to the application of thermal insulants (i.e. cavity-wall or attic insulation). Strictly, thermal insulation embraces all methods by which a system may be brought nearer to a state of thermal isolation from its environment. Thus, any device or arrangement which suppresses heat transfer is a thermal insulator. The four basic modes of heat transfer occur by conduction, convection, radiation, and mass transfer.

The insulation index required in buildings varies between the climatic zones: It inreases from humid, temperate to hot and dry climate zones.

4.5.2 Conduction

Conduction of heat takes place in solids and in stagnant fluids and may be inhibited by reducing the number of solid bridges across a boundary by

- reducing areas for heat flow
- increasing the lengths of the thermal paths
- using low conductivity materials.

Stagnant gases have low thermal conductivities. Thus most thermal insulants trap air in interstices between solid particles. The insulating effectiveness is often proportional to the amount of fluid contained within an insulant. Liquids have higher thermal conductivities (an order of magnitude greater than gases and vapours), and so wet insulants result in much higher heat transfer rates. When two solid surfaces are pressed together, as a result of the very small real area of solid contact produced , the interfacial contact resistance is many times greater than the solid resistance of the abutting materials.

4.5.3 Convection

The exposed areas from which convective heat transfer occurs can be reduced to inhibit convective losses (i.e. changes in human posture, such as folding the arms to reduce heat losses). Natural convection is suppressed when Gr < 2000. The dimensions of heat flow channels can be reduced to obtain lower values of Gr. Thus the smaller a cavity separation, the less convection which ensues. Heights of cavities may also be reduced but not at the expense of introducing further solid transmission bridges. Draughts and stack effects should be avoided. Powders, foams, and fibres all serve as low-conductivity insulants by suppressing convection using small interstitial pores. Cellular pockets on surfaces, curtains, blinds, and shutters also inhibit convective movements.
The Grashof number is defined as

$$Gr = \frac{buoyancy\ forces}{viscous\ forces} = \frac{\rho^2\, g\, \beta\, \Delta T\, L^3}{\mu^2}$$

Gr = Grashof number [-]
ρ = density [kg/m^3]
β = coefficient of volumetric expansion [1/K]
g = acceleration due to gravity [m /s]
μ = dynamic viscosity [kg/ m s]
ΔT = temperature difference [K]
L = length [m]

4.5.4 Radiation

Even when convection is completely absent from a system, heat transfers still occur by radiation. This mode of heat transfer can take place in a vacuum requiring no intervening transport substance. Radiative energy transport may be minimised by reducing surface areas, by introducing highly polished, low emissivity shields and bends to prevent different temperature surfaces 'seeing' each other, and by the use of low emissivity surfaces wherever possible. The rougher a surface, the nearer it resembles a black- body radiator because radiation is absorbed during inter-asperity multiple reflections. Roofs designed to exclude solar radiation are more efficient for this purpose when painted matt- white rather than when silvered because the surface equilibrium temperature depends upon the balance between emission and absorption.

4.5.5 Mass transfer

The transport of heat within a displaced fluid is akin to convection but can also refer to thermal energy exchanges resulting from infiltration. These may be reduced by adhering to basic ventilating requirements. Rates of heat transmission associated with melting, evaporation, condensation, and solidification are often very much greater than rates of heat transfer resulting from any other mechanism. High heat transfer rates across very small temperature gradients can be accomplished when changes of phase occur (such as condensation upon windows or walls, or in the evaporation of a liquid from a wet insulant) . Any insulated system must be designed so that phase changes do not occur at the boundaries. Hence vapour barriers are sometimes used to contain condensable vapours within a system at temperatures above the prevailing dew- points (or to exclude vapour ingress from the external environment). The resulting humidity of the internal environmental air then becomes greater and often either increased ventilation or air conditioning becomes necessary.

4.5.6 Cavity walls

The air gap introduced into a solid boundary by the inclusion of a cavity wall provides the major additional thermal resistance. The smaller the gap, the less intercavity convection that takes place. Radiant and conductive heat transmission through the fluid still occur. When the dimensions of the gap are such that the Grashof number Gr~ 2000 natural convection is completely suppressed and most heat passes across the cavity by gaseous conduction which increases if the gap is made smaller. There exists an optimum intercavity separation (~19 mm for a vertical cavity) for minimum heat transference. An intercavity radiation shield will further increase the thermal resistance. The introduction of a cavity fill insulant reduces thermal transmission by conduction, convection, and radiation. Vapour barriers should be incorporated to prevent vapour movements and condensation within the wall.

4.6 MATERIALS

4.6.1 General

There are two basic points which have to be considered when materials are selected:

- availability and
- performance

There are obvious advantages in using local materials:
The avoidance of foreign exchange expenditure and the useful employment of local labour. Although the extent and rate of deterioration of building materials is caused in part by design, workmanship and use, environmental factors are the major influence and have a profound effect on the durability and behaviour of materials and structures.

Moisture, temperature, ultra- violet radiation and salt laden winds can all have a detrimental effect on materials and two or more of these elements acting together almost invariably produce greater deterioration if they were acting independently. Not only must the materials used be suitable for the specific climatic conditions involved, but the design and detailing must be appropriate to both the materials and the climatic conditions.

4.6.2 Availability and performance

The table below lists the availability, use and problems/ durability of different building materials.

material	availability	usage	problems and durability
Cane, leaves and grass	cane and leaves in the warm humid zones; grass in the intermediate and subtropical zones	vegetable fibres of all sorts: vines, bamboo, palm fronds ... have been traditionally used for buildings in the warm humid zones. being waterproof, lightweight, little heat storage and allow free air passing when used as screens. Bamboo can be used as a reinforcement in concrete.	These materials have a short lifespan (with exception of bamboo). They are easy to repair and replace. Deterioration due to termite attack. Fire is a problem as these materials burn easily. They can harbour insects and vermin.
timber	both hardwoods and softwoods are commonly found in most climatic zones, with the exception of hot dry zones	timber for use in buildings should always be properly seasoned and dried to approximately its equilibrium moisture content in use. On external woodwork preservative stains should be used rather than paints or varnishes which tend to deteriorate rapidly in hot zones.	Continual dimensional changes produce checks, splits, warping and raising of the grain. Wind blown sand and grip gradually erode exposed timber. In warm dry zones timber is particularly susceptible to wet and dry rot and to attack by termites and beetles.
metals	Most metals have to be imported in finished form.	There is no excessive corrosion of most metals in hot dry zones, except in coastal zones. Aluminium and cooper have good durability in all climatic regions. Profiled, galvanised iron is generally unsuitable in very hot climates.	Corrosion due to high humidity in warm, wet zones and salt laden air produces severe conditions in this respect.
asbestos cement	Locally manufactured in the most parts of theworld.	Widely used as roof covering and wall cladding as well as for sun screening components and low pressure piping systems.	In warm humid regions algae tends to grow on damp sheets and leads to blackening. Sheets tend to become brittle and can be damaged by hail. High brakeage rate when material has to be transported long distance.

glass	Widely used and available almost everywhere. Trans-port cost and wastage are high.	Large areas of glass are justifiable only if adequately shaded or in regions where solar radiation is required during cold winter seasons.	Wind blown sand causes etching and abrasion in arid areas.
plastics	Basic raw material is oil.	Used as insulation materials such as fibreglass, expanded polystyrene and polyurethane.	Deterioration is started by ultra violet radiation and accelerated by high temperatures. Plastics are far less durable in hot climates than in temperate regions. Some types are combustible and emit unhealthy gases when burning.
earth	Most widely used material in hot dry lands. Earth can be used as wall and roof element.	Pise and adobe are the two main construction methods. Pise (monolithic construction): damp earth is laid between formwork and compacted by ramming. High sand content, density and low moisture content after ramming reduces problem of cracking Adobe: sun dried mud bricks which are allowed to shrink before being laid in the wall. Soil with a high clay content is required.	Surface cracking of adobe walls. Walls exposed to weathering rain require frequent repair work. Water proofing can be obtained by using cement or lime renderings. Stabilisation by using small quantities of cement or bitumen.
clay and calcium silicate bricks	Burnt clay bricks are one of the most widely used building materials. Sand-lime bricks from indigenous materials can be produced.	Considerable differences in size, shape, material composition and quality. Calcium silicate bricks are more expensive than concrete blocks but can be used as external facings and are more durable.	Clay bricks can be penetrated by continuous driving rain.
paints	Local production of paint in many places.	Exposure to solar radiation and high temperature causes them to break down. Frequent repainting (particularly for roofs) is necessary. Limewash is an excellent solar reflector and another advantage is its ability to emit long wave radiation.	Frequent changes between rainy and sunny conditions causes chalking. Large changes in temperature result in brittleness and cracking. Limewash has to be renewed regularly.

water-proofing bitumen, sealants	Bitumen is one of the bypassing products of oil refining.	Built up bituminous roofing systems can be badly affected by fatigue, ultra violet radiation and water vapour built up underneath the membranes. Normal mastics are not capable of retaining their elasticity in warm humid rregions. Bitumen is used to treat timber and gives protection against rot, fungi and insects.	Wetting and drying seriously affects the visco-elasticity.
concrete blocks	WWidespread use of locally manufactured concrete blocks	Both solid and hollow blocks are available. Quality tends to be low but blocks are generally not used for load bearing walls. Production on site possible. Surface exposed to driving rain have limited impermeability and should be rendered	Cracking due to shrinkage caused by temperature ffluctuations.
concrete	Concrete and reinforced concrete are widely used throughout the non- temperate zones. The large amount of water needed can present the greatest difficulties in hot arid areas.	In hot climates concrete can detoriate rapidly as a result of minerals, water, bad workmanship and climate. High temperatures accelerate chemical reactions, large diurnal temperature differences causes considerable movements, hot winds can dry the concrete too rapidly and high humidity can saturate it. Expert advice is to be sought.	In areas of high humidity concrete may set prematurely in the concrete sacks. Considerable movements can lead to pronounced cracking either in the concrete itself or in adjacent parts of the structure. In hot dry areas the rapid evaporation and shortage of water makes proper curing difficult and can result in low strength, cracking and high permeability. Damage to concrete near or below ground due to salts or humic acids present in the soil.
plaster	Used everywhere (see concrete)	sand cement plaster most commonly used. Lack of skilled plasters in many places makes the use of lime and gypsum difficult because of their fast set in high temperatures.	sand cement plasters are brittle and have a high drying shrinking rate accelerated by improper curing. They are vulnerable to cracking.
stone	A wide variety of building stone are founexpect of the low lands in the warm humid zones and some sandy parts of the arid zones.	often cheap but labour costs are high.	It can be difficult to find good stonemason. High temperatures may cause cracking.

[Konya, 1980]

4.6.3 Insulating materials

In the following section materials with insulating characteristics are compiled:
These materials are produced in South Africa and will be examined as ceiling insulation in low cost housing.

- Low emission foil

There are different types of foils available to lower the emission of the ceiling. The table below shows the technical data of Sisalation®. This foil consists of two outer surfaces of aluminium foil bonded with polyethylene.

Sisalation® reinforced aluminium foil			
type	spec. mass [kg/ m²]	reflectivity/ emission [-]	price (inc. VAT) [R per m²]
SIS 400	0.212	0.95/ 0.05	6.8
SIS 410	0.200	0.95/ 0.05	5.8
SIS 420	0.224	0.95/ 0.05	7.0

- Hardboard

Hardboard is used for ceilings. The table below shows the technical data of Masonite® Insulation Boards Products:

Masonite® Insulation Boards			
type	spec. mass [kg/ m²]	thermal conductivity [W/ m K]	price (inc. VAT) [R per m²]
plain 10 mm	2.3	0.045	8.55
plain 13 mm	2.3	0.045	10.4

- Expanded Polystyrene

Expanded Polystyrene is available in different thicknesses and different types of foil added to the material. It can be used as a painted ceiling or in combination with Hardboard.

Sagex® Insulation			
type	density [kg/m³]	thermal conductivity [W/ m K]	price (inc. VAT) [R per m²]

Megathane 20 mm Polyurethane	32	0.023	6.75
Megathane 100 mm Polyurethane	32	0.023	30.35
Megathane 200 mm Polyurethane	32	0.023	60.70
Kulite Polystyrene 20 mm Alufoil both sides	16	0.036	17.25
Kulite polystyrene 30 mm Alufoil both sides	16	0.036	20.06

- Alucushion

Alucushion consists of polyethylene bubblefoil (30 mm diameter) laminated on both sides with aluminium foil or on one side aluminium foil and on the other side a white polyethylene.

Alucushion®		
type	heat transfer coefficient [W/ m^2 K]	price (inc. VAT) [R per m^2]
4 mm with Aluminium both sides	0.47	8.00
4 mm with Aluminium and white colour	1.03	9.00

4.7 VENTILATION

4.7.1 General

The simplest strategy for improving comfort when the indoor temperature, under still air conditions, seems to be too warm, is by daytime ventilation, providing comfort through higher indoor air speeds (= comfort ventilation). The flow of outdoor air at a given speed through a building extends the upper limit of the comfort zone beyond the limit for still air conditions, and it may provide a direct physiological cooling effect even when the air is rather warm, up to about 30°C.
This is particularly the case when the humidity is high and so the higher air speed increases the rate of sweat evaporation from the skin, thus minimizing the discomfort from the sensation of wet skin.
When a building is cross-ventilated during the daytime the temperature of the indoor air and surfaces closely follow the ambient temperature. Therefore there is a point in applying daytime ventilation only when indoor comfort can be experienced at the outdoor air temperature (with acceptable indoor air speed).
The distinction between comfort ventilation and nocturnal ventilative cooling as two distinct cooling systems is suggested because some building elements, such as the structural materials, (and especially the amount and thermal conductivity of the building interior mass), require different designs for the optimization of each one of these ventilation strategies. Other building design factors, such as the location and details of the openings, may be the same in these two cases.

The effect of the outdoor air flow on the indoor daytime temperature depends on the temperature that the interior would have without the ventilation, which, in turn, depends on the design details of the building, its internal heat generation, and the amount of penetrating solar energy (e.g. for day- lighting).
In buildings that are well protected from solar radiation and that have high insulation of the envelope (roof and walls) and high thermal mass, the indoor daytime temperature, in the absence of ventilation, could be well below the outdoor level. In this case daytime ventilation would raise the indoor air and the radiant temperature of surfaces. This occurs most often in residential buildings with low internal heat generation.
When a building is naturally ventilated through open windows and the wind reaches even moderate speeds, the indoor air temperature tends to approach the outdoor temperature level. A high indoor air speed also increases the rate of heat exchange between the indoor air and the interior mass of the building.
In most regions the wind speed during the daytime is much higher than at night, when it is often almost imperceptible. In the absence of wind a much greater difference may exist between indoor and outdoor temperatures. Consequently the indoor air speed, even when the windows are open, is significantly lower at night, and the indoor-outdoor temperature difference is greater than during the daytime.
Building materials absorb heat from the warm ventilation air during the day. The rate of heat absorption is enhanced by the higher convective heat transfer coefficient, resulting from the high daytime indoor air speed in a cross- ventilated building. Because of the thermal time lag of the building materials the indoor surfaces are cooler than the indoor air in the morning hours and warmer in the afternoon and evening,

when heat flows from the interior mass to the indoor air. Thus the indoor air temperature in a high mass building reaches its maximum in the evening. Therefore, even if a building is ventilated continuously day and night, for comfort ventilation, the indoor temperature is close to the outdoor level during the daytime but is higher than the outdoor during the night hours. As a result of the combination of low air speed and warm temperature the indoor environment is often most uncomfortable during the evening hours.

4.7.2 Comfort Ventilation

When comfort ventilation is chosen as the main strategy, the building design should aim at achieving high air speed and fast cooling of the interior during the evening hours, when the wind usually subsides. This calls for relatively large but well shaded windows. Materials should not absorb and store too much heat during the daytime hours. Therefore the preferable structural materials for buildings relying on comfort ventilation would be lightweight ,for example, wood, lightweight concrete, or perforated bricks.

Comfort ventilation can be applied to all types of buildings. In regions with moderate to high daytime wind speeds the ventilation can be natural. In places without sufficient wind speeds and/ or in buildings where effective cross ventilation is not possible due to the design of the interior, the indoor air can be exhausted by a fan, with outdoor air entering the building through all the open windows.

As the main function of the air flow in buildings designed for comfort ventilation is to provide direct physiological cooling, the design of the windows should direct the flow toward the areas where the inhabitants are staying.

4.7.2.1 humid climate

Comfort ventilation would be the simplest strategy in warm, humid regions. During the day with effective cross ventilation, accompanied by a relatively high indoor air speed the indoor air closely follows the outdoor level. Therefore the temperature limit of applicability of comfort ventilation is the comfort limit at the enhanced air speed. Assuming an indoor air speed of 1.5- 2 m/s, comfort ventilation is applicable mainly in regions and seasons when the outdoor maximum temperature does not exceed about 28°C to 32°C, depending on the acclimatization of the population, and when the diurnal temperature range is less than about 10 K. These conditions are typical of warm humid climates. In these regions the relatively small diurnal temperature range does not produce a significant reduction of the indoor daytime temperature below the outdoor level, even in a closed, high- mass, well insulated building.

Daytime ventilation is therefore needed to minimize the physiological effect of the high humidity and to enhance the convective heat loss from the body.

In hot humid climate, ventilation is the most effective way to minimize the physiological effect of the high humidity. The small diurnal temperature range characteristic of such regions does not enable, in any way, a significant reduction of the indoor daytime temperature below the outdoor level without some cooling system. A spread- out

building allows better natural cross-ventilation than a compact one by providing more wall areas, and in more directions, for catching the winds.
Once the building is cross- ventilated during the daytime hours its indoor temperature tends to follow the outdoor pattern. In this case, the heat flow through the envelope is small and the larger surface area does not significantly affect the daytime indoor temperature. On the other hand, during the evening and night hours, when winds usually subside, the envelope's larger area permits faster cooling.

4.7.3 Nocturnal ventilative cooling

When a building is ventilated at night its structural mass is cooled by convection from the inside, bypassing the thermal resistance of the envelope. During the daytime the cooled mass, when it is adequately insulated from the outdoors, can serve as a heat sink. By radiation and natural convection it can absorb heat penetrating mainly through the windows, along with the heat generated inside.
To this effect, the building should be closed (unventilated) during the daytime to prevent the interior being heated by the hotter outdoor air. In this respect daytime comfort ventilation and nocturnal ventilative cooling are mutually exclusive.

From the climatic aspect the main relevant factors affecting the performance of convective cooling are the diurnal temperature range and the typical maximum temperature during the hottest months. A large diurnal range is needed because the achievable drop of the indoor maximum below the outdoor maximum is, for a building designed for this purpose, roughly proportional to the outdoor temperature range.
For a high mass, well insulated, and well shaded building a drop of the indoor maximum below the outdoor maximum of about 35% to 45% of the outdoor range [Givoni 1994] (depending on the actual thermal resistance, heat capacity, and solar protection levels) is possible when the building is unventilated day and night. Indoor minimum temperature will be higher than the outdoor minimum also by about 35% to 45% of the outdoor range. A typical indoor temperature swing for such a high mass building is about 10% to 20% of the outdoor range.
Ventilating the indoor space during the night lowers the indoor temperatures. It is possible to lower the indoor minimum more than the maximum. With nocturnal ventilation rates practical at night in residential buildings the indoor minimum in a building ventilated at night could be lowered below the level of an unventilated building by about half of the difference between the minimum of a closed building and the outdoor minimum.
Ventilative cooling is applicable mainly in arid and desert regions, which have a large diurnal temperature range (about 15 K to 30 K or more) and where the night minimum temperature in summer is below about 20°C. In such regions it is possible to store the coolness of the night air in the structural mass of the building. The flow of outdoor air at night through the building can be induced naturally by the wind (where wind speed at night at the building site is sufficient, above 2- 3 m/s). During the following day the cooled mass serves as a heat sink, maintaining the indoor temperatures well below the outdoor level, if possible within the comfort range. This temperature reduction can be

achieved only when the building is well insulated, with the insulation external to the structural mass, and if the building is not ventilated by the hot outdoor air during the daytime hours.
The ventilation of the building during the night time cools the interior mass. The cooled mass absorbs heat during the following daytime hours and lowers the indoor temperatures. The drop in the indoor daytime temperature of a high- mass building below the outdoor maximum by night ventilation is roughly proportional to the outdoor temperature range.

It can be estimated that in arid and desert regions, with a diurnal temperature range of 15 K - 20 K, the expected reduction of the average daytime indoor temperature is 2- 3 K below the level of similar buildings that do not have night ventilation. Indoor maximum temperature can be lowered by about 7- 8 K below the outdoor maximum. On very hot days, which usually have a larger diurnal range, the drop of the indoor temperature during the time of the outdoor maximum may be up to about 10 K.
Nocturnal ventilative cooling would be the preferable strategy in regions where the diurnal temperature range in summer is large enough to enable a significant reduction of the indoor air temperature below the outdoor maximum. Nocturnal ventilative cooling as a building design strategy is preferable to comfort ventilation in regions where the daytime temperatures in summer are above the upper limit of the comfort zone (with air speed of about 1.5 m/s) and it is applicable mainly in arid regions where the daytime temperature is between 30°C and 36°C and the night temperatures below about 20°C.
In this situation daytime ventilation is not desirable because it would raise the indoor temperature. The large diurnal temperature range, typical of arid regions, allows the indoor daytime temperature to be reduced significantly below the outdoor level by night ventilation.
In arid regions with daytime temperatures above 36°C, night ventilation would not maintain the indoor temperature at an acceptable level. Other passive cooling systems should be considered during the too hot hours as supplements to convective cooling, systems such as evaporative cooling or earth cooling. But even when an additional cooling system is provided the use of convective nocturnal cooling can significantly reduce the amount of additional cooling. Some practical problems may limit the applicability of nocturnal convective cooling. These problems include:
The need to open and close windows at prescribed times and issues of security.

Nocturnal ventilative cooling can be applied to all types of buildings, provided that they are well insulated and their interior mass permits effective thermal storage of the night coolness. Low- mass buildings, even if ventilated at night, cannot retain enough 'cool reserve' to reduce significantly the rate of temperature rise during the daytime. [Givoni, 1994]

4.8 WINDOWS

4.8.1 General

The functions of windows are numerous in any climate, among other things they provide daylight visual contact with the outdoors, sun penetration in winter and ventilation in summer. Here only the impact of window design on the ventilation and cooling needs of building are discussed.

The demands placed on daytime ventilation are very different in hot dry and hot humid climates and the thermal effect of windows is also very different in these two types of hot climates Consequently the issues of a window size and its effect on the cooling load of buildings are treated separately.

4.8.1.1 Hot dry regions

In hot dry regions the daytime temperature in properly designed buildings is much higher outdoors than indoors. Heat gain through windows, per unit area, is much higher than through walls or the roof. Conventional windows tend therefore to raise the indoor temperature and the larger the window area the greater its heating effect, especially when sun penetration is not effectively prevented by shading or orientation. Even when sun penetration is effectively eliminated and the windows are closed their small thermal resistance and the air infiltration through the surrounding cracks makes them the weakest point from the aspect of heat gain. Sunlight in hot dry regions is very intensive and large windows may cause glare discomfort reinforcing the notion that small windows are more suitable for desert regions, than larger ones.

This view was supported by the observation that vernacular buildings in desert regions, built mainly from compacted mud, adobe blocks, or stone usually have very small windows. It should be pointed out that the traditional way of life of the inhabitants of vernacular houses in hot dry regions was to sleep on the roof or in a courtyard testifying to the uncomfortable indoor conditions that prevailed indoors at night. [Givoni, 1976]

Good ventilation is of primary importance in hot dry climates during summer evenings and nights. Ventilation can enhance physiological comfort as well as increase the rate of cooling of the building structural mass. Without effective nighttime cross ventilation a building interior may be unbearably hot at night, just when comfort is essential for restful sleep.

With special design details, in these regions large windows can provide thermal advantages. When highly insulated shutters are added to large openable windows, their thermal effect can be adjusted to varying needs, both diurnally and annually. In summer the shutters can be closed during the hot hours. Then, light will filter into the house only through the small areas provided by the shutters. In the evening the shutters and the windows can be opened, increasing the rate of cooling of the interior. In winter, large northern windows can provide significant direct solar heating of the interior. Closing the insulated shutters during the night traps the heat indoors and reduces the rate of cooling. This helps to maintain comfortable indoor night temperatures.

4.8.1.2 Hot humid regions

In a cross ventilated building the indoor temperature follows the outdoor pattern closely. If penetration of solar radiation is prevented, no significant heat flow through the envelope takes place and thus well shaded large windows do not affect the cooling needs of the building.

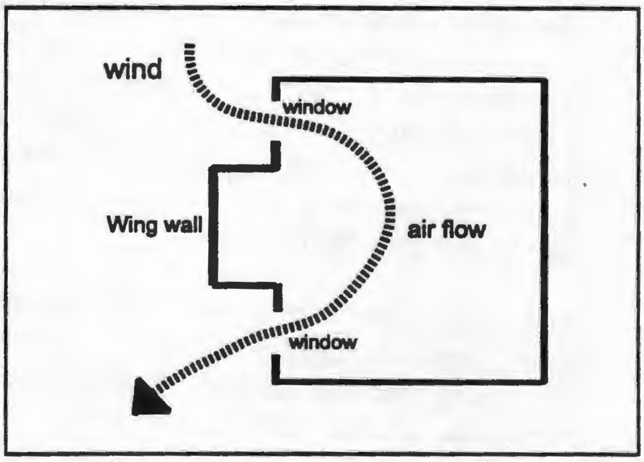
Openings in a hot humid climate play a major role in determining the thermal comfort of the occupants as their location and size determine the ventilation conditions of the building. In this respect, large openings in all the walls can provide the design solution for effective cross ventilation. Solar radiation can penetrate directly through unshaded openings into the interior of the building and elevate the indoor temperature above the outdoor level. Therefore, most care should be taken in ensuring that all openings in the envelope of the building are effectively shaded.

It is desirable to ensure independent cross ventilation to every individual room in the building. This means that each room will have at least two openings, in different walls, preferably one of them in a wall facing the direction of the wind. In practice it is difficult in many cases to have independent cross ventilation of every individual room in the building, especially in townhouse rows. In such cases, it is important to make sure that air can flow in and out of every room passing through a series of rooms in the building on its way to the outlet openings.

When the wind direction is at an acute angle to the wall, when it is nearly parallel to it, it is still possible to create effective cross ventilation. There must be at least two windows in the windward wall and each one must have a single 'Wing wall', a single vertical projection on one side of the window. (This can be designed as shading device as well.)

In each one of these windows the projection should be installed on alternate left and right sides. The windows should preferably be vertical, that is, narrow and high. With the wind coming from any direction across angles down to about 15° from the wall, one window will be in a wind pressure zone acting as inlet and the other window will be in the suction zone, acting as outlet.

By using the wing wall the indoor air speed improve from 8% up to 35 % of the outdoor wind speed (with wind affecting the wall under an angle of 30° to the window surface. [Givoni 1976]



air flow with wing wall

4.9 SURFACE COLOUR

All building materials exposed to solar radiation will absorb heat to a greater or lesser degree, depending on the absorption of the exposed surfaces to solar or higher temperature radiation. This can have a pronounced influence on the thermal response of buildings.

4.9.1 General

The heat flow through a material is directly related to its surface temperature. Therefore the colour and the material plays an important role in the performance of building.
The intensity of heat radiated by a surface is given by the Stephan Bolzmann law:

$$q_r = \sigma \epsilon A T^4$$

$\sigma = 5.6697 * 10^{-8} W/m^2 K^4$ $[W/m^2 k^4]$
ϵ = emissivity [-]
A = area $[m^2]$
T = Temperature in °C + 273.15 [K]
α = absorptivity [-]
r = reflectance [-]

For thermal radiation the absorptance is equal to the emissivity at each wavelength.
$\epsilon = \alpha$

Furthermore $\alpha + r + \tau = 1$

For non- opaque materials the transmittance, $\tau = 0$ and therefore $\alpha + r = 1$

Average emissivity, absorptions anreflectivity for some surfaces common to building:

Surface	Emissivity/ Absorption		Reflectivity
	Low-temperature	Solar radiation	r
Aluminium, bright	0.05	0.2	0.8
Asbestos cement	0.95	0.65	0.25
Brick, light buff	0.9	0.6	0.4
Brick, red rough	0.9	0.7	0.3
Cement, white	0.9	0.4	0.6
Concrete, uncoloured	0.9	0.65	0.35
Glass	0.9	-	-

Paint, aluminium	0.55	0.5	0.5
Paint, white	0.9	0.3	0.7
Paint, brown	0.9	0.7	0.3
Paint, black	0.9	0.9	0.1
Paper, white	0.9	0.3	0.7
Steel, new	0.25	0.55	0.45
Steel, weathered	0.25	0.7	0.3
Tiles, red clay	0.9	0.7	0.3
Tiles, black concrete	0.9	0.9	0.1
Tiles, uncoloured concrete	0.9	0.65	0.35

To combine the radiation with other heat transfer processes the surface coefficient is introduced:
Surface coefficients of heat transfer takes into account heat transfer by conduction, convection and radiation. These are influenced by factors such as the emissivity of the surface, its roughness, the rate of the air movement over it, its temperature in relation to that of the air near it and its position. The main effects of these variables can be summarized as follows:

- An increase in the emissivity of a surface will result in increased heat loss from the surface by radiation with the result that its surface coefficient will also increase. Similarly, when a surface radiates to an area of low temperature such as a clear sky during the night, its surface coefficient will increase. In this connection it is not uncommon for the surface temperatures of light- weight components to drop below outdoor air temperature during the night:

- The higher the rate of air movement across a surface the higher the rate of heat transfer by forced convection and consequently the higher the surface coefficient.

- Generally the bigger the temperature difference between a surface and the air near it, the higher the surface coefficient will be because of the increase in convective heat transfer. Large temperature differences are often experienced in practice, particularly in the case of dark-coloured sunlit components.

- An increase in the roughness of a surface also leads to an increase in heat transfer by convection and thus in higher surface coefficients. This is related to the turbulent nature of the air flow over such surfaces, as compared with smooth surfaces, as well as with the increase in surface area associated with roughness. For example, the surface coefficient for a corrugated surface is quoted as being 20 per cent higher than that for a flat but otherwise similar surface.

The surface coefficients are different for vertical and for horizontal surfaces. In the latter, the surface coefficient also depends on the direction of the heat flow. For upward heat flow the coefficients are slightly bigger than for downward heat flow, mainly because heat flow is assisted in the first instance by natural convection currents and not in the latter.

4.9.2 Colour of the surface

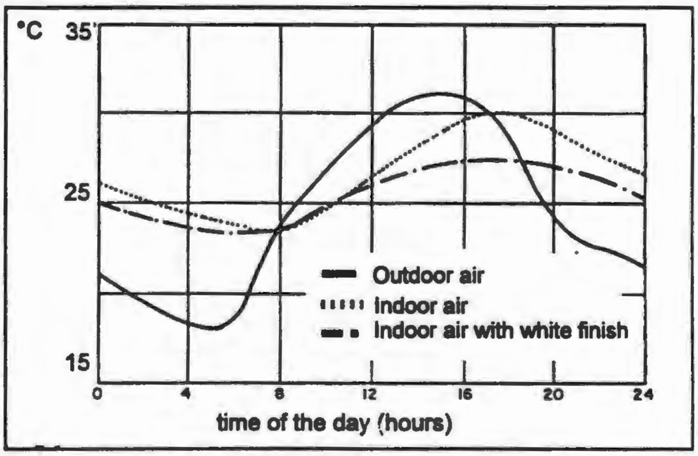
The colour of the external surfaces of the walls and the roof has a tremendous effect on the impact of the sun on the building and on the indoor temperature, particularly in regions where solar intensity is high. It may affect the practicality of applying passive cooling to a given building even in climates where the potential for passive cooling does exist.

The effect of the external colour of walls and roofs was studied by [Givoni and Hoffman, 1968] at the Technion in Haifa, Israel (a coastal city with a humid Mediterranean climate), with different types of thermal models. The research covered the effect of colours of roofs and walls. The effect of roof colour was tested with lightweight roofs made of insulated panels. The effect of wall colour was studied with test cells built of different materials. Each test cell had two small windows (25 x 40 cm) that could be closed by insulated panels.

The diurnal average of the external surface temperature was lower than the air average, and the ceiling minima were lower as the roof was thinner; indicating that the 24 hour longwave radiant loss was greater than the solar absorbed in the white roofs. This phenomenon of white roofs being at lower diurnal temperatures than the ambient air, was observed repeatedly, with different roof types, even in midsummer on very clear days.

In the figure beside the influence of white wall finish on indoor air temperature of a brick dwelling during warm summer conditions in Pretoria is shown.
[Van Straaten, 1967]

As the choice of colour does not involve extra costs: Reflective colour of the building envelope is a very powerful architectural climatic control feature and it is the most cost- effective way to minimize the buildings heat load in summer.



Temperature range during the day

Because of the different intensities of solar radiation incidence on the roof and on walls of different orientations the importance of colour as a controller of the indoor temperature is variable. For the roof the influence of colour is at a maximum. The difference in the maximum external surface temperature between a white roof and a black one in a hot arid climate in the summer can be 30 K to 40 K. The resulting heat gain to the building interior depends on the themophysical properties of the roof, but in general it is significant. A western wall is almost as sensitive to the effect of colour as the roof. Eastern and northern walls are also very sensitive to their external colour, while the southern wall is the least sensitive. The northern wall presents a special case because it receives most radiation in winter, when heating may be desirable.

4.10 COOLING

4.10.1 Radiant cooling

Any ordinary surface that 'sees' the sky looses heat by the emission of longwave radiation toward the sky and can be regarded as a heat radiator. Although the radiant heat loss takes place day and night, only during the night is the radiant balance negative. During the daytime the absorbed solar radiation counteracts the cooling effect of the longwave emission and produces a net radiant heat gain.
Roofs are usually insulated to minimize heat loss in winter and heat gain in summer. As the radiant loss takes place at the external surface of the roof the insulation minimizes the actual cooling that a building can utilize from the nocturnal radiation, unless specialized designs (radiant cooling systems) are applied.

4.10.2 Massive roofs with movable insulation

The simplest concept of radiant cooling is that of a heavy and highly conductive roof (for example, one made of dense concrete) exposed to the sky during the night but highly insulated externally by means of operable insulation during the daytime. Such roofs can be very efficient in losing heat at night, both by longwave radiation to the sky and by convection to the outdoor air, which cools down faster than the massive roof. During the daytime the (installed) external insulation minimizes the heat gain from solar radiation and from the hotter ambient air. The cooled mass of the roof can then serve as a heat sink and absorb, through the ceiling, the heat penetrating into and generated inside the building interior during the daytime hours.

4.10.3 Long wave radiators

In order to utilize the cooling effect of nocturnal radiation by buildings with ordinary insulated roofs, the cold produced at the external surface, above the insulation, should be transferred into the building interior. Usually this 'cold transfer' is provided by air flow under the radiating element, cooling it to a temperature below the ambient. The cooled air is blown through the interior space to cool the mass of the building, in a similar way to nocturnal ventilative cooling, but with a temperature below the level that can be achieved by direct ventilation with the outdoor air. The cooled mass then serves during the following day as a sink for heat penetrating into and generated inside the building.
Any painted metallic layer placed over the roof, with an air space of about 5 to 10 cm beneath it, could serve as a radiator. The radiator can serve also as a rain- proofing element. When air flows under the radiator at night it is cooled, while the radiator

temperature rises. Metals have low emissivity and thus are poor radiators. Therefore the external surface of the metal should be painted so that the paint would provide an emissive layer in thermal contact with the conductive metal underneath.

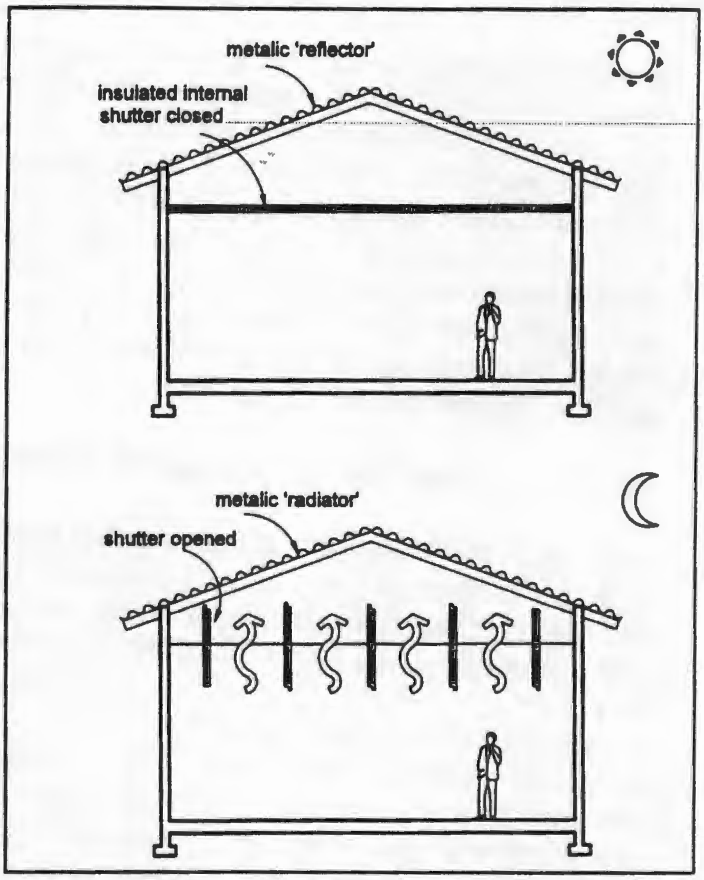
The temperature drop attained by a radiator without air flow underneath is the 'stagnation temperature drop.' To be of any value as a cooling system the radiator stagnation temperature should be lower than the ambient air by some minimum temperature drop, at least 5 K. If it is not, the simpler and less expensive nocturnal ventilative cooling could be applied. Ambient air drawn under the radiator can be cooled by about one third to two thirds of the stagnation depression achieved by the radiator, depending on the flow rate.

4.10.4 Applicability of radiant cooling

The roof is the element of a building that has most exposure to the sky and therefore it is the natural location for a nocturnal radiator. High-mass roofs with operable insulation, either of concrete or with roof ponds, provide the functions of cold collection and of storage in one element. Therefore, these types of radiant cooling are effective in providing daytime cooling in almost any region with low cloudiness at night, regardless of the air humidity.

A radiant cooling system that uses a metallic radiator with a fan-driven air flow underneath can cool the night air below the ambient level. The main climatic requirement is again low cloudiness during the nights. Humidity is less important as long as the nights are clear. In arid regions a temperature drop of about 3 K to 5 K, depending on the flow rate exiting from the radiator, can be expected. In humid regions with clear skies the expect temperature drop would be about 2 K to 3 K. In humid regions, moisture would be condensed out of the air while flowing under the radiator, thus lowering both the indoor humidity and the temperature. This cooled and partly dehumidified air can be used directly to cool a building during the evening and night hours in regions where the outdoor air is too warm provide comfort by direct ventilation.

In many developing countries corrugated metal or asbestos cement roofs are very common. During the nights the low- mass roof cools down rather quickly, acting in effect as an effective nocturnal radiator located directly above the living space. The indoor night conditions in such buildings are often more comfortable than in buildings with high- mass roofs. During the daytime hours the indoor climate in buildings with such roofs is often uncomfortably hot, as the uninsulated lightweight roofs are heated to much higher temperatures than a massive concrete roof would be. Installing centrally hinged interior insulating parallel plates under the roof can greatly reduce the daytime heating without interfering too much with the cooling effect of such roofs during the nights. When the plates are in a horizontal position (closed), during the daytime, they form a continuous insulation layer under the roof, minimizing the heat flow into the interior space. During the nights the plates should be turned into a vertical position, enabling radiant and convective heat flow from the interior space to the ceiling, which is cooled by the long- wave radiation to the sky (see figure radiant cooling). [Givoni 1994]



radiant cooling

Interior insulation plates are not exposed to the wind and the rain and thus can be simpler in construction, lighter, and much less expensive than external insulation panels. The changes in their position, vertical or horizontal, can be controlled from the interior manually, through such means as a rope.
A major potential hazard with interior insulation that is made of expanded plastic materials is posing a fire hazard. A possible design made of noncombustible operable interior insulation is a wood frame lined with aluminium foil. Such panels, when in horizontal (closed) position during the day, act as an effective radiant barrier between the hot roof and the interior space. Such simple devices can, with appropriate instructions, be 'manufactured' and installed by the residents themselves and they also can be retrofitted easily in existing buildings.

During summer evenings the outdoor temperature in many hot dry regions (and in almost all hot regions during some months) drops down rapidly and reaches a level below the indoors, within or even below the comfort zone. This situation changes the desired climatic performance of the building. The objective in the summer evenings then would be to speed up the cooling rate of the interior as much as possible. From the layout aspect this calls for a spread out building with greater exposure to the outdoor air. The need to enhance the rate of cooling in the evenings is of special importance in the case high mass buildings, which naturally have a very slow response to changes in the outdoor temperature.

Using the architectural design, it is possible change the effective surface area of the building envelope, on a seasonal, daily, or even an hourly basis, and thus to increase the exposure of the building mass to the cooler evening air while maintaining a compact configuration during the hot hours.

When the building façades are 'indented' by deep and narrow porches the surface area of the envelope is greatly increased. However, these porches can be equipped with closeable insulated shutters along the lines of the adjoining walls. When these shutters are closed they become an integral part of the building envelope. These shutters could be in the form of insulated doors or they could take other forms. An illustration of this configuration is shown in the figure above.

When the insulated shutters are closed the porches, and the openings of the adjoining rooms leading to them, are within an interior or semi- interior space. They are thus protected from hot air, solar radiation, and dust. During the evening and night hours, on the other hand, the insulated shutters should be opened. The porches are then exposed directly to the outdoor air, increasing the surface area of the envelope and the openings through which the building can be cooled by ventilation.

With such geometrical configuration and operating procedures the building is compact during the summer daytime hours (as well as during the winter) and widespread during the nights. The changeable surface area of the effective envelope minimizes the rate of daytime heating and increases the rate of cooling in the evenings.

Air conditioning, is too expensive for the vast majority of people in developing countries, which cover most of the hot, humid regions.

4.11 HAZARDS

This section describes hazards like moisture and condensation and explores the physical background.

4.11.1 General

When an insulating material absorbs moisture its thermal conductivity rises significantly. The moisture contained can also increase rates of corrosion, mould growth and damage of the structure materials. Radiation shielding can be rendered useless by the deposition of very thin liquid film on the surfaces because the emissivity of the most liquids are very high.

4.11.2 Vapour diffusion

Vapour diffusion occurs through a vapour porous material whenever a difference in vapour pressure Δp_v exists across the building material. Then heat loss associated with mass movements can take place even under isothermal conditions.

The rate of vapour flow through a material is given by

$$G_v = \Delta p_v \frac{k^\cdot}{d}$$

The permeability of a material can be expressed as a fraction of the permeability of air.

$$k^\cdot = \frac{k^\cdot_a}{\kappa} = \frac{1}{\kappa}\frac{D^\cdot}{R_v T}$$

with $C^* = k^* / d$

G_v = vapour flow $[\,kg/\,m^2\,s\,]$
Δp_v = vapour difference $(\,p_v - p_{sat}\,)$ $[\,N/\,m^2\,]$
k^* = vapour permeability $[\,kg\,m/\,N\,s\,]$
k_a^* = permeability of air $[\,kg\,m/\,N\,s\,]$
d = thickness of the material $[\,m\,]$
C^* = permeance $[\,kg/\,N\,s\,]$
κ = diffusion resistance factor $[\,-\,]$
D^* = diffusion coefficient for water vapour $[\,m^2/\,s\,]$
R_v = gas constant for steam $[\,kJ/\,kg\,K\,]$
T = temperature of air $[\,K\,]$

$R_v \approx 0.462$ kJ/ kg K
$D^* \approx 2.8 * 10^{-5}\ m^2/\,s$
$k_a^* \approx 20 * 10^{-11}$ kg m/ N s

The rate of vapour flow can be expressed alternatively as

$$G_v = \frac{\Delta p_v \; k^*_a}{\kappa \; d}$$

Vapour pressure gradients can be calculated similar to the temperature gradient. Typical values for the diffusion resistance factor and the permeance are given in the table below [O'Callaghan, 1978].

Material	Diffusion resistance κ [-]	Material	Permeance C^* [kg/ N s]
Brick	10	Aluminium foil	0- 0.6
Brickwork	35	Building paper	1.7- 45
Cement mortar	45	Painted insulation board	5.7- 290
Clinker block	420	Kraft paper	170- 460
Concrete	40	Painted plaster	5.7- 17
Cork slab	10	Painted plywood	14
Foam glass	0	Polythene	0.6
Insulation board	5	Roofing felt	1- 23
Mineral wool	1	Painted wood	1.7- 11
Plaster	10	Aluminium painted wood	25- 54
Plasterboard	8	-	-
Plywood	200- 700	-	-
Wood	20- 300	-	-
Air	1	-	-

4.11.3 Condensation

Condensation through vapour diffusion will occur whenever the calculated vapour pressure is equal to the local saturation pressure.
Condensation occurs as well when moist air comes into contact with a surface whose temperature is below the prevailing dew- point temperature of the physiometric mixture. Condensation cannot take place if the surface temperature is above the dew-point. Condensation or evaporation is accompanied by the release or absorption of latent heat H_{fg} being the latent heat transferred per kg during the phase change. The total rate of heat dissipation or absorption is calculated from

$$Q_{diss} = G_v * H_{fg} \qquad [W/m^2]$$

with

$H_{fg} \approx 2.5 * 10^3$ kJ/ kg (water at T = 293.15 K)

Condensation conditions can only be avoided by constructional details (vapour barrier on warmer side, ventilating cavities) or varying the indoor conditions.

Once condensation has taken place within an insulant or building material its effective thermal and mass transport properties change. This modifies the temperature and vapour pressure distribution through the system and further calculations are required to obtain an indication of quasi steady state behaviour.
A first order indication of the effects of water content in porous materials can be obtained by assuming that the thermal resistant of an insulant is dependent upon the amount of dry air contained and the air flow inside the material.
The overall conductivity of the dry insulant then depends upon the volume voidage of the medium and the conductivity of the solid constituent.

$$U_{dry} = V_{air} * U_a + (1 - V_a) * U_b \qquad \text{(Cond. 1)}$$

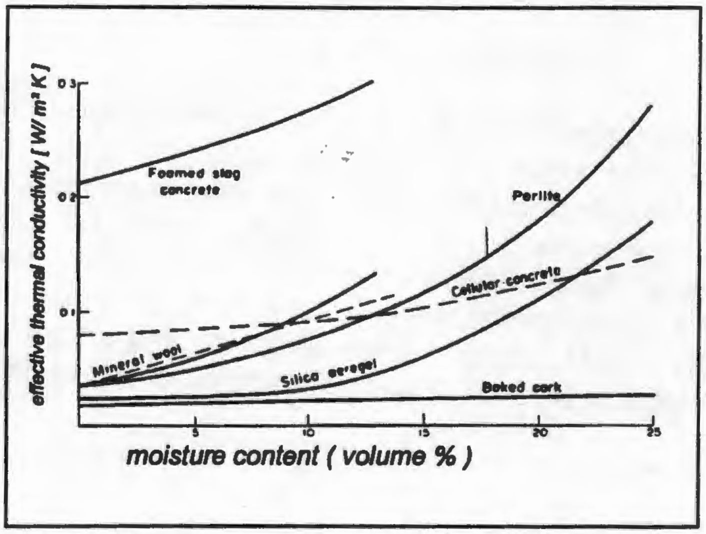
because any liquid water contained in damp insulants displaces its own volume of air,

$$U_{wet} = V_a * U_a + V_{water} * U_{water} + (1 - V_a - V_{water}) * U_b \qquad \text{(Cond. 2)}$$

U_{dry}	= U value of dry insulant	[W/ m² K]
U_{water}	= U value of water	[W/ m² K]
U_a	= U value of air	[W/ m² K]
U_b	= U value of solid component	[W/ m² K]
U_{wet}	= U value of wet insulant	[W/ m² K]
V_a	= Volumes voidage of air	[%/ 100]
V_{water}	= Volumes voidage of water	[%/ 100]
V_{air}	= Volumes voidage of air	[%/ 100]
U_{water}	≈ 0.57 W/ m² K (at 293.15 K)	

The approximate equation gives a linear relationship which predicts conductivity values within the limits of experimental measuring errors. [O'Callaghan, 1978]

The figure beside presents experimentally derived relationships for various insulants. The non-linearity of these characteristics indicates transient and stratification effects.



effective thermal conductivity

Damage of material caused by condensation and vapour diffusion should be considered of the cost benefit analysis. It strengthen the argument for improving the thermal performance of buildings.

Summary:

- Passive design options imrove the thermal performance
- Climatic zones have to be considered in the design process
- Building material and structure effects strongly indoor conditions

5 ECONOMIC ANALYSIS

This chapter introduces three economic analysis:
The method of cost benefit analysis, life cycle analysis and sensitivity analysis are pointed out. The perspectives of the end- user and Eskom are taken into consideration. Input and output data are documented.

5.1 GENERAL

Economic analysis can provide an important and helpful tool for making decisions. But it is only no more than a tool, depending strongly on the assumptions made in the analysis. Problems involving social policy and value judgements must be considered and weighed in conjunction with the results of the analysis and the final decision made by the human policy maker.

5.1.1 Cost classifications

Costs can be classified into three categories.

- first costs
- fixed costs
- variable costs

The first cost (start up costs) is the set of costs associated with the start of a project. These costs normally occur only once for a given project.
The term fixed cost identifies those costs that remain relatively constant over a wide range of operational activity as measured by output or some other appropriate quantity. (Costs related to taxes, insurance, interest, maintenance, administration, and so on are of this type)
Variable costs are those costs that vary more or less directly with the volume of input. These include the costs of materials, labour, fuel, and electrical power.

5.1.2 Asset life

An asset is an item having monetary value. For engineering economy purposes, an asset can have three kinds of lives.

- ownership life
- physical life
- economic life

The ownership life is the time period between the date of acquisition and date of disposal by a specific owner.
The physical life of an asset is the time period from when it is new to when it is ultimately disposed of. Over its physical life an asset can have a succession of owners.

The economic life of an asset is the time period dating from its installation to when it is removed from the intended primary service because the cost of a replacement asset is less than the cost of keeping it for an additional period. A strong factor in the replacement decision is often the increase in operating and maintenance costs which take place as the asset provides service.

At the end of an asset economic life it is replaced but not necessarily disposed of, for it may pass into a new economic life for the same owner performing a secondary service role. If it is disposed of, it may go on to additional economic lives with a new owner. The salvage value of an asset is the amount that is recovered or that could he recovered when it is removed from service.

5.1.3 Time value

Interest is the rental amount charged for the use of money.

A Rand in hand today is worth more than a Rand received one year from now because having the Rand now allows the opportunity for investing it for the year.

Money has a time value because the purchasing power varies with time and the productive value when it is invested in economic a process. During periods of inflation the number of Rands required to obtain a given amount of goods increases over time. The notion that money has a time value means that equal Rands amounts at different points in time have different worth.

When alternative engineering options are evaluated, it is essential to account properly for the time value of money used both currently and in the future. This brings in the subject of life- cycle costing and cost- benefit analysis.

5.1.4 Present worth

Calculating an obligation recurs every year and inflates at a rate i per period, a present worth factor of the series of N such payments can be established (with a discount rate of d) [Duffie J.,1991].

$$PWF\ (N,i,d) = \frac{1}{(d-i)}\left[1-\left(\frac{1+i}{1+d}\right)^{N}\right], \qquad (d \neq i)$$

PWF = present worth factor [-]
i = inflate rate [%/100]
d = discount rate [%/100]
N = number of years [-]
d - i = real interest rate [-]

5.1.5 Pay back time

The pay- pack time indicates the time for a certain investment to be paid back by energy savings.

$$PT = \frac{lg(C_{sav}) - lg[C_{sav} - I\ (d - i)]}{lg(\frac{1 + d}{1 + i})}$$

PT = payback time [years]
C_{sav} = fuel saving costs [R/ a]
I = energy saving investment [R]

5.1.6 Energy increase factor

The energy increase factor (EIF) determines the future increase of costs of fuels or energy. It is calculated by dividing the average energy costs (during the period of economic evaluation) by the today's costs.

$$EIF = \frac{average\ fuel\ costs\ \ (20\ years)}{todays\ fuel\ cost}$$

Over a period of 20 years, EIF can be assumed as up to 2. An EIF of two is equal to a yearly increase of energy costs of 1.3%. The sensitivity analysis examine the effects of different EIF.

5.1.7 Degree of rigour

In an economic analysis three degrees of rigour can be used:

- BTBI (before tax and before inflation) ignoring the effects of both tax and inflation
- ATBI (after tax and before inflation) taking into account the effects of tax
- ATAI (after tax and after inflation) taking into account the effects of both

The sensitivity analysis in this study takes into account the effects of both, tax and inflation.

5.2 COST BENEFIT ANALYSIS

5.2.1 Introduction

To press non- economic values into the framework of economic calculations, economists use the method of cost benefit analysis. Cost benefit analysis indicates the least cost options by comparing different benefit- cost rates.
In the following contemplation fuel costs, investment costs and energy savings are taken into consideration.
Other quantities as indoor air temperature, comfort and social costs (health benefits, environmental benefits, transport costs...) are not implemented to the benefit cost ratio.

5.2.2 Benefit- cost ratio

The benefit- cost ratio is calculated by dividing the energy savings per year through the discounted energy saving investment over its economic life. (Only quantities that can be expressed in monetary value are taken into consideration).

$$f_{CB} = \frac{benefit}{costs} = \frac{C_{sav}}{I_d} \; ; \qquad I_d = \frac{I}{PWF\ (N,i,d)}$$

where

f_{CB}	= benefit/ cost rate	[-]
I_d	= discounted Investment	[R/ a]

The ratio can be:

1	(neutral investment),
>1	(economic benefit) and
<1	(economic loss).

The same figure can be calculated by dividing the annualized fuel savings by the today's investment.

5.3 LIFE CYCLE ANALYSIS

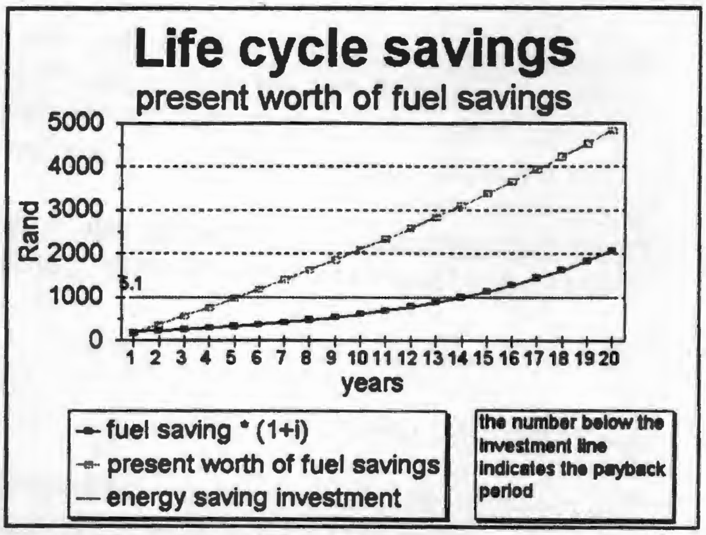
5.3.1 Discounted fuel savings

To illustrate the monetary value of fuels, fuel savings and investment costs, the following graph was developed:

The x- axis displays the time flow in years (1- 20 years) and the y- axis indicates the financial value in Rand.

In this graph the increase of fuel caused by inflation (lower line) and the present worth of the saved fuel (upper line) is displayed.

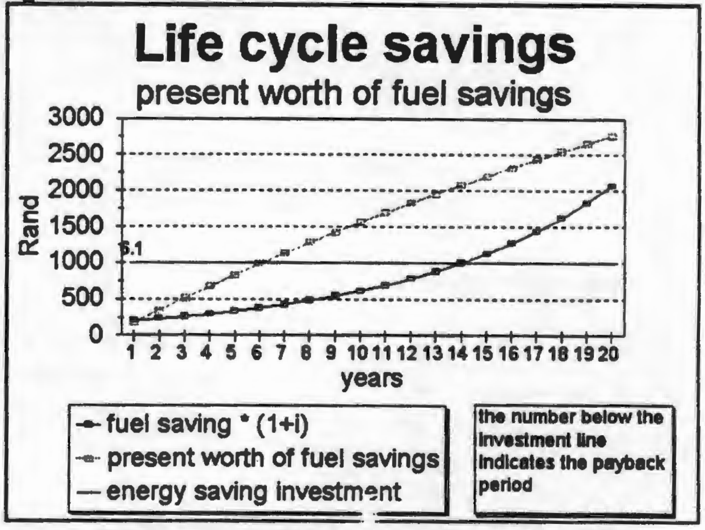
The horizontal line indicates the investment for the energy saving device in the first year.



(I= 13%; d= 10%; I= R 1000; Esav.= 70%; Ecost= R 710/ a)

These graphs show an example of a particular investment, analysed using different inflation rates:

Depending on the inflation and discount rate the payback time of an investment varies from 5.1 years (d=10%) to 6.1 years (d=16%) (investment of 1000 Rand, inflation rate = 13%).



(i= 13%; d= 16%; I= R 1000; Esav= 70%; Ecost= R 710/ a)

The present worth is increasing during the time when i (inflation rate) is greater than d (discount rate) and decrease when i is less than d.

5.3.2 Life cycle costing

The term life-cycle costing refers to the analysis of all costs associated with a device or facility over its life. This requires a systematic evaluation of all relevant costs:

The first cost and the salvage value, operating costs for fuel, labour and material, costs for interest, insurance, depreciation, taxes, etc.
A properly drawn life-cycle cost analysis requires an economic forecast of the future. It is necessary to make judgments about things like the general inflation rate and how interest rates and fuel costs will change. In predicting future costs, there are many uncertainties:
Some future costs are potentially widely variable, being subject to a variety of economic pressures and political decisions.
Also, the number of years selected as the life can significantly influence the outcome of the analysis and the conclusions drawn from it. While life-cycle costing analyses are quantitative in character, it should be recognized that the numerical values used for the required parameters are determined from some combination of forecasting, established corporate policy, experience and judgment on.

5.3.3 Perspectives

The results of an economic analysis depend strongly on the perspective (end users, investor, environment, energy utility, national-, world wide ...). Two perspectives are examined in this study:

5.3.3.1 End user

The analysis is calculated from the perspective of the end user:
The extra investments (insulation, ceiling, paint ...) on the house are spend by the owner or by the builder. The analysis takes into account the fuel savings caused by the improved design.

5.3.3.2 Eskom

Another analysis is drawn from the perspective of the national utility Eskom:
Eskom is the largest and most significant energy institution in South Africa (It supplied 98% of electricity in S.A. in 1991, 42 000 employees 1993). One of their strategic priorities is to electrify 3 million homes by 1996.

This analysis takes into account the costs for installed peak power and the income of electricity sale.

Two options are compared:

- OPTION 1

net benefit = net income of sold electricity - investment in 1 kW peak power
Eskom invests in power plants to meet the peak demand in winter.

- OPTION 2

net benefit = net income of sold electricity - investment in energy savings
Eskom invests in improving the thermal standards of houses which results in a less peak power demand in winter and less income of electricity sold:

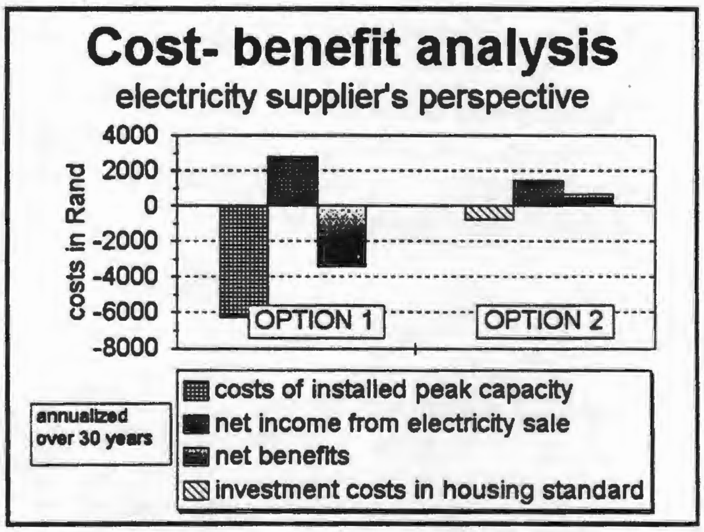
The analysis examine 30 years.
The interest rate used for investments by Eskom is 7 %. The assumed costs for 1 kW installed power are R 5000, with an utility factor of 0.8.
Dependencies are:

- discount and inflation rate of the investments
- investment cost for installed peak power
- investment of energy saving devices in houses
- costs of generating and selling electricity
- utility factor
- peak demand saved by improved house standard

The graph displays an example of improving a house with a EPS ceiling: The financial situation is shown in a today's perspective. It illustrate the net benefit of both options:

'OPTION 1' (left side) indicates a negative net benefit:
The benefit cost rate is 0.4

The net income of sold electricity is less than 'OPTION 2', but the net benefit is positive.
The benefit cost rate is above one.



5.4 SENSITIVITY ANALYSIS

Sensitivity analysis provides a second look at an economic evaluation. It questioned whether the original estimates represent the future conditions that could affect a proposal if it were implemented.
It's purpose is to assist decision makers. The decision maker gets a better feeling for the situation and how sensitive it is.

The following sensitises are explored:

- interest rate
- fuel price increase
- fuel usage for space heating

The interest rate varies between 0, 5, 10, 13, 15, 20 %.

The fuel price increase factor varies between 1.0, 1.5 and 2.0

The fuel usage varies between 100 % Electricity and 'fuel mix' (60 % wood, 20 % electricity, 20 % paraffin, % of MJ/a)

Another important sensitivity is the distribution of fuels. This affects strongly the price of the fuel that is used: The price for coal sold in little buckets is much higher then in bigger amounts. The price on wood is depending on the occurrence.

5.5 ANALYSIS IN/ OUTPUT

To do a quick analysis of different design options a Quattro Pro Spreadsheet was programmed. This calculates the required output data and displays the results as diagrams.
The following data are to be entered to the spreadsheet:

Input to calculation		
inflation rate		%
interest rate		%
energy saving investment		R
energy consumption		MJ/m^2 a
house area		m^2
improved energy consumption		MJ/m^2 a
improving factor: in %		%
years of calculation		a
increase of fuel price over 20 years		-
percentage of fuel use (electricity, wood, ...)		%

Output of calculation		
payback time PT		years
present worth of fuel savings		R
benefit after n years		R
benefit/ cost rate		-

The inflation rate and interest rate are variable figures. The 'energy saving investment' depends on the amount of money invested to improve the design of a house.
The figures 'energy consumption', 'improved energy consumption' and 'house area' depend on the design of the houses and will be imported from the simulation program.

5.5.1 Investment costs

Investment costs are taken from supplier price lists (1995 prices), including 14 % VAT. Installation and maintenance costs are not taken into account.

5.5.2 Space heating

General heating appliances used in low cost housing are [Allison, 1994]

- coal stove
- gas heater
- wood stove
- paraffin heater
- coal brazier
- fireplace
- open internal fire
- electric heating systems, (if electricity is available)

The choice and consumption of fuels refers to the climate, state of development and urban/ rural situation of the houses.

5.5.2.1 usage

The table below indicates the use of fuels in 'percent of households' and the monthly expenditure on fuel for heating, lighting and cooking (Cape Province). There is a complex system of interrelationships between the various fuels. Multiple fuel use is the rule rather than the exception [Viljoen 1990].

Type/ fuel in %	candle	dry-battery	car-battery	wood	paraffin	gas	electricity
old formal housing	17.5	29.8	15.8	0	77.2	31.6	49.1
new formal housing	50	55	37.5	2.5	97.5	55	10
all Cape Province	37.8	50	22.8	1.7	92.2	31.7	17.8
Type	expenditure in Rand per week						
old formal housing	0.34	0.32	0.79	0	3.13	3.5	5.9
new formal housing	1.04	0.65	2.1	0.15	3.59	7.83	1.26
all Cape Province	0.6	0.45	1	0.3	3.9	3.7	2.2

[Viljoen 1990]

5.5.2.2 operating costs

The table below presents the total operating costs including capital.

Fuel	spec. energy MJ/ kg	Price [R/ kg]	Cost [c/ kWh]
Electricity	-	-	14.8
Coal	23.6	0.20	12.9
Paraffin	46.7	1.66	21.0
Anthracite	31.7	0.48	41.1
Gas	49.1	3.12	30.2
Wood	18.1	0.50	36.6

[Allison C., 1994]

The operating costs are calculated using the following expression (assuming a 1000 hour per year operating period):

operating costs = capital costs + running costs

$$\text{operating costs} = \frac{\text{heater cost} \ [\,c\,]}{\text{output per life} \ [kWh]} + \frac{\text{energy costs} \ [\,c\,/\,kWh\,]}{\text{efficiency}} \quad , \ [\,c\,/\,kWh\,]$$

According to the percentage of use, the prices of the various fuels are multiplied with the percentage of use of that particular fuel.

Summary:

- The benefit cost ratio indicates cost effective options
- Fuel costs for heating are depending on occurance and usage
- Sensitivity analysis examines the effects of interest rate, fuel price and future increase of fuel costs

6 SIMULATION

This chapter points out the role of the computer simulation in this document. The simulation program 'quick' is described and the input/ output data are summarized.

6.1 METHODOLOGY

The following diagram pictures the central role of the simulation in this study.

Climate

- temperature
- humidity
- solar radiation

Architecture

- structure
- material
- flor plan

Design options

- orientation
- shading
- ceilings

QUICK simulation program

Economic analysis

- cost/ benefit
- payback time
- fuel savings

Sensitivity analysis

- inflation
- interest rate
- time period

Conclusion

- investment
- policy
- future research

The inputs are climate data, architectural design and various design improvements. The data from the simulation program are then used in an economic and a sensitivity analysis. In the following subchapter the simulation program quick is described.

6.2 QUICK

6.2.1 General

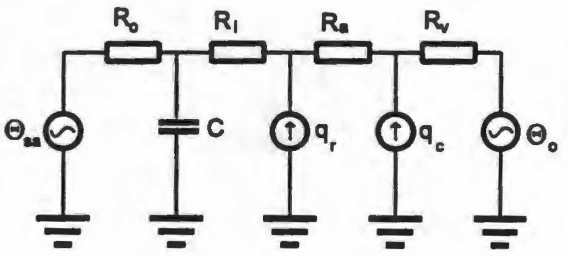
Quick was developed by the Center for Experimental and Numerical Thermoflow CENT, at the University of Pretoria.
It analyses the thermal performance of buildings which includes the prediction of indoor air temperatures and total heat or cooling loads (In this study version 4.02 has been used).

6.2.2 Physical model

The simulation program is based on a first order thermal model. The physical phenomena are reduced to concentrated parameter: For example heat storage capability of a building zone is simulated with a simplified single capacitance. Heat storage in the ground underneath and a phase correction are based on empirical studies.

The figure beside illustrates the thermal model for a building zone.

First order thermal model for a whole building zone



θ_{sa} = sol air temperature
θ_o = outdoor air temperature
q_r = radiative heat source
q_c = convective heat source
C = thermal capacitance
R_o = outdoor resistance
R_i = indoor resistance
R_a = combined indoor air thermal resistance
R_v = ventilation resistance

This extremely simplified model has the advantage of the possibility to interpret the physics, it is based on uncomplicated, quick calculation procedures and requires limited input information. As the program was validated on a wide range of buildings, it can compare well with other more sophisticated models.

6.3 INPUT DATA

6.3.1 Structure

- roof data

Quick defines the roof of the building zone as the horizontal surface forming the top of a zone. The roof of a zone on the middle level of a building can thus be the floor of the level above it. The roof can either be exposed or unexposed to the outdoor environment. A skylight can be entered as a separate roof with its corresponding values for absorptance and solar transmission. It is assumed that the skylights are not openable.
The shade factor is the approximate percentage of roof area that is in shade during daylight. This shade may be caused by other buildings, trees etc. Shading factor relates to areas in the shade and should not be confused with shading coefficient. The total area of the roof and skylight sections should correspond to the total of the floor area specified in the floor screens.

- floor data

Quick can predict the effect of a building or building zone in direct contact with the ground. To account for the effect of the active ground capacitance, the floor layers up

to a depth of 300 mm must be defined. Specify the layers from the inside down towards the soil. A simple poured concrete floor of 75 mm, will therefore be defined as two layers: 75 mm poured concrete and 225 mm soil.
A floor cannot be in ground contact as well as exposed to the outdoor.

- surface data

Quick defines the building zone by means of 3 different vertical surfaces. A surface can be classified as one of the following:
Exposed to the outdoor environment, not exposed to the outdoor i.e. the dividing wall between zones or indoor partition with both sides exposed to the indoor air volume.
The orientation of the surface is the angle with respect to the reference azimuth. This is only relevant to exposed surfaces and the azimuths of other surfaces may be ignored. Note that the positive (+) angle is used (degrees east of north).
Transmittance values are only applicable to translucent surfaces (windows). The shading factor is the percentage of shaded area in relation to the total exposed area of a surface. Quick provides the options of specify specific shading device or constant shading factor.

6.3.2 Orientation

A reference azimuth angle is used, which determines the orientation of any specific vertical wall area. This is the angle between the true north and the perpendicular on the exterior surface.

6.3.3 Climate

Climatic data for a specific location can be entered. The options are:

- Location

This includes the name of the location, the altitude, standard time longitude, the longitude and latitude.

- Hot day

This is the outdoor design data for a hot day in a specific region. Take note that the temperature values are dry-bulb values. Relative humidity is the variable that accounts for humidity levels.

- Cold day

This is the outdoor design data for a cold day. The same applies as for the hot day.

- Year

With this option the user can enter climatic data for each of the 12 months. For each month there are two entries that are important: operating days and hot/ cold month. With operating days the user must specify the number of days that the air conditioning system will operate in that specific month.
Hot/ cold refers to the other data files, e.g. the ventilation data, that are divided into a hot and a cold section. When a month is specified to be cold, the cold section of the data files will be used in the simulation of that specific month.

6.3.4 Occupancy

The number of people inside the zone can be specified to determine the contribution to heat generation. Variables for the comfort calculations can be entered.
The following data can be entered.

- metabolic rate

This is a measure of the activity level of occupants in a building. Quick will only accept values between 0.86 and 1.95. This covers most indoor activities. A value of 1 met corresponds with approximately 58 W/m² human skin area.

- clo value

This is a measure of the type of clothing worn by the occupants. Only values ranging from 0.3 to 1.3 are accepted. An average value for men and women can be determined.

6.3.5 Internal load

Quick can evaluate the effect of convective, radiative and latent heat that are generated inside a zone by means of lighting, heaters and other appliances. The implementation only accounts for convective heat generation that is applied directly to the indoor air volume of the building zone.
Quick is based on a design day that is periodic. The heat loads are therefore also assumed to be periodic and do not change from day to day.

6.3.6 Ventilation

Ventilation specifies the rate of replacement of indoor air with outdoor air, evaporatively cooled air or air at any specified temperature

Ventilation rates are in terms of air changes per hour. The airchange rate for buildings with closed windows usually vary between 0.1 to 1.0. For open windows it can vary from below 1.0 to values over 10. The following equations approximate the air change value:

$$ACH = 0.49 + 0.09 * V \qquad \text{(Closed windows)}$$

$$ACH = 0.29 + 1.03 * V^2 \qquad \text{(Open windows)}$$

V = outdoor wind speed [m/s]
ACH = airchanges per hour [1/ h]

6.4 OUTPUT DATA

6.4.1 Temperatures and humidity

Both the calculated indoor temperatures for a hot/ cold day and the comfort limits are displayed. A file containing temperatures and humidifies can be generated.

6.4.2 Energy consumption

The total load for the hot and cold day is calculated. A load for the hot day indicates the need for more indoor air movement or shading devices.
The total yearly load is the base for the cost benefit analysis.

6.4.3 Peak load

The total peak load is calculated on a cold winter day. This indicates the peak energy demand for that particular building in the cold period of the year.

Summary:

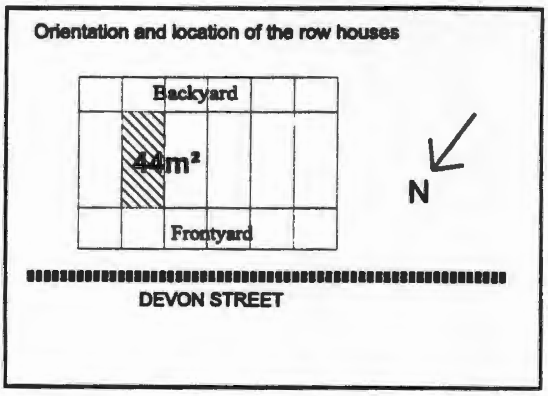
- the simulation program 'quick' is based on a first order, concentrated parameter model
- the simulation is the connecting link between building design, climate and economic evaluations
- the simulation program calculates indoor temperatures and energy consumption of buildings

7 PROJECT DEVON STREET

This chapter examines a typical low cost housing project in Cape Town. The existing design and various improved options are examined. The summer and winter temperature range and the energy consumption/ peak demand is calculated by using a simulation program. Economic values of these options are analysed.

7.1 GENERAL

'Devon Street' is a typical low cost housing project: Six houses are attached and single storied. Each house has 44 m² floor area including a kitchen, bath, living room and two bedrooms. There is a court of 4 m² in the middle of each house. The entrance is pointing to Devon Street. The project is located in the district 'Lower Woodstock', Cape Town. The orientation of each house is SE- NW. The photographs in the appendix illustrate the location.



7.1.1 Architect and Investor

The architecture and urban design office BAYNHAM & THÉRON ASC. have been planing this low cost housing project. The investor is the New Housing Company (NewHCo), West Cape. This company is dedicated to provide affordable housing on a sustainable basis to disadvantaged communities.

7.1.2 Building materials

- foundation/ floor
20 mm screed; 75 mm concrete slab; 250 mm micron; 50 mm sand blinding

- wall
  external: 230 mm cavity wall:
  with 90 mm concrete block; 50 mm airspace; 90 mm concrete block
  internal: 90 mm concrete block, (non- load bearing)
  190 mm concrete block, (load bearing)

- roof
  0.5 mm unpainted galvanized mild steel

- ceiling
  no ceiling/ ceiling optional (Hardboard, Aluminium foil, EPS)

- windows
  windows to comply with NBR specifications for light and ventilation.
  painted light

- doors
  Two panel meranti external doors(top panel glazed) in meranti frames (painted white), steel frames

7.2 SIMULATION

This section describes the simulation procedure:
The assumed input and output data are the following:

7.2.1 Input data

- internal load

The internal load is determined to be 2 kW from 11h°° -13h°° (cooking). Electrical lighting is neglect. Temperatures are calculated without space heating.

- occupancy

The occupancy is determined to be 2 persons (9h°°-19h°°) and 3 persons (20h°°- 8h°°)

- ventilation

Hot condition: 3 ACH (9h°°- 20h°°), 2 ACH (8h°°, 21h°°), 1 ACH (22h°°- 7h°°)
Cold condition: 0.5 ACH (7h°°- 21h°°), 1 ACH (8h°°- 20h°°)
(outside air is used for ventilation)

- climate data

The climate data were provided by the South African Weather Bureau. The reference year is 1994:
Two design days for a cold and a hot day are defined and stored in the file (Capetown.clm): Hourly temperature data, hourly humidity data, hourly solar global radiation, hourly solar diffuse radiation.

For yearly energy simulation climate data are required for every month (see design days). Monthly average hourly data are stored in 12 files (Capetown.001 ... Capetown.012) and are requested by the simulation program during the calculation.

- air condition

The option of an air condition plant is used as a virtual heating application, simulating space heating in winter.

The air condition plant is off during the temperature simulation. For calculating the monthly/ yearly energy demand in winter the air conditioning is on 'heating mode' (simulating a radiant heater). There is no air conditioning during summer.

Space heating is working during the time of 8h°° to 22h°° with an achieved indoor air temperature of 20° C.

- space heating

The source of space heating is varied in the sensitivity analysis:
The options are (with increasing costs): Electricity, fuel mix, wood.

- structure

Building materials and proportions are according to the drawings.

7.2.2 Output data

- temperature data for hot and cold days

The simulation calculates the hourly temperatures for a cold and hot day. These are imported to a diagram, picture 24h°° and the temperature as ordinate:
These diagrams picture the comfort temperature zone, the outdoor temperature and the calculated indoor temperature during the day (1h°° to 24h°°). The time step of the calculation is one hour (No space heating inside the building).

- peak temperatures

The calculated indoor maximum and minimum temperature is exported to a spreadsheet which pictures the peak temperature of the various design options. The maximum and minimum temperatures are examined.

- energy consumption for space heating during the winter

The monthly and total yearly energy consumption is calculated and exported to a spreadsheet. This figure is used for cost benefit analysis.

- peak demand for heating

The grant total load for the cold day is calculated. This data indicates the maximum peak demand for the cold winter days.

7.2.3 Efficiency

To compare different design options an energy efficiency factor is introduced:

$$e_{eff} = \frac{\textit{current energy consumption}}{\textit{improved design energy consumption}} \; ; \qquad \frac{[MJ\ /\ a]}{[MJ\ /\ a]}$$

This factor ranges between 0.9 and 3.

$e_{eff} > 1$ indicates improved energy consumption.

7.2.4 Economic analysis

To illustrate the financial benefits this economic evaluation was done:
The basis of this is explored in the previous chapter.

Design options for

attached houses and detached houses:

- ceiling insulation
- wall insulation

Economic analysis

Payback time

Benefit cost ratio

Sensitivity

The following data and graphs are examined by the economic evaluation:

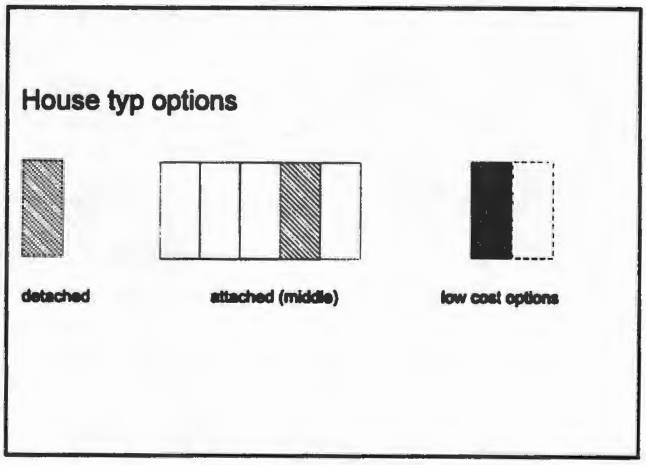
- Costs of the investment in Rand
  (excluding costs for installation, service and maintaining)
- Life cycle savings (graph)
  (interest rate = 13 %, inflation = 10 %, energy increase rate = 1.5)
- Fuel saving benefits (graph)
  (interest rate = 13 %, inflation = 10 %, energy increase rate = 1.5)
- Benefit cost ratio
  (interest rate = 13 %, inflation = 10 %, energy increase rate = 1.5
  electricity / fuel mix for space heating)
- Payback time in years
  (interest rate = 13 %, inflation = 10 %, energy increase rate = 1.5
  electricity / fuel mix for space heating)
- Eskom's perspective of two scenarios (graph)
  (peak power investment or energy saving investment)

- Sensitivity analysis of a EPS ceiling insulation on a row house and a Sisalation ceiling insulation on a detached house.
  dependency on energy cost increase (EIF = 1, 1.5, 2) and dependency on fuel usage for space heating are examined.

7.3 HOUSE TYPE OPTIONS

The following design options are simulated and examined:

- row house
- detached house
- low cost options
- improved options



7.3.1 Design options of attached houses

- existing building (Devon street, row houses)
- ceilings optional (Hardboard, Aluminium foil, Hardboard and Expanded Polystyrene (EPS)
- insulation on outside walls and HB ceiling
- cavity walls optional

7.3.2 Design options of detached houses

- design as existing in Devon street, detached
- low cost option 1 (no foundation, 130 mm concrete wall, no ceiling)
- low cost option 2 (no foundation, 130 mm light construction wall, no ceiling)
- low cost option (1) and improved ventilation
- low cost option (1) and improved absorption of roof and walls
- low cost option (1) and improved shading
- low cost option (1) and foundation
- low cost option (1) and cavity walls
- low cost option (1) and ceiling (Hardboard, Aluminium foil, Hardboard and Expanded Polystyrene (EPS)
- low cost option (1) and EPS ceiling and outside wall insulation (8)
- low cost option (8) and windows orientated to W (270°)

7.4 THERMAL PERFORMANCE OF ATTACHED HOUSES

In this section row houses (attached) are examined:
Various improvements as described above are simulated and illustrated.

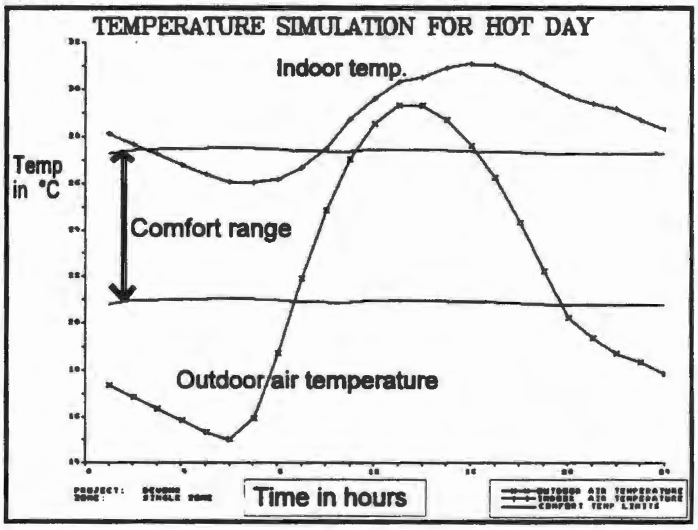
7.4.1 Existing building (row houses)

This simulation examines the existing houses in Woodstock, Cape Town.
The construction is according to the drawings. No ceiling insulation.

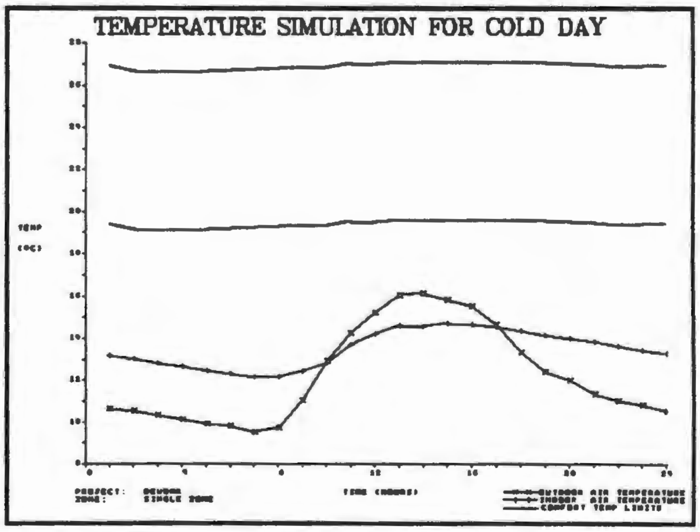
- energy performance

The calculated energy demand in the winter months is 1557 MJ/ a and is used as basis for the economic analysis. The peak energy demand is 10.1 kW.
The energy efficiency factor is determined as one; $e_{eff} = 1$

- temperatures



The summer temperatures vary between 26°C and 30.9°C and are mostly above comfort level. Only during the morning the temperature drops to 26°C. After sunrise the indoor temperature increases to 30.9°C and does not drop significantly before 20h°°. During most of the night the temperature is above comfort level.
The maximum peak temperature is high above outside air temperature of 29.3°C at 13h°°. There is a time lag of 4 hours between maximum indoor/ outside air temperature. The difference between the minimum indoor/ outdoor air temperature is 11 K.



The winter temperature ranges from 12.1°C to 14.7°C. These are temperatures calculated without heating inside the building.
There is a time lag of 2 hours reaching the maximum temp. at 15h°°.
The temperature does not drop below 12.1°C even when the outside air temperature is below 10°C.

7.4.2 Ceilings optional (Aluminium foil)

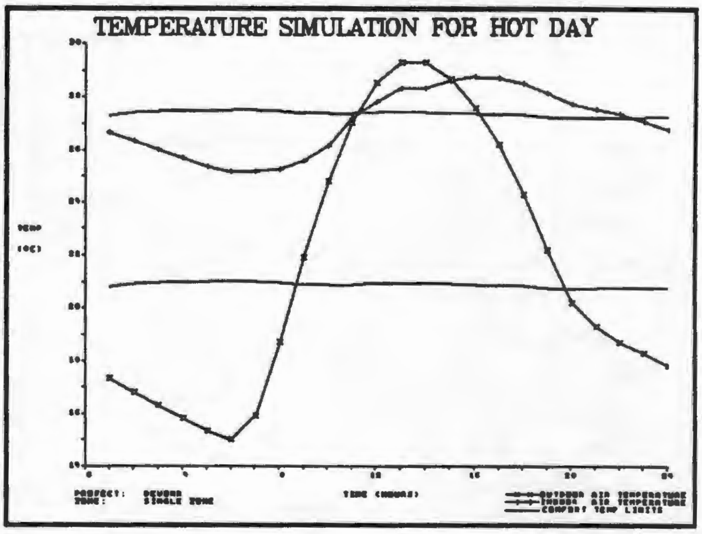
- improvement

This option uses a Sisalation© Aluminium foil as ceiling insulation. There is an airspace of 50 mm between roof and foil. The Foil consists of two outer surfaces of aluminium foil bonded with polyethylene. The investment costs are R 308.
Because of the high light reflectivity of the foil there is a improved light distribution inside the building.

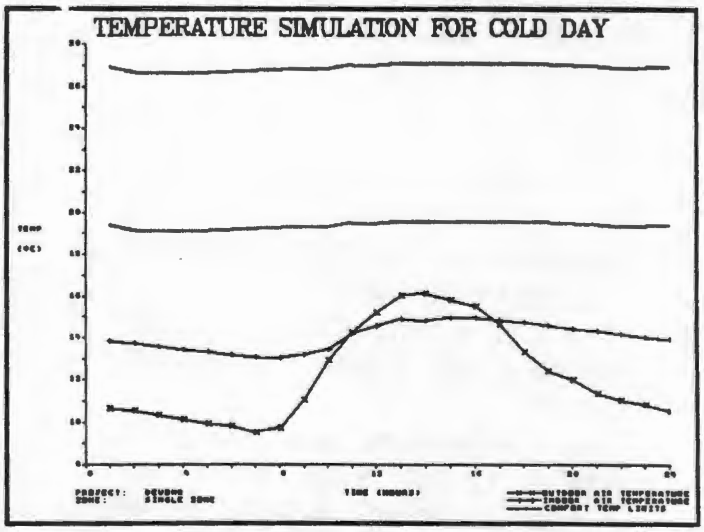
- energy performance

The calculated energy demand in the winter months is 877 MJ/ a. $e_{eff} = 1.8$
The peak energy demand is 5.8 kW.

- temperatures



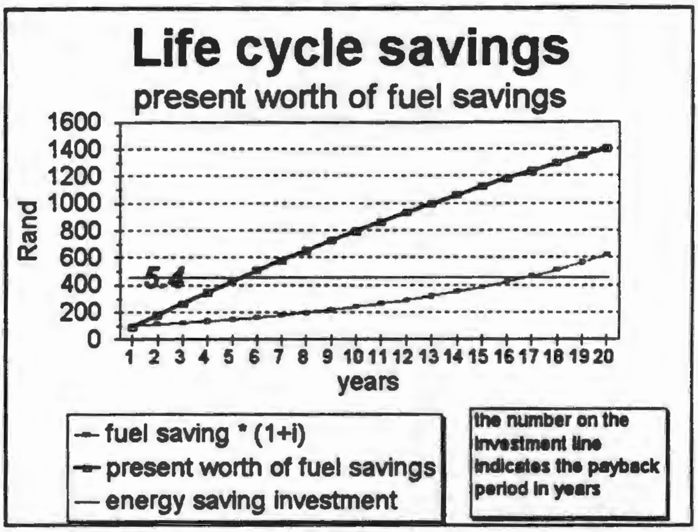
The temp. range in summer varies from 25°C to 28.8°C. The maximum is reached at 16h°° while the minimum was calculated at 6h°° according to the minimum outside air temperature. The indoor temp. reaches comfort conditions between 22h°° and during the night until 11h°° in the morning. During the day the there are uncomfortable conditions inside the building. There is a time lag of 3 hours between maximum indoor/ outdoor temperature.



The winter temp. range varies from 13°C to 14.7°C.
The minimum indoor temp. is 3.5 K above minimum outside air temp.
The comfort zone will drop to a lower level caused by the high reflectivity of the foil.
The peak energy demand is reduced by 5 kW.

- economic analysis

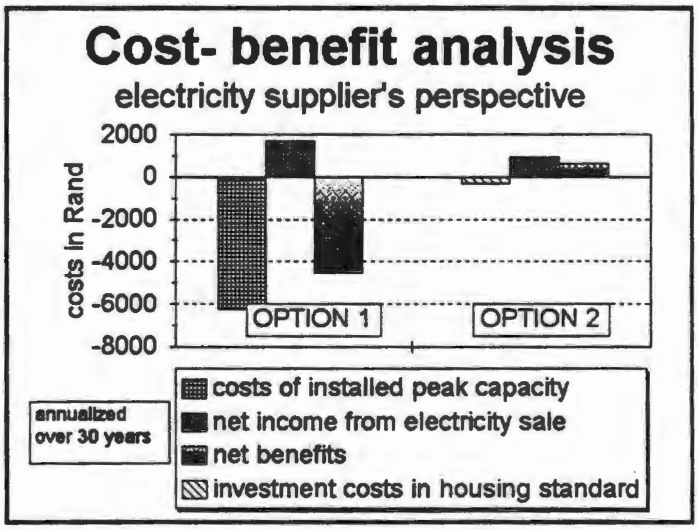
This graph pictures the life cycle savings over 20 years.



The assumptions are 10% inflation rate, 13 % interest rate and a energy increase rate of 1.5 over a period of 20 years.

The fuel savings after 14 years are over R 1000. The payback time is 5.4 years.

- supply perspective



This diagram illustrates the discounted net benefit for the electricity supplier Eskom:
There are two scenarios calculated:

1. Investing in peak power for non improved houses (high peak demand in winter)
2. Investing in energy savings (ceiling insulation).

Assumptions are determine in the chapter 'economics'.
The right bars shows the net income of Eskom: (investment minus electricity sold, annualized over a period of 30 years). 'Option 1' indicates a negative net income, resulting of non insulated buildings. The net income of 'option 2' is positive.

7.4.3 Ceilings optional (Hardboard HB)

- improvement

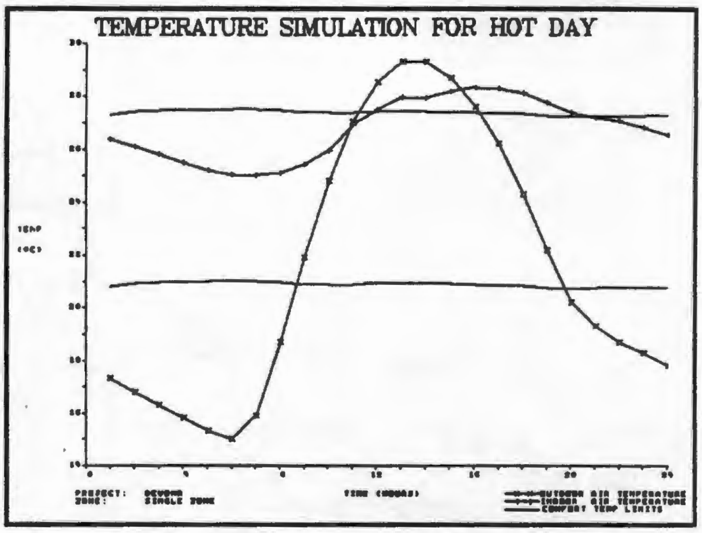
This option has a 13 mm Hardboard ceiling with an airspace of 200 mm between the roof and the ceiling. The investment costs are R 457.

- energy performance

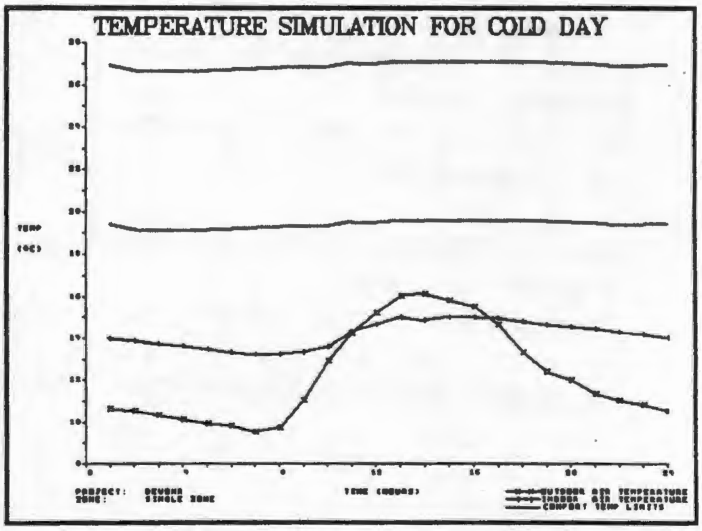
The calculated energy demand in the winter months is 815 MJ/ a. $e_{eff} = 1.9$
The peak energy demand is 5.5 kW.

- temperatures

The temperature ranges from 25°C to 28.3°C in summer.
The peak temp. occurs at 16h°° with a time lag of 4 hours. From 21h°° to 12h°° the indoor temp. is in the comfort zone, still above 25°C.

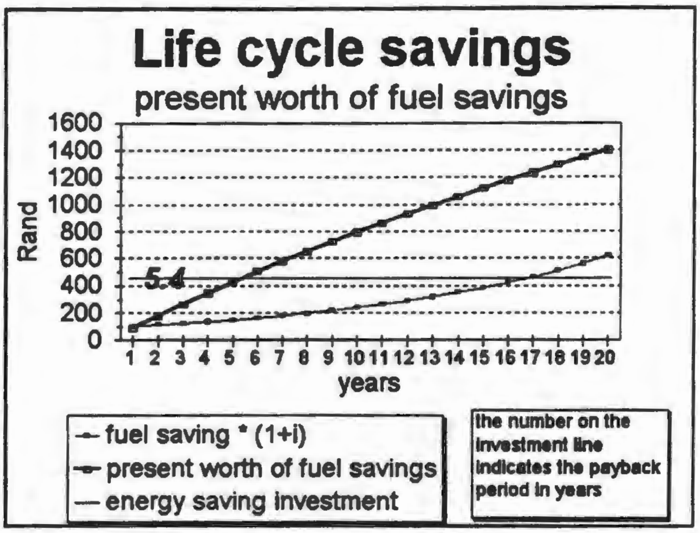


Extreme temperatures in winter do not drop below 13.2°C; 3.7 K above minimum outside temperature. During the day the temp. rises up to 15°C. The peak energy demand is 5.5 kW.



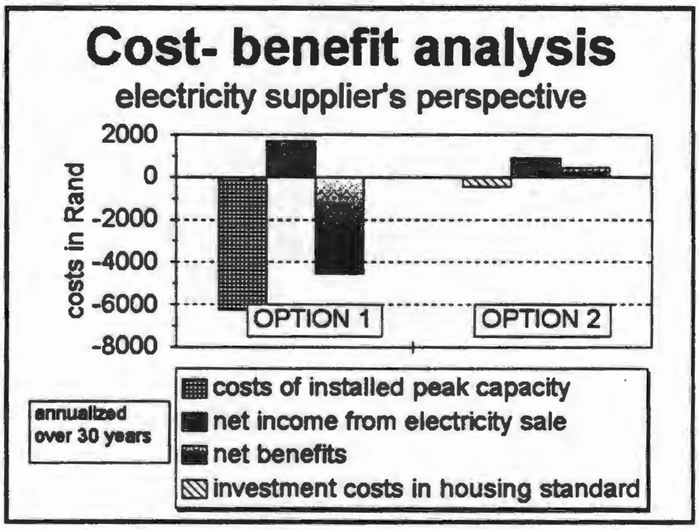
- economic analysis

The life cycle analysis indicates a payback time of 5.4 years.
The present worth of fuel savings for a time period of 14 years is over R 1000.



- supply perspective

The right bar of 'option 2' indicates a positive net income.



7.4.4 Ceilings optional (Expanded Polystyrene)

- improvement

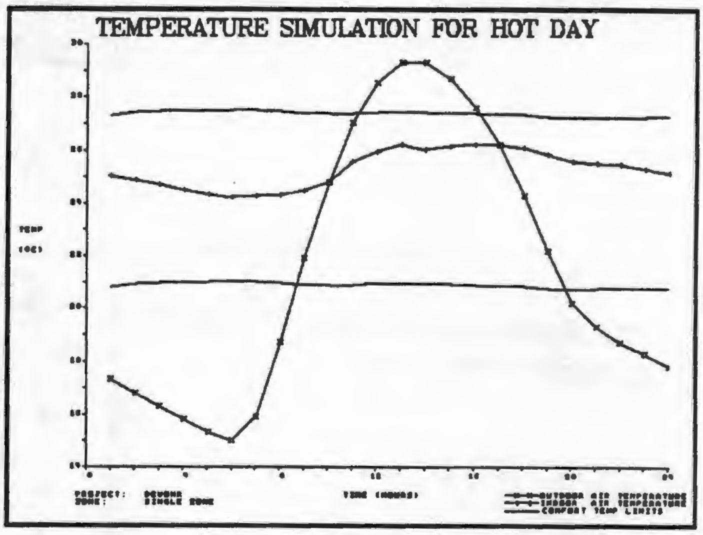
This option has a 10 mm Expanded Polystyrene as a ceiling insulation. There is a 100 mm airspace between ceiling and roof.
The investment costs are R 198.

- energy performance

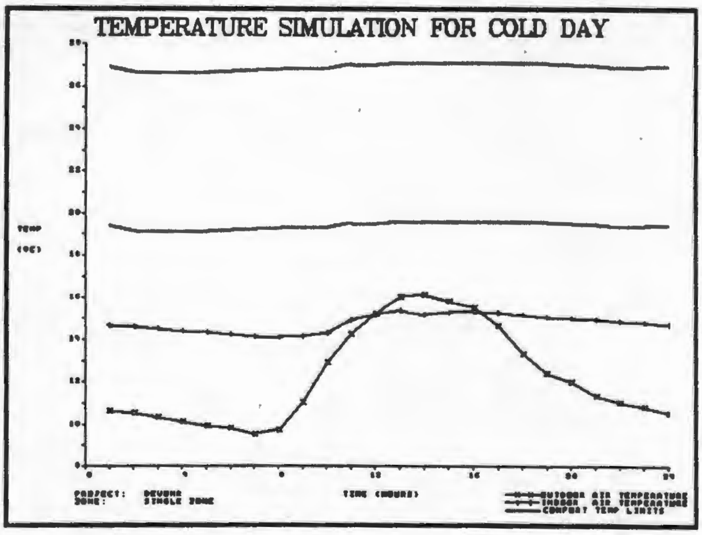
The calculated energy demand in the winter months is 620 MJ/ a. $e_{eff} = 2.5$
The peak energy demand is 4.8 kW.

- temperatures

Extreme summer temperature are mainly constant with a range of 24°C to 26.2°C. The maximum temperature calculated at 13h°° is still in the comfort zone.
In the evening from 20h°° on the temperature drops to 26°C and decreases to 24°C in the morning. These might be sufficient maximum indoor temperatures on a extreme summer day. The temperatures never reach uncomfortable conditions.

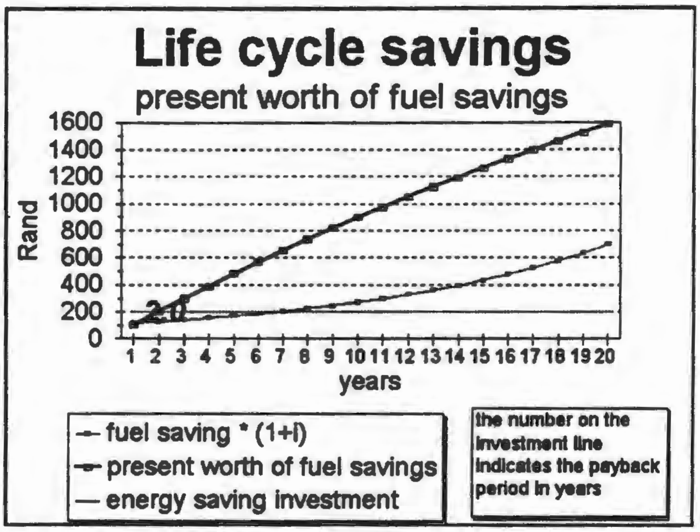


Extreme winter temperatures remain constant between 15°C. The minimum temp. is with 14.1°C 4.5 K above minimum outdoor temperature.
The peak energy demand on a cold winter day drops to 4.8 kW.
The figure of yearly energy consumption indicates a good insulation standard in winter.



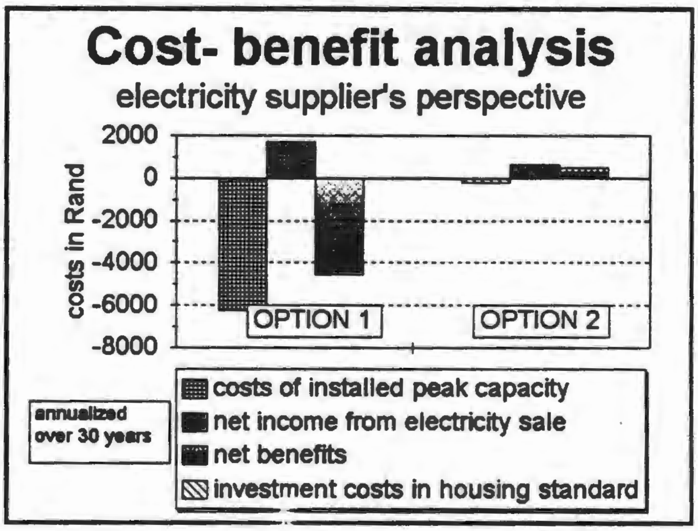
- economic analysis

This analysis indicates a very little payback time of only two years. Present worth of fuel savings reaches R 1000 after only 11 years.



- supply perspective

Even with high investment costs of the HB and EPS ceiling, the net income of 'option 2' is positive and in comparison to 'option 1', there is a difference of almost R 5000.



7.4.5 Insulation on outside walls and HB ceiling

- improvement

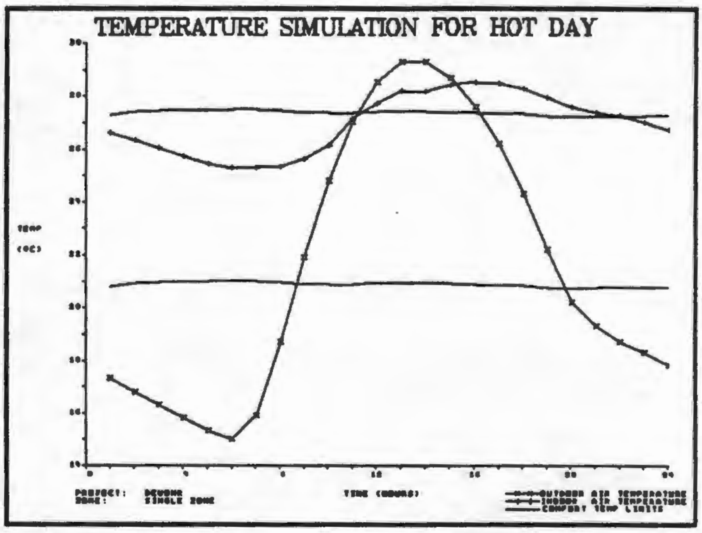
This option has insulated outside walls with 20 mm EPS and a ceiling (13 mm Hardboard). The investment costs are R 754.

- energy performance

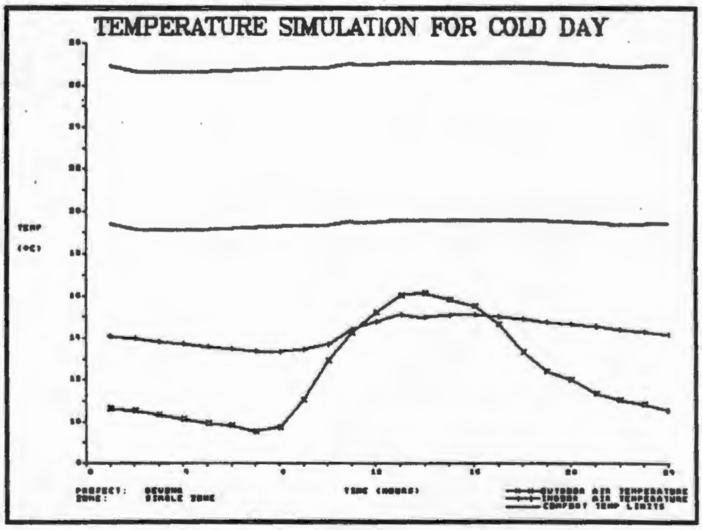
The calculated energy demand in the winter months is 771 MJ/ a. $e_{eff} = 2.0$
The peak energy demand is 5.4 kW.

- temperatures

Extreme summer temperatures reach 28.5°C which is little higher than without insulation on the outside walls. There are similar characteristics like the 'option HB', discussed above. From the evenings on to the morning the temp. lies in the comfort zone, but rises above during the summer days.

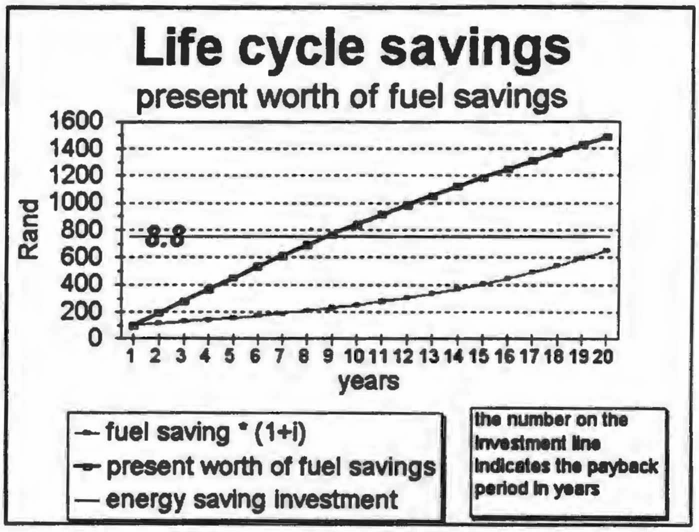


There is a similar temperature characteristic like without insulation on outside walls, but the yearly energy consumption drop another 6%. The peak energy demand is only 5.4 kW.



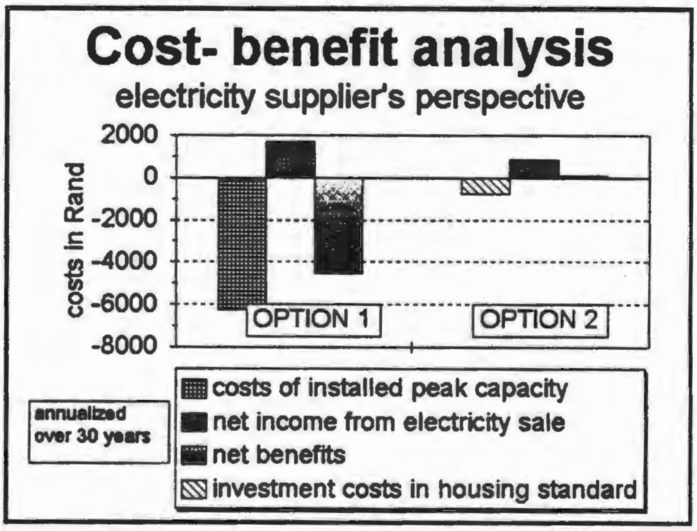
- economic analysis

Through the high costs of wall insulating material the payback time is almost nine years.



- supply perspective

'Option 2' does not indicate a negative net income, as 'option1'.



7.4.6 No cavity walls and HB ceiling

- improvement

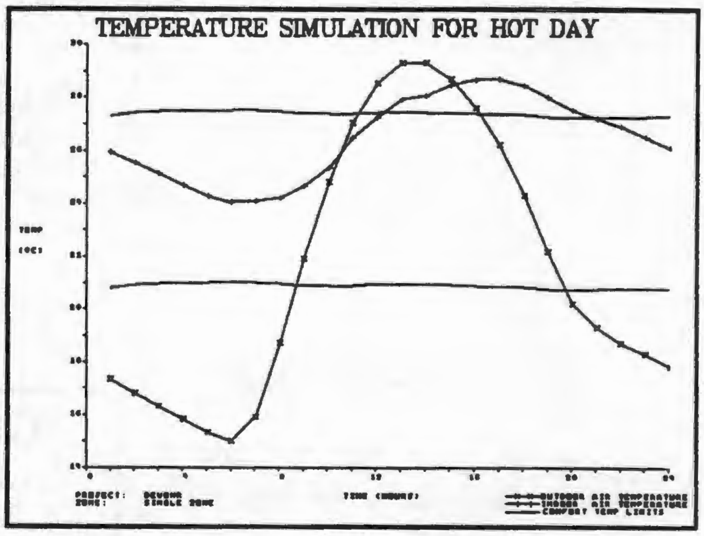
This option has no cavity walls but 130 mm concrete walls. There is a ceiling of 13 mm Hardboard. The investment costs are R 457.
There are savings of investment for using no cavity walls.

- energy performance

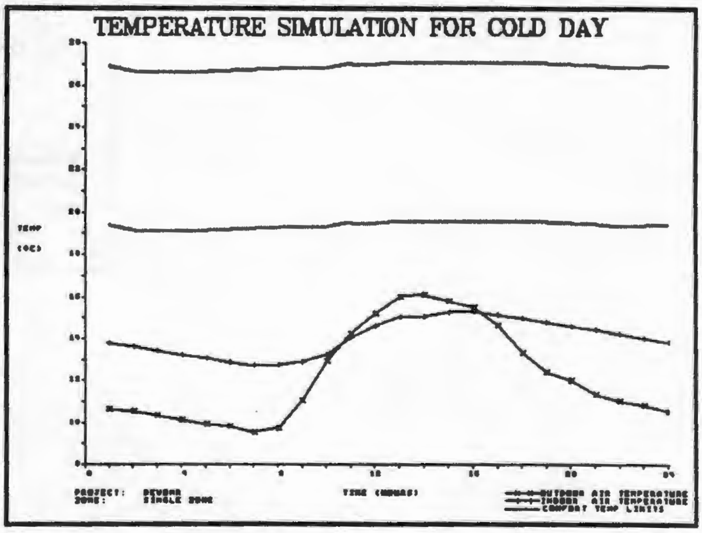
The calculated energy demand in the winter months is 934 MJ/ a. $e_{eff} = 1.7$
The peak energy demand is 6.2 kW.

- temperatures

The characteristics are mainly the same as 'option HB'. The maximum temperature is 0.5 K higher than the option with cavity walls.
During the night the temperature drops to 24°C: 1 K less than the option with cavity walls.

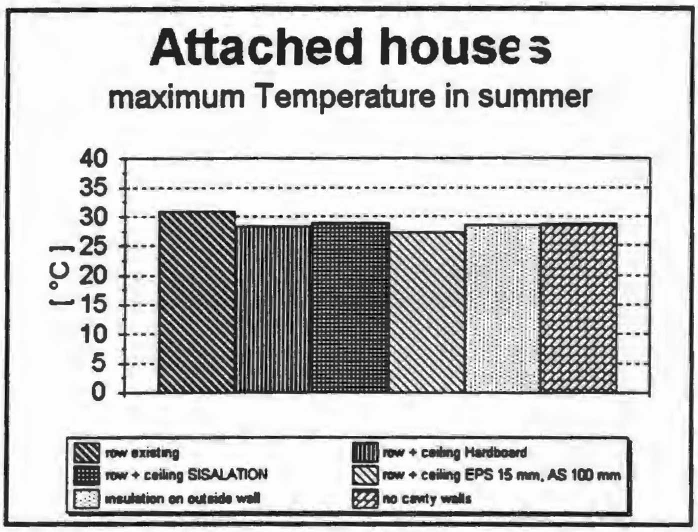


Minimum temp. in winter is 12.7°C, 0.5 K lower than the 'option HB'.
By using non- cavity walls the yearly energy consumption increases 14% and the calculated peak energy demand is 6.2 kW (+12%).



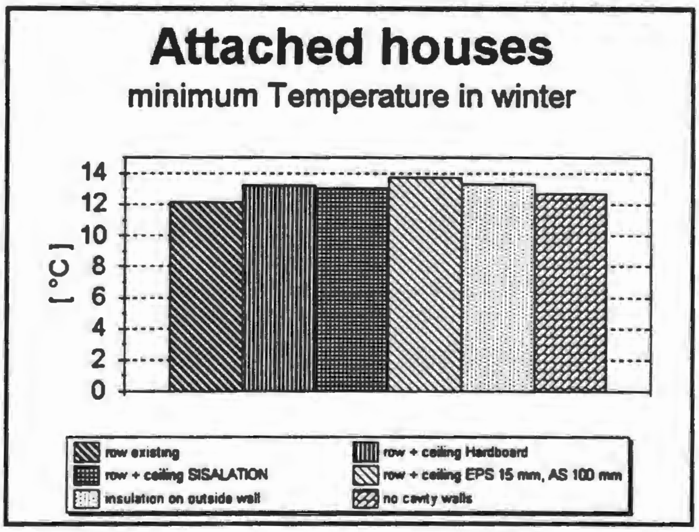
7.4.7 Summary

- maximum temperature in summer



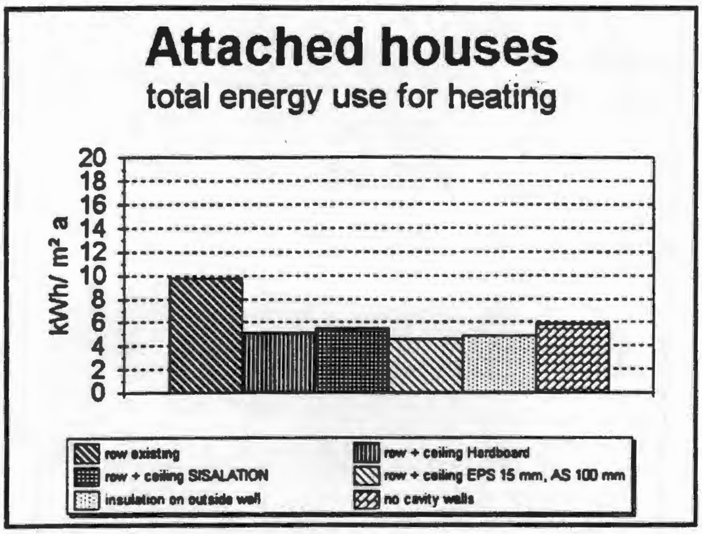
The average temperature characteristic of row houses is balanced:
Maximum temperatures above 32°C do not occur even without ceiling insulation. Ceiling insulation can reduce the peak temperature. Depending on the ceiling, the range of extreme temp. in summer is 5 K. The indoor peak temp. calculated in the existing building is 30.9°C, while improved design can reduce the max. temp. to 26.2°C, below outside air temperature.

- minimum temperature in winter



Winter minimum temperatures never drop below 12.1°C (without space heating). Improved design can increase that value to 14°C; improving by 2 K.
Peak energy demand for space heating can be reduced significantly from 10.1 kW to 4.8 kW.

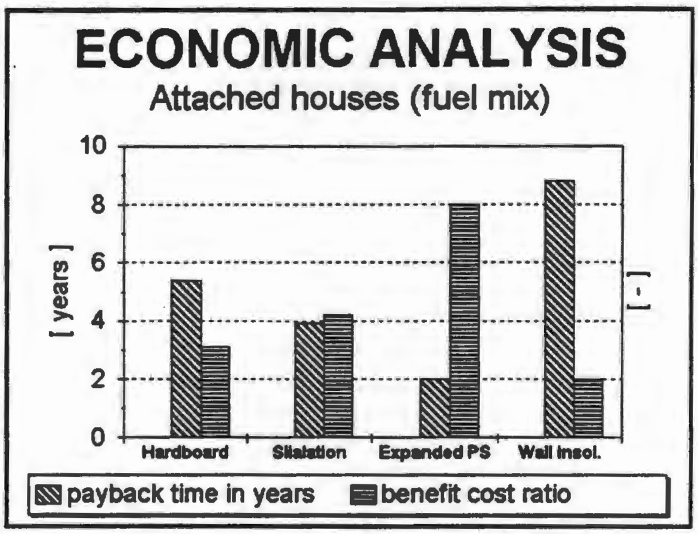
- energy consumption of row houses



This figure illustrates the energy consumption for space heating. The scale is similar to the diagram for detached houses next subchapter (0- 20 kWh/ m² a).
The energy consumption of the existing row houses in Devon street is approximately 10 kWh/ m² per year. Improved design reduces the energy consumption to 4 kWh/ m² per year. This implies improving by 60 %. Cheap and cost effective ceiling insulation reduce the energy consumption by 50 %. The lowest energy consumption is calculated for a row house using EPS as ceiling insulation. The difference between energy consumption of houses with HB ceiling and HB ceiling plus insulated outside walls can be neglected.

7.4.8 Economic analysis

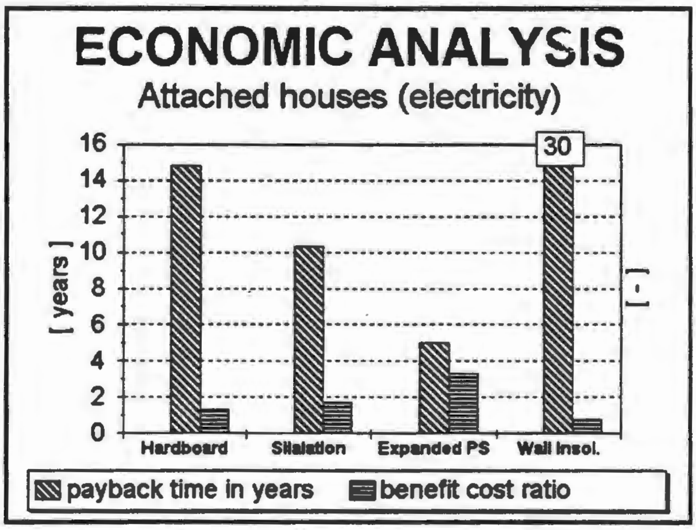
These are the results of the economic evaluation: Payback time and benefit cost ratio of the options are displayed in this figure:



The assumptions are:
Use fuel mix for space heating (average costs), discount rate of 13%, inflation of 10%, and future energy costs increase by 1.5.

The highest benefit cost ratio was identified by the EPS ceiling: It is above 8. The payback time is two years.
In order of increasing benefit cost ratio and decreasing payback times the options are: EPS, Sisalation, Hardboard and wall (plus ceiling) insulation. The last option has still a benefit cost ratio of above one.

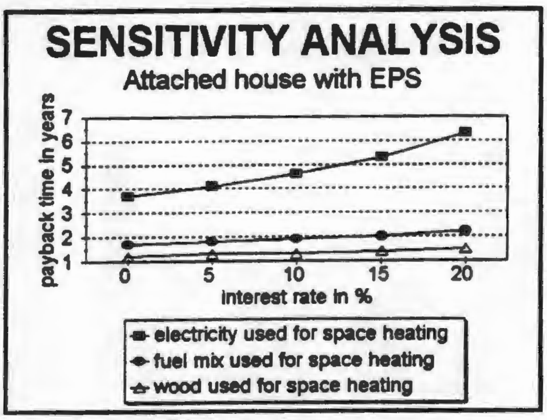
In this figure electricity was assumed for space heating (low cost on energy):

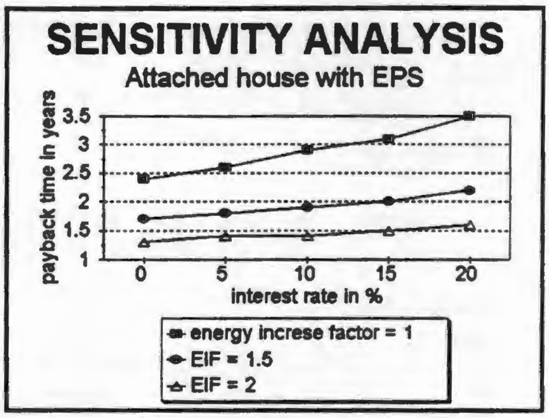


Payback times rise up from 5 to 30 years. Benefit cost ratios drop to 3 for a EPS ceiling and below 1 for a wall and ceiling insulation.

7.4.9 Sensitivity

These diagrams illustrate the sensitivity of an investment (EPS ceiling insulation) to the energy increase in the future and to various fuels used for space heating. The x axis displays various interest rates (0- 20%).





The left diagram pictures the sensitivity to the use of electricity, various fuels and wood. The costs are increasing from electricity to wood. If wood is used for space heating the payback times for an EPS ceiling are 1.2 years to 1.5 years, depending on the interest rate on the investment. If electricity is used for space heating the payback times for that investment are from 4 to 6 years (interest rate 0- 20%).

The right diagram pictures the sensitivity to future energy increase factors: The upper curve illustrates the payback times for the investment if there is no increase of energy costs. Payback times of 2.5 to 3.5 years are calculated.
If energy costs will increase by 1.3 % (EIF = 2) per year payback times of 1.3 to 1.6 years can be expected.

7.5 THERMAL PERFORMANCE OF DETACHED HOUSES

7.5.1 Design without ceiling insulation

This option reflects the design of the houses in Devon Street without ceiling.
The buildings are simulated as detached houses, all walls are exposed to the outdoor environment.

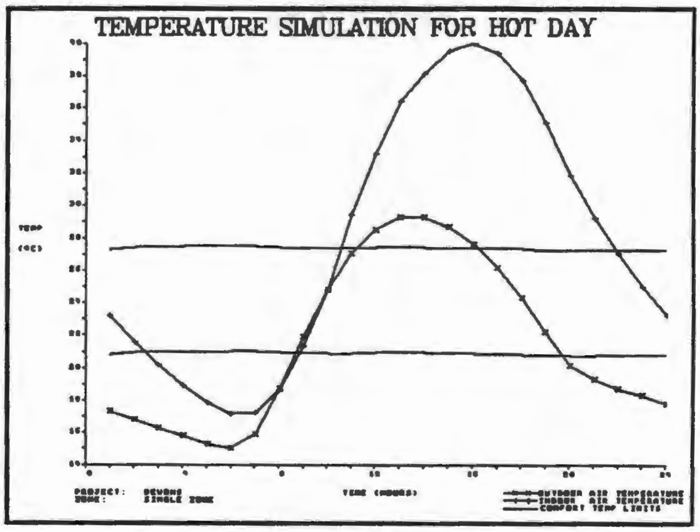
- energy performance

The calculated energy demand in the winter months is 2452 MJ/ a. $e_{eff} = 1.1$
The peak energy demand is 13.1 kW.

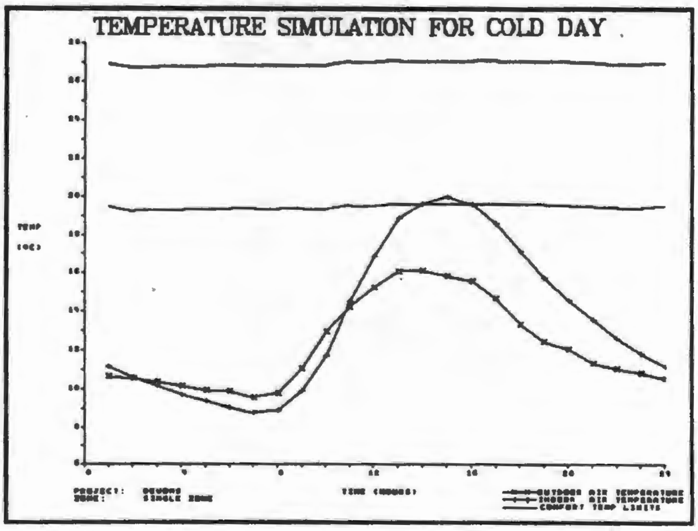
- temperatures

The summer temperature ranges from 40°C to 17°C, almost 23 K. The highest temp. appears with a time lag of 2.5 h at 16h°°. The indoor temp. drops to 17°C in the morning at 7h°° when the outside air temp. is 15°C.

The indoor conditions are not comfortable during most of the day, only in the morning from 5h°° to 9h°° the temp. is below 21°C.
The gradient of the indoor temp. rise is steep. Also the decrease in the evening shows a steep gradient of 2 K per hour.



The winter temperature varies strongly between almost 20°C at 15h°° and 8.8°C at 7h°° in the morning.
The increase of the daytime temperature is caused by the immediate temp. increase of the roof caused by a global radiation of almost 400 W per m² per hour at noon. From the time of sunrise at 8h°° the temp. increases with a rate of 2 K per hour.
During the night the temp. drops 0.7 K below outside air temp. of 9.5°C. This is caused by the radiant effect of the metal roof, radiating heat to the cold sky.
Energy consumption is high: 15.5 kWh/ m² per year and a peak energy demand of 13.1 kW on a cold winter day.



7.5.2 Low cost option 1 (no foundation, 130 mm concrete wall)

This option is a low cost house with a 75 mm concrete floor and soil underneath. The wall is built of 130 mm concrete blocks. No cavity walls and ceiling are added. This option (1) is used as basis for the economic analysis.

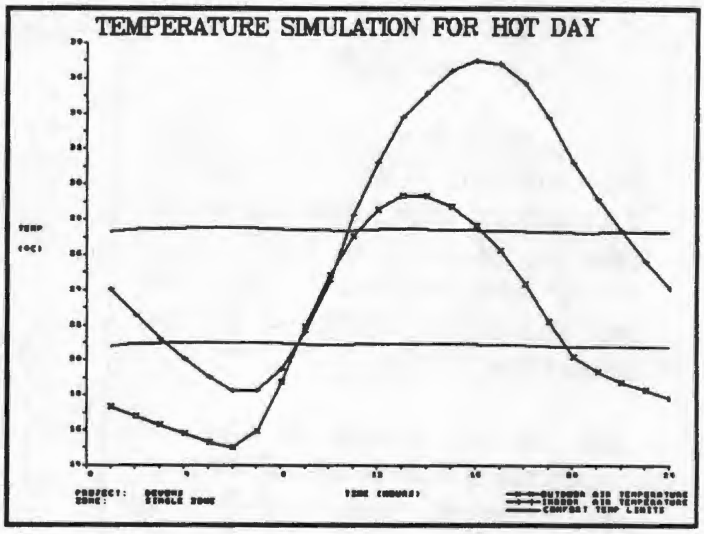
- energy performance

The calculated energy demand in the winter months is 2559 MJ/ a. e_{eff} = 1.0
The peak energy demand is 14 kW.

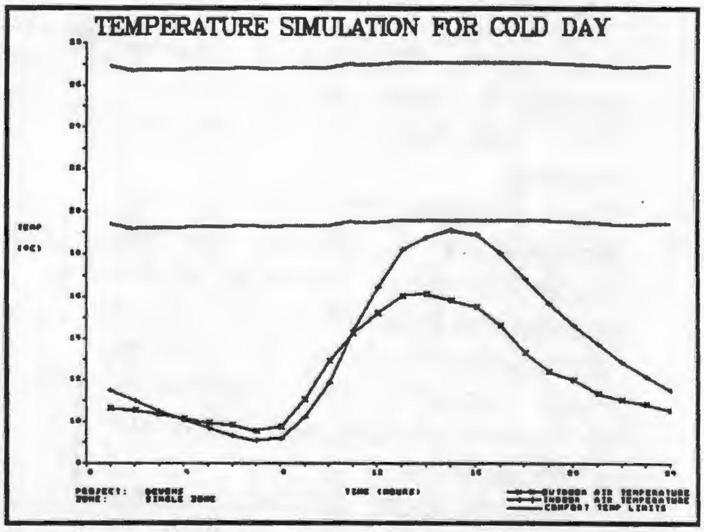
- temperatures

The temp. range on a summer day is 19 K, reaching 37°C at 16h°°. During the night the temp. drops to 18°C at 6h°°, 3 K above outside air temp.

During the day the conditions are extreme hot, most of the time 10 K above comfort conditions.



Winter temperatures drop to 9°C at 7h°° below outside air temp. This effects are discussed under the previous option.
Energy consumption is high:
16.2 kWh per m² per year indicate high expenditures on fuels used for space heating.
Peak energy demand for heating rises up to 14 kW.



7.5.3 Low cost option (1) and improved ventilation rate

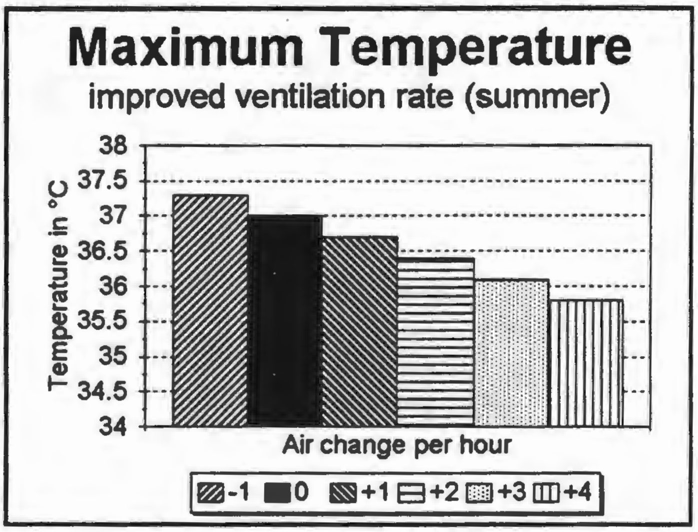
- Improvement

In this option the ventilation rates are improved in summer, up to 7 air changes per hour. This can be achieved using wing walls and well designed openings.

- temperatures

The simulation program calculates a maximum Temperature in summer of 35.8 °C (7 ACH during daytime) up to 37.3 °C (2 ACH during daytime).
The difference is 1.5 K only by improving the natural ventilation of the building.

This figure displays the different maximum temperatures according to the ventilation rates per hour.



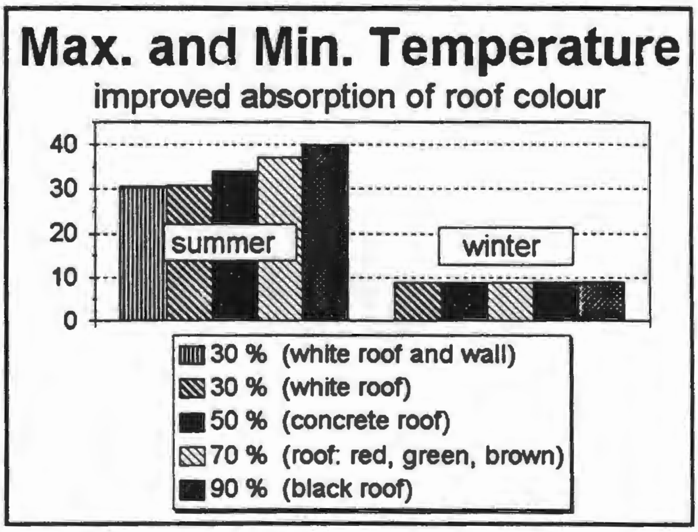
7.5.4 Low cost option (1) and improved absorption

- Improvement

In this option the absorption of the roof and wall varies:
It ranges from white colour (30% absorption), concrete (50%), red, green, brown colour (70%) up to 90% for a black colour.
The figure below shows the increase of indoor temperature in summer and winter using different roof/ wall materials or colours.

- temperatures

The maximum temperature in summer varies from 30.5 °C (white roof and wall) to 40.1 °C (dark roof colour). There is a significant difference of 10 K.
The minimum temp. in winter remains at 8.8 °C (white colour) and 9,1 °C (dark colour).
The difference can be neglected.
Roof materials or colour have an important effect on summer indoor temperatures.



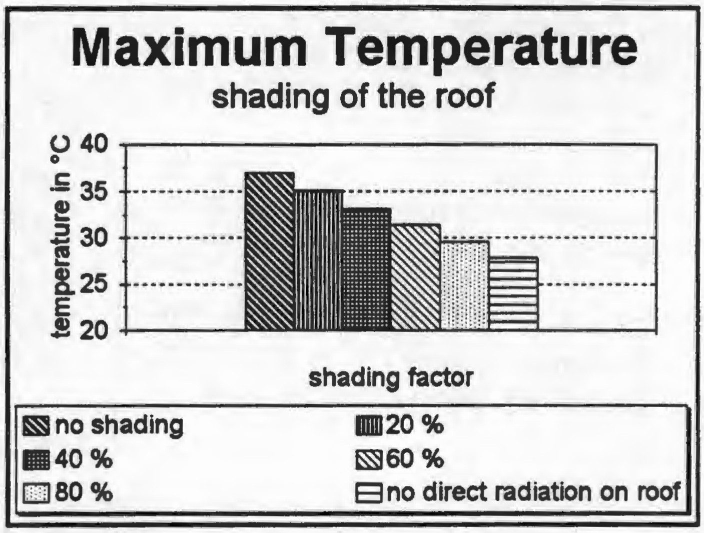
7.5.5 Low cost option (1) and improved shading

- Improvement

In this option the roof is shaded:
It ranges from no shading to a shading factor of 99%. This can be achieved by plants or other buildings around.
The figure below shows the decrease of indoor temperature in summer:

- temperatures

Maximum temperatures without shading is 37°C. The range of temperature decrease with shading is almost 10 K. Shading of 30 % reduces the peak temperature 2 K. Another 20 % to 32.3°C.
Combining the effect of 50% shading and white painted roof reduces the maximum temp. to 29.3°C.
A total shaded roof would drop the indoor temp. of the building 2 K below outside air temp. to 27.9°C.



7.5.6 Low cost option 2 (no foundation, 130 mm light construction wall)

- improvement

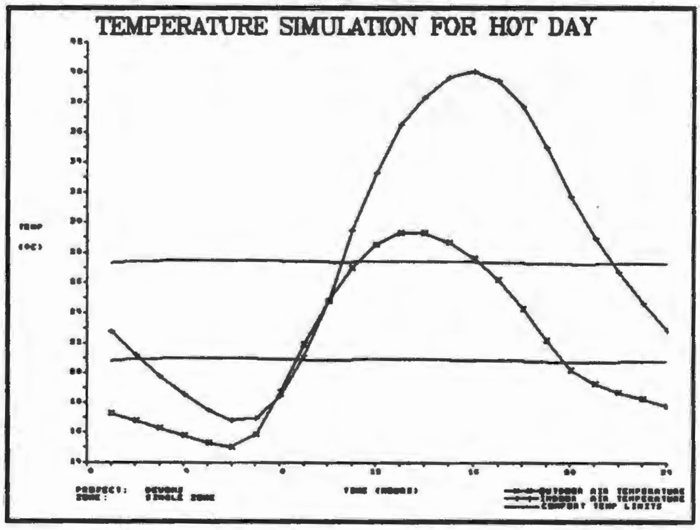
This option is build as option (1) using a light wall construction (12 mm Wood teak, 110 mm Airspace, 9 mm Wood teak)

- energy performance

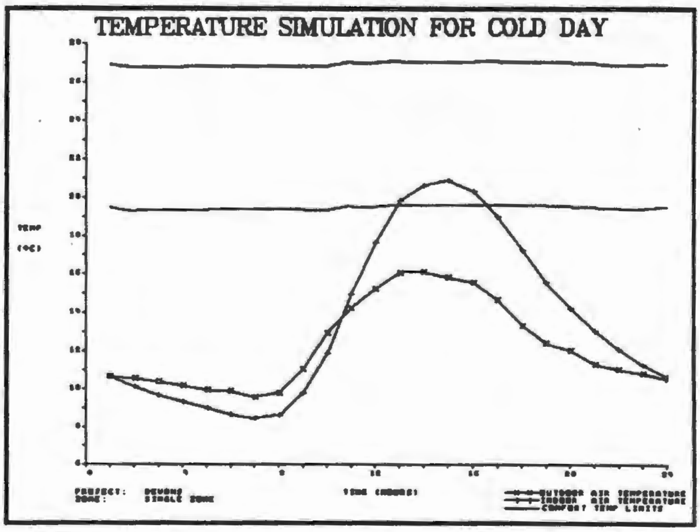
The calculated energy demand in the winter months is 2628 MJ/ a. $e_{eff} = 0.97$
The peak energy demand is 14.2 kW.

- temperatures

Summer temperatures ranges 23 K from 17°C up to 40.1°C. There is a slightly reduction of time lag between maximum in and outside air temperature to 2 hours.
The maximum temp. is 3 K above 'option 1', the minimum temp. drops to 17°C during the morning, 1 K below 'option 1'.
This is caused by less thermal capacity of the walls.



Winter temperatures have a wide range of 12 K: In the morning at 7h°° the temp. drops to 8.4°C, 1 K below outside air temp. and rises up to 20.5°C at 15h°°.
The energy consumption during the winter and the peak energy demand are slightly higher than 'option 1'.



7.5.7 Low cost option (1) and foundation

- improvement

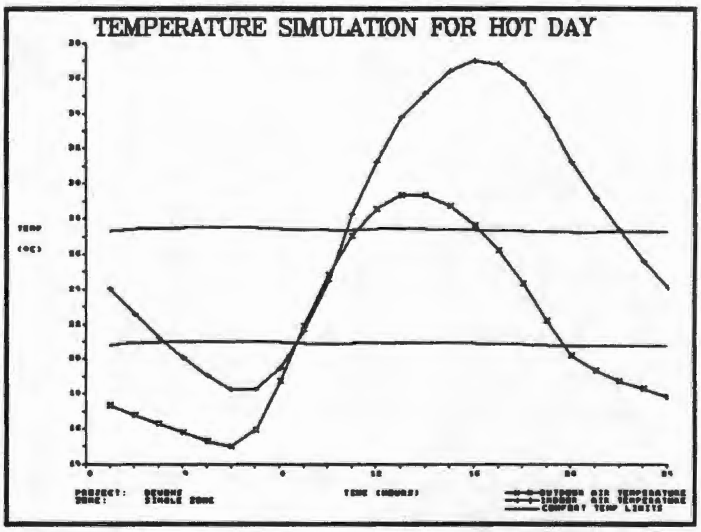
This option is a variation of option (1) with a foundation as specified under 'current design'.

- energy performance

The calculated energy demand in the winter months is 2559 MJ/ a. e_{eff} = 1.0
The peak energy demand is 13.2 kW.

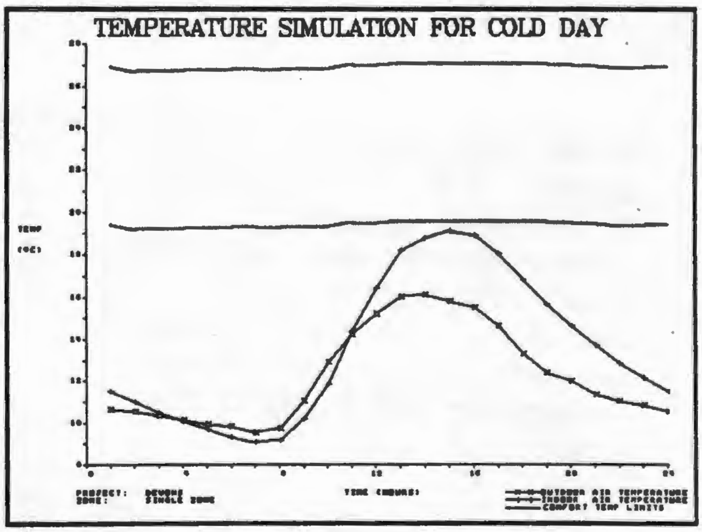
- temperatures

Summer temp. characteristics are similar to the 'option 1'.
Maximum temperatures are calculated to 37°C.



Winter temperatures are similar to 'option 1'.
The peak energy demand is slightly little decreasing to 13.2 kW.

Foundation has little impact on indoor temperatures and energy consumption.



7.5.8 Low cost option (1) and cavity walls

- improvement

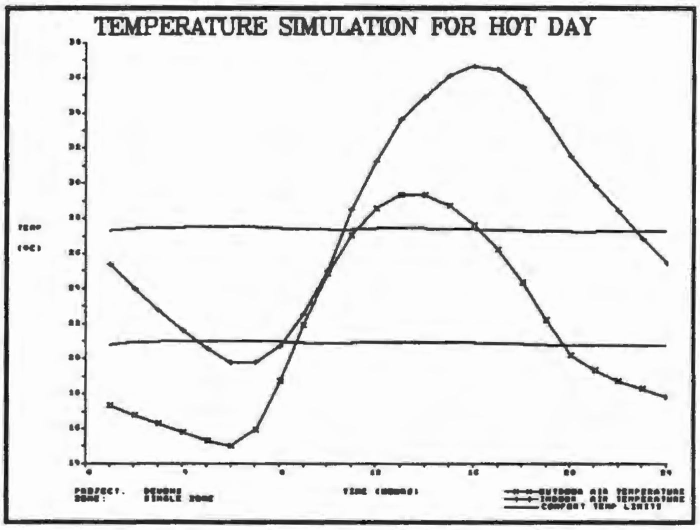
This is a variation of option (1), with cavity walls instead of a concrete block wall.

- energy performance

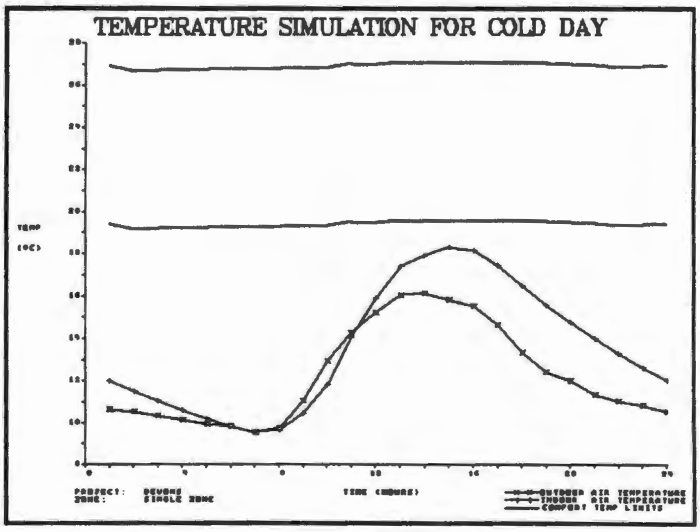
The calculated energy demand in the winter months is 2193 MJ/ a. $e_{eff} = 1.1$
The peak energy demand is 12 kW.

- temperatures

Summer temp. are most of the day not in the comfort zone. The temperature rises to 36.7°C and drops only to 19.5°C, 1.5 K above 'option 1'.
In the morning the indoor temp. remains 4.5 K above outside air temp.



Winter temperatures vary between 9.5°C and 18°C at 15h°°. The temp. does not drop below outside air temp. but is 10 K below comfort level during the night.
Energy consumption improves by 14%. Peak energy demand decreases 2 kW to 12 kW.



7.5.9 Low cost option (1) and ceiling (Hardboard)

- improvement

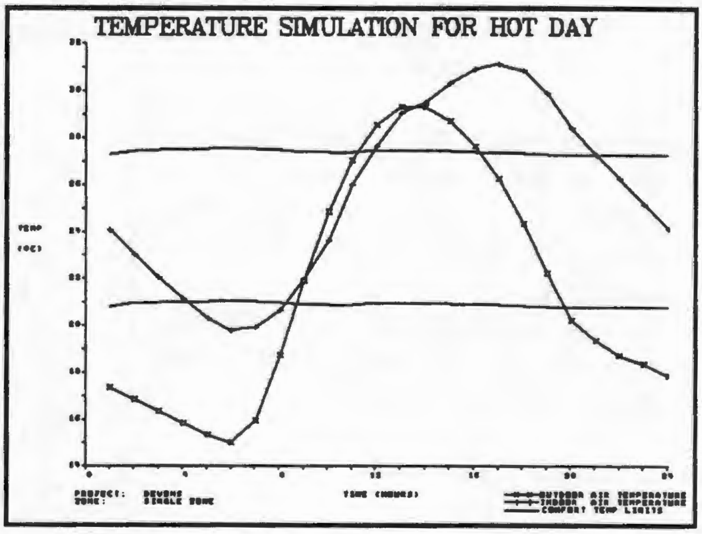
This option is like option (1), improved with a 13 mm Hardboard ceiling (200 mm airspace between ceiling and roof).

- energy performance

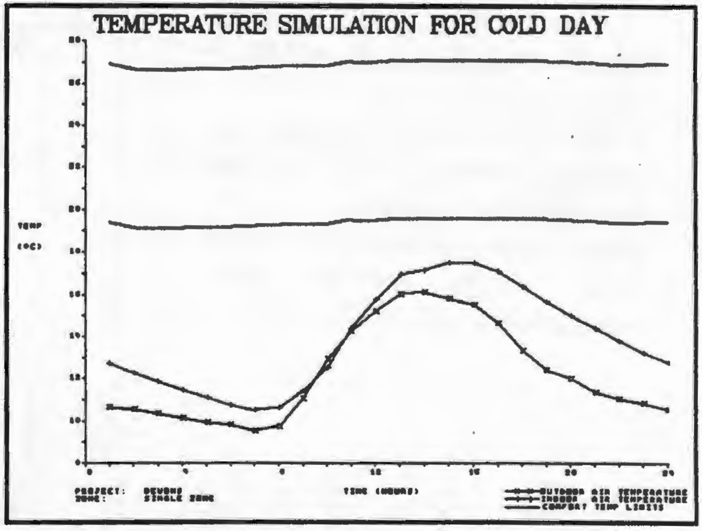
The calculated energy demand in the winter months is 1584 MJ/ a. $e_{eff} = 1.6$
The peak energy demand is 9.1 kW.

- temperatures

Extreme summer temp. vary between 19.5°C and 31.1°C. The time lag between maximum indoor and outdoor temp. is 3.5 hours, the maximum temp. occurs at 17h°°. In comparison with 'option 1' the peak temp. drops 6 K. The indoor temp. are in comfort conditions from 21h°° to 12h°°. During the day the temp. rises above 27°C.

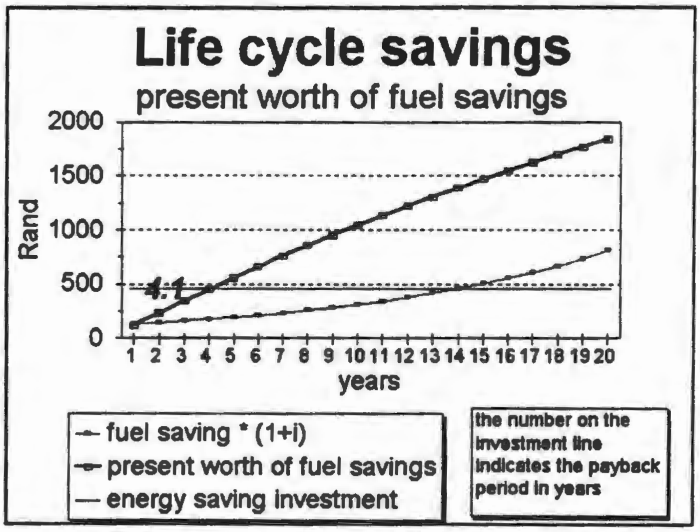


Winter temp. drop to 10.5°C, 1 K above outside air temperature. The Hardboard insulation improves the energy consumption to 1584 MJ per year, 60% of 'option 1'. Peak energy demand on a cold day is reduced to 9.1 kW.



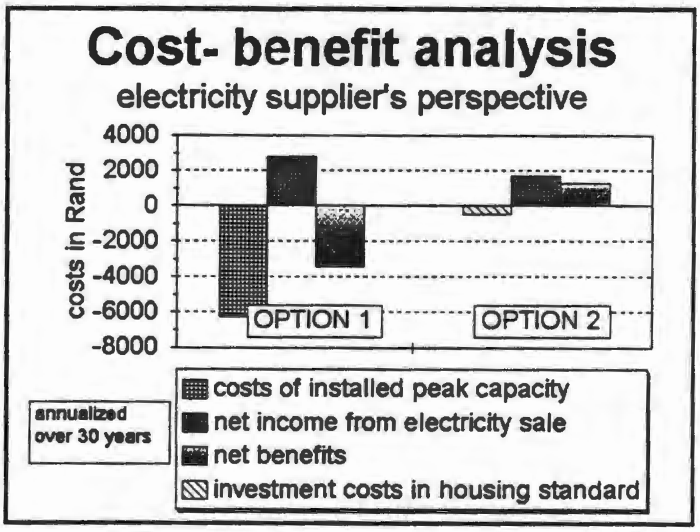
- economic analysis

The life cycle analysis shows a payback time of 4.1 years.
The assumptions are 10% inflation, average fuel costs, energy increase factor of 1.5 and 13% interest rate on the investment.



- supply perspective

The net income from electricity sale is lower in 'option 2', but there are great differences in the net income. The net income of 'option 2' is above R 1000 while it is R -3700 in 'option 1'.



7.5.10 Low cost option (1) and ceiling (Aluminium foil)

- improvement

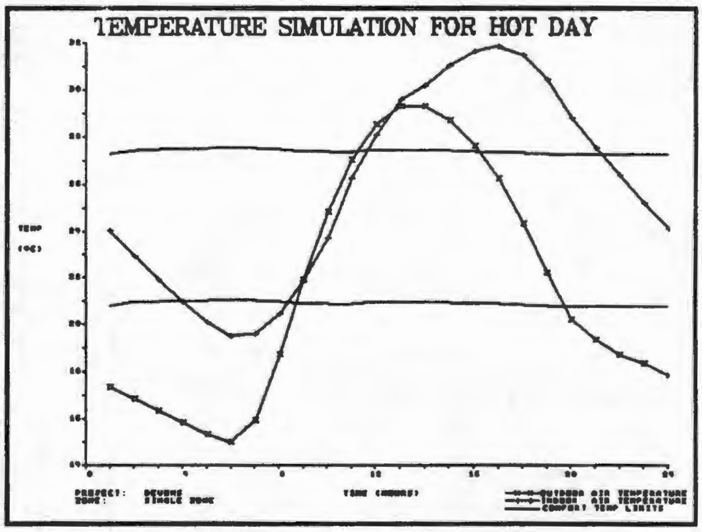
This option is improved by using Sisulation (Aluminium foil) as a ceiling insulation (50 mm Airspace between ceiling and roof).
Investment costs are R 308.

- energy performance

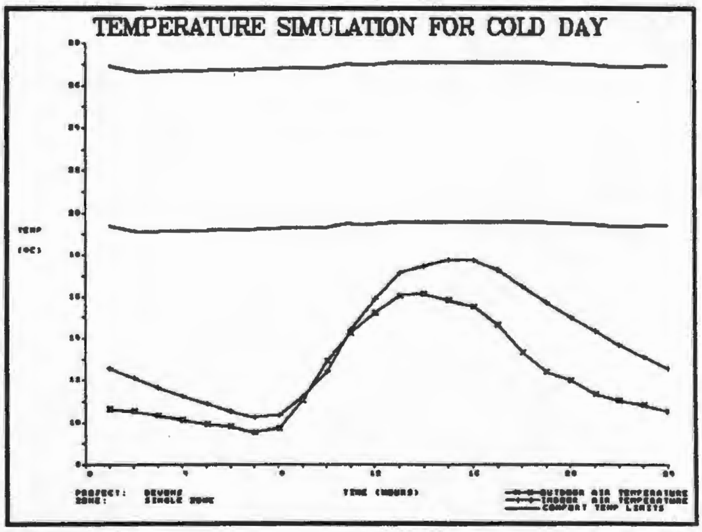
The calculated energy demand in the winter months is 1678 MJ/ a. $e_{eff} = 1.5$
The peak energy demand is 10 kW.

- temperatures

Temperature characteristics are similar to the 'hardboard option'. Maximum temperatures are calculated to be 31.5°C at 17h°°. Most of the day the temp. is below 27°C, in the afternoon it rises above that level.

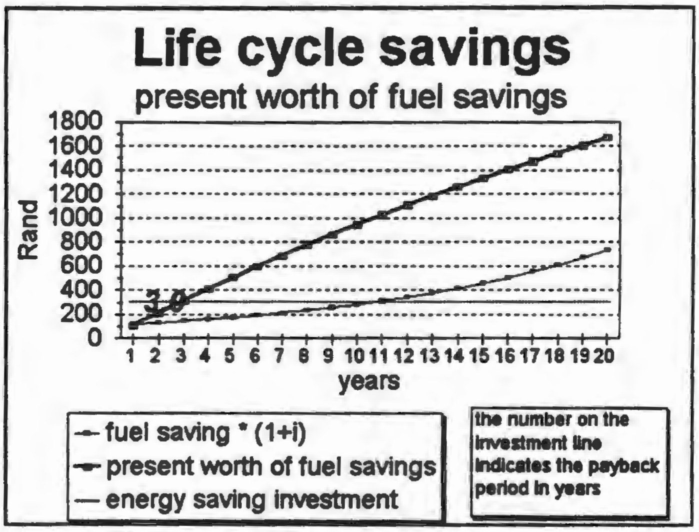


In winter the minimum temp. is 10.3°C at 7h°°.
Energy consumption is improved by 35%.
Peak energy demand is 10 kW on a cold day.



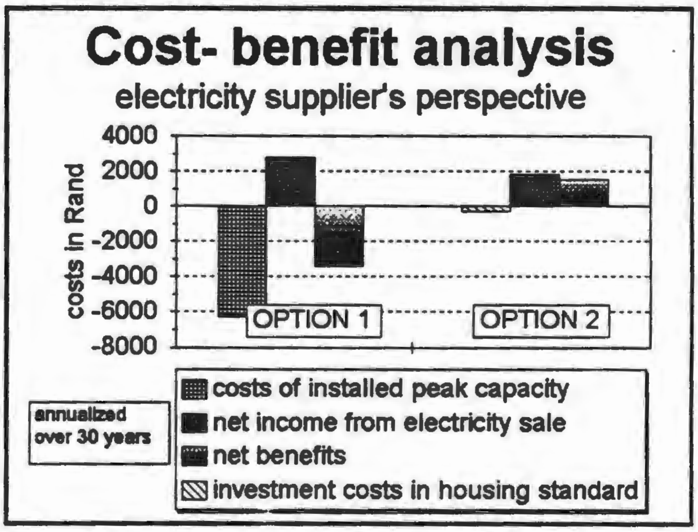
- economic analysis

The life cycle analysis displays a payback time of 3 years, which is below of the HB option.



- supply perspective

There is a significant difference in net income and benefit cost ratio: The net income varies between minus R 3200 and R +1500.



7.5.11 Low cost option (1) and ceiling (EPS, HB)

- improvement

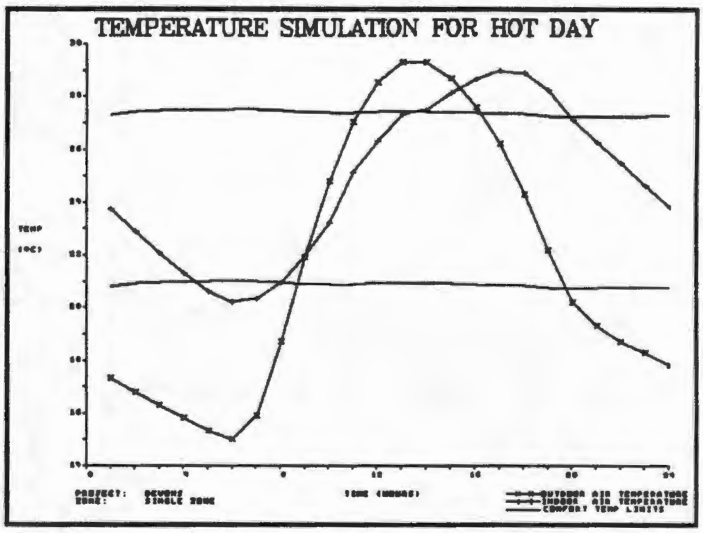
This option is improved by using Expanded Polystyrene and Hardboard as a ceiling insulation. (50 mm Airspace, 30 mm EPS, 10 mm Hardboard).
The investment costs are R 777.

- energy performance

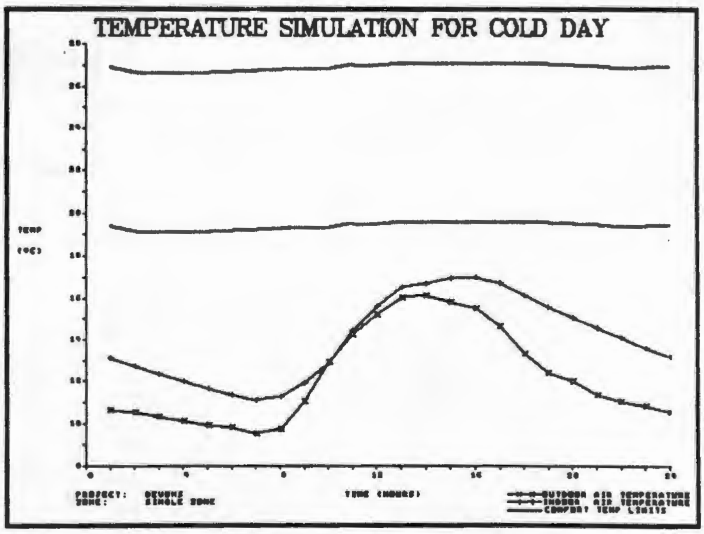
The calculated energy demand in the winter months is 1340 MJ/ a. $e_{eff} = 1.9$
The peak energy demand is 8 kW.

- temperatures

The summer temperatures are balanced and range from 20°C to 29°C. The maximum indoor temperature is below maximum outdoor temperature, still above comfort conditions.
From 20h°° to 14h°° the indoor conditions are in the comfort zone.

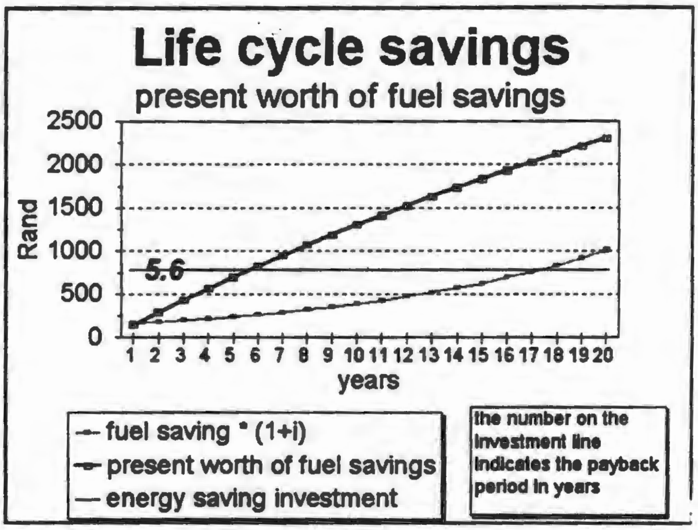


Winter temp. drops to 11.1°C on cold days, 1.5 K above outside air temperature.
Energy consumption is very low: Only half the energy as 'option 1' is required.
Peak energy demand is 6 kW less than 'opt. 1'.



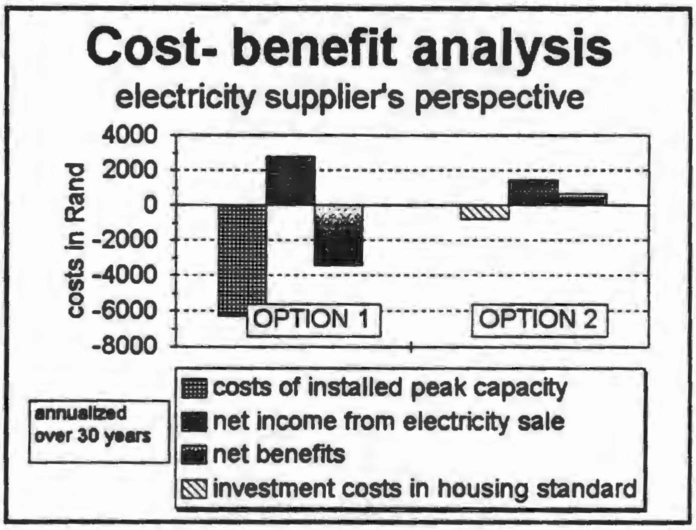
- economic analysis

With the assumption above mentioned the payback time is 5.6 years caused by the high investment costs of R 777.



- supply perspective

Option 2 provides a benefit cost rate which is above one. The difference of the options is almost R 3000.



7.5.12 Low cost option (1) and wall insulation on the inside

- improvement

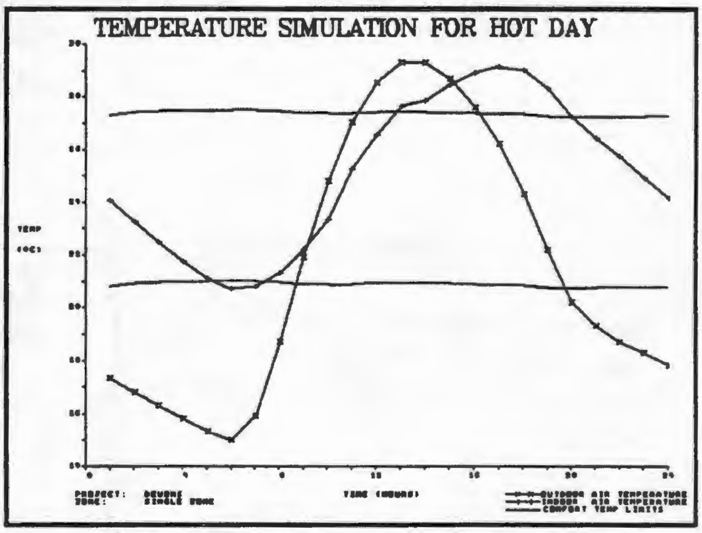
This option has wall insulation (10 mm EPS) facing the inside and a ceiling of 100 mm EPS and 10 mm HB (100 mm airspace between roof and ceiling).
The installation costs are R 978.

- energy performance

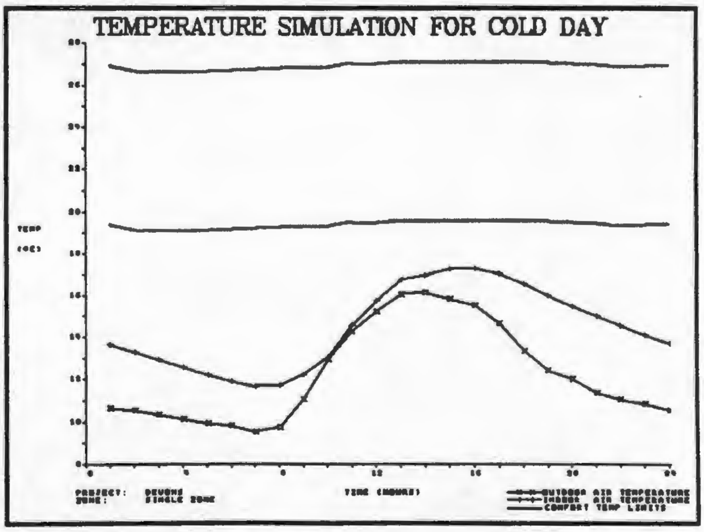
The calculated energy demand in the winter months is 954 MJ/ a. $e_{eff} = 2.7$
The peak energy demand is 7.0 kW.

- temperatures

The extreme summer temp. ranges from 20.8°C to 29.1°C. The temp. remains below outside air temp. but does not drop below 20°C during the night.
Improved air changes (3 ACH) during the night reduces the minimum temp. to 19.8°C and the maximum temp. during the day to 28.9°C.

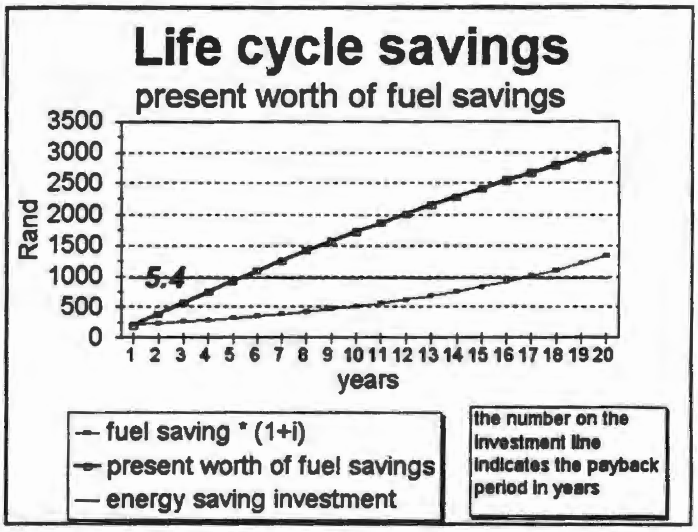


Winter minimum temperatures are 2 K above outside air temperature: 11.6°C. The required energy in winter is only 37% of 'option 1'.
The peak energy demand is reduced significant by the half.



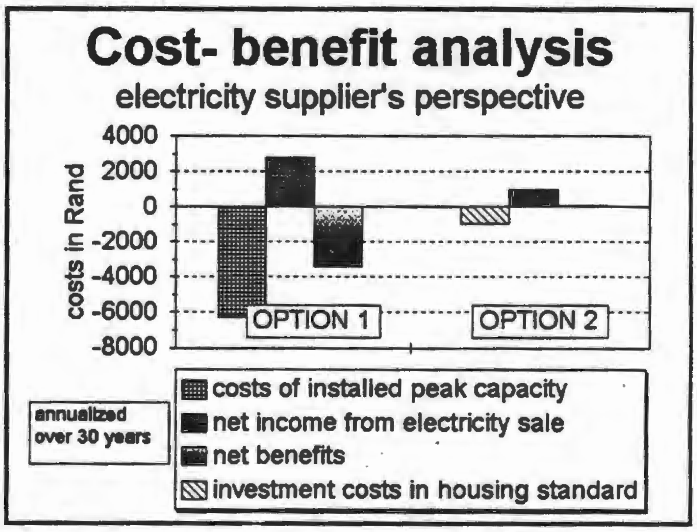
- economic analysis

The payback period is 5.4 years with the assumptions mentioned above.



- supply perspective

This figure displays a difference of almost R 2500 between the both options.
Benefit cost rate of 'option 2' is 1.



7.5.13 Low cost option (1) and wall insulation on the outside

- improvement

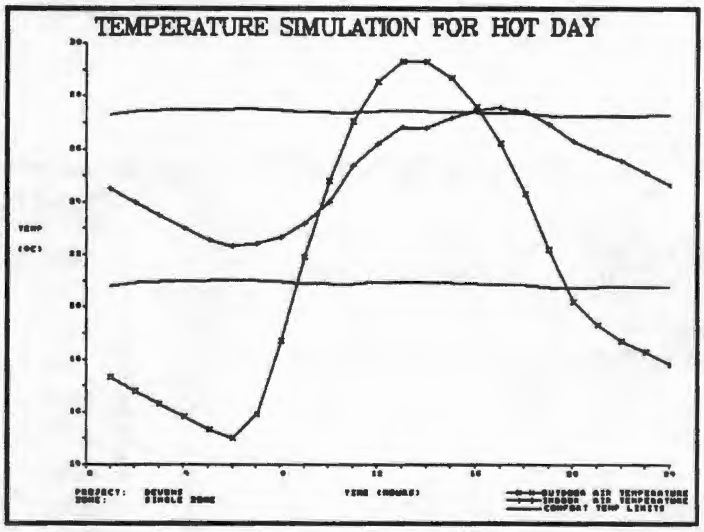
This option has wall insulation (10 mm EPS) facing the outside and a ceiling of 100 mm EPS and 10 mm HB (100 mm airspace between roof and ceiling).
The installation cost are R 978.

- energy performance

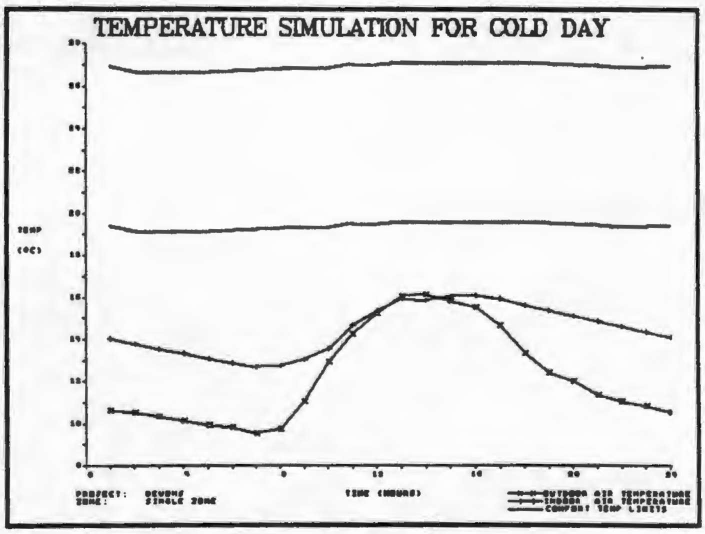
The calculated energy demand in the winter months is 845 MJ/ a. $e_{eff} = 3.0$
The peak energy demand is 6.0 kW.

- temperatures

The summer temperatures are in the comfort zone 24h°°.
The maximum temp. is 27.6°C, 2 K below outside air temp.
The decreasing temp. gradient in the evening is gradually: 0.3 K per hour.



Winter minimum temp. is 12.7°C: 3 K above outside minimum air temp., even without heating.
The temp. characteristics are similar to attached houses.
Low energy consumption of only 845 MJ per year: 33% of 'option 1'.
Peak demand is reduced to 6 KW.
Condensation might be a problem in winter.



7.5.14 Low cost option (1), wall insulation and window to W

- improvement

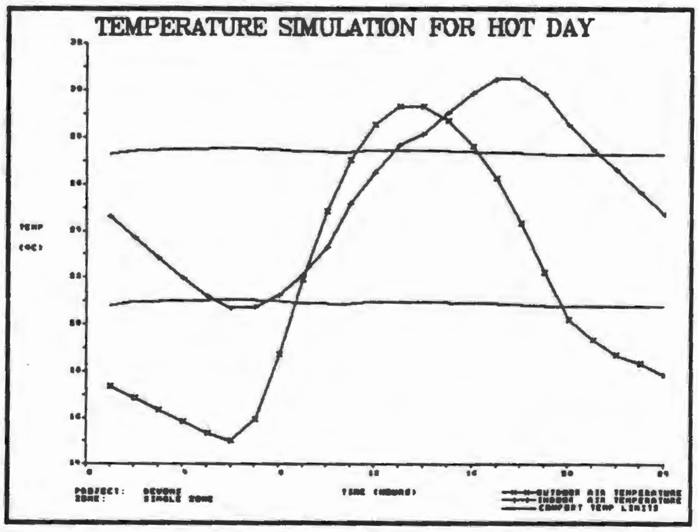
This option has insulation on the outside walls (10 mm EPS), a ceiling of 100mm EPS and 10 mm Hardboard (100 mm airspace between roof and ceiling).
An extra window is added (4 m², d = 4 mm, transmittance = 74 %, absorbtion = 17 %) on the West side (270°).

- energy performance

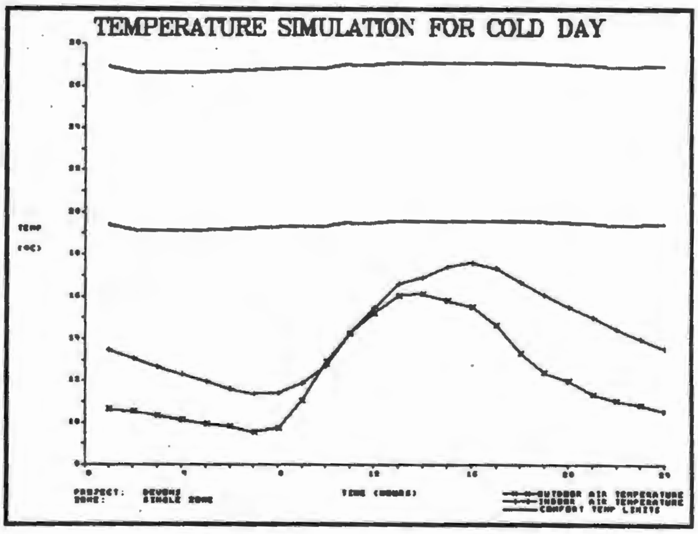
The calculated energy demand in the winter months is 1082 MJ/ a. $e_{eff} = 2.3$
The peak energy demand is 7.0 kW.

- temperatures

Mostly similar characteristics like previous option. Summer maximum temp. rises up to 30.5°C, 1 K above outside air temp.

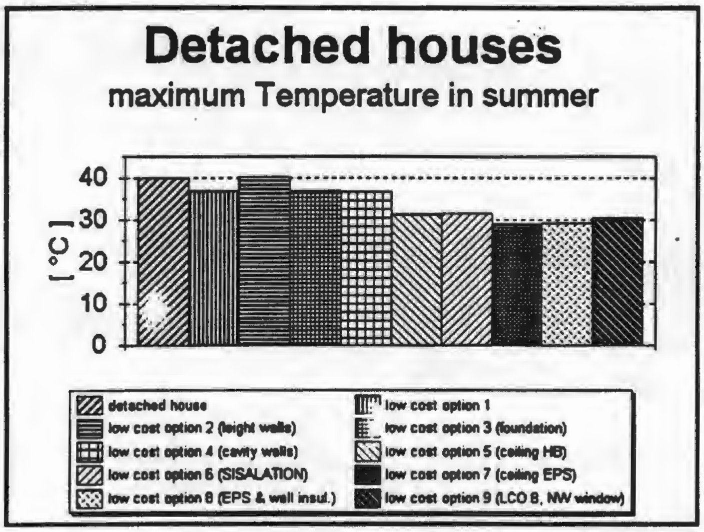


Minimum winter temp. drops to only 11.3°C, still lower than without the extra window facing West.
The heat losses through the window are more than the heat gains through solar radiation.



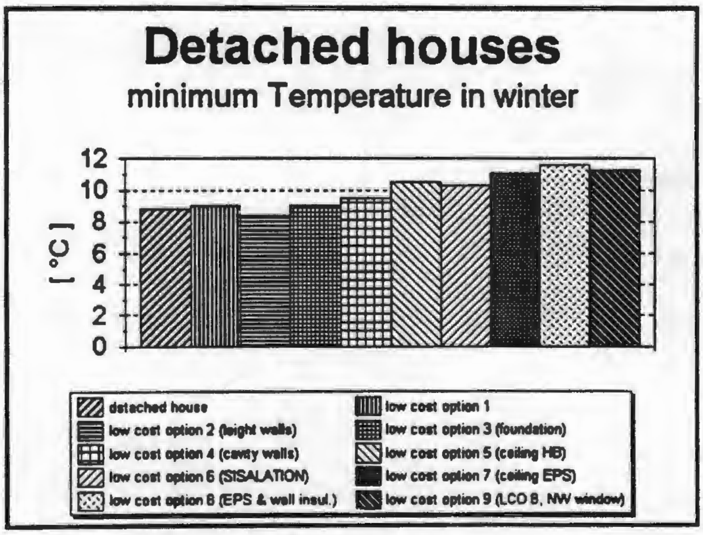
7.5.15 Summary

- maximum temperature in summer



The range of maximum indoor summer temperatures is 11 K by improving design: Indoor temperatures rise up to 40°C (10.7 K above outdoor temp.) in buildings without ceiling insulation and can be reduced to 27.6°C (1.7 K below outdoor temp.). Both, the existing design and a light constructed building show high extreme indoor temperatures of 40°C. Cavity walls reduce the maximum temp. to 37°C. HB and Sisalation ceiling insulation reduce the max. temp. to 31°C. The lowest max. temp can be achieved by an EPS insulation. The temp. drops to 29°C, below outside air temp. It was found that windows (on west side, 4 m²) do not affect the indoor conditions by more than 1 K.

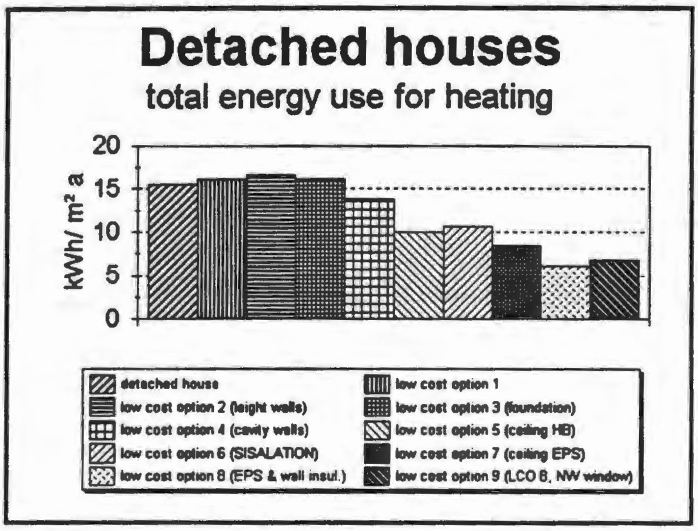
- minimum temperature in winter



Winter indoor temp. (without heating) vary from 8.4°C to 12.7°C:

The difference of 4 K is significant. Light constructed houses do occur with low indoor temperatures in winter. HB and Sisalation ceilings improve the minimum temp. to above 10°C. EPS improves that value to 11°C and additional wall insulation to almost 12°C.
There is a important decrease of peak energy demand on the cold days, ranging from 14 kW to only 6 kW depending on the insulation.

- energy consumption of detached houses

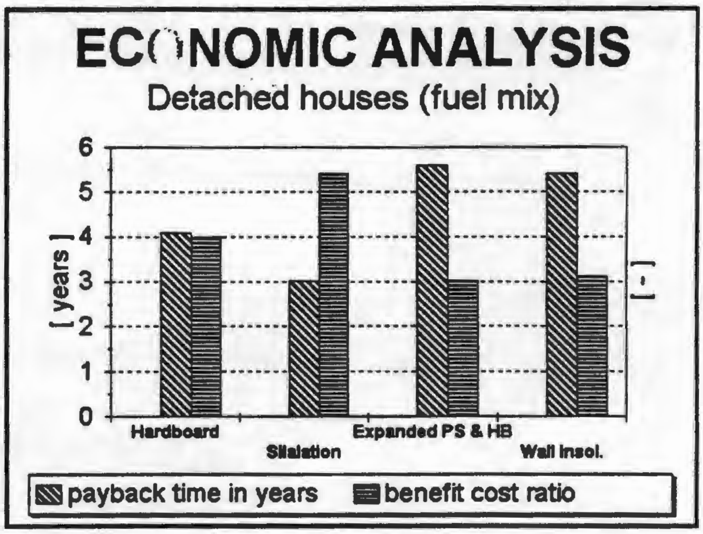


There are significant differences of 300% in energy consumption using various designs for single houses. It ranges from 16.6 kWh per m² a to 5.3 kWh/ m² a.
EPS has the best insulation characteristics: There is a reduction of 50% by using a EPS (100mm) ceiling insulation.
Sisalation reduces the energy consumption by 34 %.
By using wall insulation 63 % energy usage reduction are possible.

7.5.16 Economic analysis

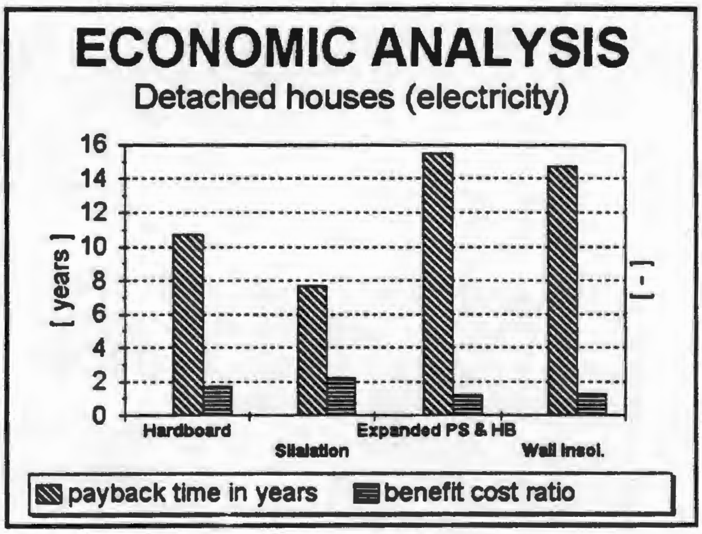
This illustrate the payback times (PT) and benefit cost ratio (BCR) of the options:

This figure shows the PT and BCR assumed a fuel mix for space heating.
Sisalation ceiling has the highest benefit cost ratio of 5.3. The payback time is only three years.
Hardboard occurs with an benefit cost ratio of four.
Both options, HB and EPS ceilings and the option of wall insulation combined with HB ceiling have benefit cost ratios of above three.
The payback times are below five years.



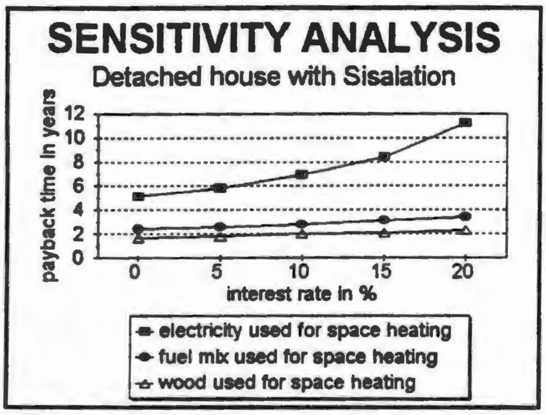
This figure shows the PT and BCR assumed electricity for space heating:

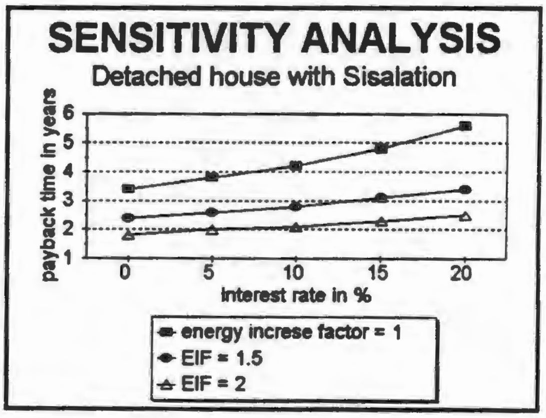
PT are increasing to 14 years and BCR drop to 1-2.



7.5.17 Sensitivity

These diagrams illustrates the sensitivity of future energy cost increase and different fuels used for space heating
:





In the case of electricity used only for space heating the payback times are between 5 and 11 years. Using wood or fuel mix for heating the payback times drop to 1.7 and 3.4 years depending on the interest rate.

The influence to the payback time of future energy cost increase is the following: Assuming a EIF of 2, PT are between 1.8 and 2.5 years. With no future energy cost increase PT are 3.4 to 5.6 years.

7.6 DISCUSSION OF RESULTS

The above mentioned assumptions were made in the simulation and analysis. Assumptions are simplifying. In this subchapter the results are discussed and the limitations are pointed out.

7.6.1 Assumptions

- outdoor air temperature

The simulation program uses temperature data of 1994. This might not be an average year nor an extreme year (in case of temp. and solar radiation). This could be improved by using an average of at least 3 years.
The objective of the simulations was to calculate maximum temperatures. Outdoor air temperatures of the design days (hot day, cold day) were not at the bottom or top end of recorded maximum temperatures in Cape Town. The maximum and minimum temperatures used in the simulation were taken of a summer day in February (29.3°C) and of a winter day in July (9.5°C). Temperatures below or above these levels might occur.

- indoor conditions

To predict energy consumption during the winter the above mentioned comfort conditions were determined. User behaviour can deviate and will cause less or higher energy consumption prediction.

- ventilation rates

To assume ventilation rates is difficult: It depend on the quality of the structure and the openings, users behaviour, wind pressure on the building, orientation, occupancy and other factors which can not be taken all into consideration here.
Summer ventilation rates may often increase above 3 ACH. Winter air changes will increase above 1 ACH, caused by the need of fresh outside air to compensate air pollution inside the building (wood stoves, paraffin heater ...). The quality of low cost housing might not allow to assume ACH of 0.5 per hour during the night. Heat losses may cause lower temperatures and higher energy consumption during the winter.

- occupancy

In this simulation a periodical occupancy was assumed during the whole year. This simplification is motivated by the neglected effect on the results: Modifying this factor did not change the results significantly.

- internal load

Cooking was taken into account to the internal heat generation. There might be higher loads caused by stoves and other heat generating sources. Assuming high internal loads would change the calculations to decreasing energy demand for space heating and therefore affect the cost benefit analysis.

- location

This simulation does not take into account the location of the building in a certain region. Cape Town's climate is used for urban and rural areas. This has to be taken into consideration while discussing the energy consumption.

7.6.2 Simulation results

- simplification

The simulation program quick is based on a first order model. The physical phenomena are reduced to concentrated parameter models and calculated one dimensional.
The results should be looked at in this context.

- energy consumption

Energy consumption depends mostly on the building structure. But other factors determine the use of space heating during the winter: Income group, various opinions on comfort conditions, availability of fuels and others.
The calculated energy demand during the winter month gives an indication of the thermal performance of the house. It can not reflect the energy use of various occupants.

- peak energy demand

The calculated peak energy demand on a cold day is simulated by using radiant heater. This peak demand might not occur, caused by the lack of such high peak generating heaters. Most heating devices use maximum heat output of 2- 5 kW.

- limitations

The simulation is based on a design day that is periodic. The internal load and the number of occupants does not vary during the year. This limits the variety of input data. 'Quick' does not allow to simulate passive design options such as 'Trombe walls' or other passive heat storage applications.
There is no possibility for simulating ventilated ceilings. These effects are not predictable yet. Another limitation is caused by the hourly time step of the calculation.

7.6.3 Economics

- payback time

Payback time has importance to people living in houses and investing in energy saving devices. Investors in buildings like NewHCo and other building companies are not paying for costs of energy or fuels. They do not benefit from annual energy savings.

- Eskom's perspective

The electricity utility Eskom is interested to decrease the peak load in winter, which lowers the need for further generating facilities. Investing in improving thermal standards of houses could achieve this.

In the economic analysis the avoided peak power is determined to 1 kW per house. In extremely cold winter days this figure might increase up to 5 kW. The benefit cost rate for investing in energy saving devices of houses will increase significant.

- cost benefit analysis

The cost benefit analysis has not yet considered non financial factors and benefits: Improving the thermal performance increases air quality and comfort conditions, decreases transportation costs and pollution problems. There is an improve of peoples health and security. Time spend on collecting wood will decrease.
Dependence on particular fuels or electricity can be reduced.
Environmental effects of energy use further strengthen the argument for thermal efficient design.

Summary:

- In detached houses maximum temperature in summer can be reduced to 27.6°C (reduction of 13 K)
- In winter the minimum temperature increases 4 K without heating
- Peak energy demand drops by 8 kW with improved design
- Energy consumption can be reduced by 63 %
- Payback times of energy saving investments are low (1.5 years)
- Benefit cost analysis prove cost benefit ratios of above five

---

8 CONCLUSION

In this chapter the results are summarised, conclusions are drawn and areas for further research are formulated.

South Africa has enormous potential to implement thermally efficient housing standards at this stage. Thousands of houses will be built this years to meet the needs of millions of people without adequate homes.
This document examines the potential of thermal energy efficient design in different climatic zones. A low cost housing project in Cape Town is examined in detail. It was found that there is a high potential in energy savings for space heating. Significantly improvements of indoor conditions (temperature and humidity) towards comfort conditions can be achieved.
The simulation program 'quick' was used to predict indoor temperatures and energy consumption figures. It links together climatic conditions and building design and provides input data to an economic evaluation.

8.1 GENERAL

- Climate zones

Each climatic zone affects buildings and indoor conditions differently. This has to be taken into consideration in the layout and design process. Passive options are cost effective, improve indoor conditions and conserve energy used for space heating.

- Indoor conditions

Indoor temperatures and humilities in buildings extend beyond comfort conditions: Temperatures in summer rise high above outdoor temperature level. In winter indoor temperatures are low and relative humility is high: This causes high energy consumption and peak energy demands.

Through passive design indoor temperatures are improving: The simulation of houses in Cape Town verifies a reduction of maximum summer indoor temperature up to 13 K and an increase of minimum temperature in winter (without space heating) by 4 k.

- Energy consumption

Properly designed buildings consume 63 % less energy for space heating in winter. Benefits will arise for both, the occupants and the energy utility, by reducing peak power demands and fuel consumption. There are beneficial effects on the society and the environment.

- Economic survey

Life cycle and cost benefit analysis provide decision criteria for investments in energy saving devices:
According to the assumptions of interest rate, future energy increase and inflation rate, the economic benefits can be significant. Payback periods of two years are proved for certain design options.

8.2 LIMITATIONS

- Assumptions

Assumptions on climatic data, building materials and design, physical phenomena, economic values and others are affecting the results. To determine input data like occupancy and fuel usage careful research is required.
Dependencies on interest rate and future energy increase are examined in the sensitivity analysis.

- Simulation

The computer program simulating the temperatures and energy consumption is based on simplifications. The building is reduced to a single zone and the calculations are based on concentrated parameter models. Therefore the results do not reflect the reality but indicate the effects of improvements.

- Building design

In this study a particular housing project was examined. The results therefore do not have to be generalised or used for other buildings with different design.
This study examined low cost options which improve the thermal responds of buildings. Passive solar heating systems (Trombe wall ...) were not taken into consideration because of high first costs.

8.3 RESULTS

- Simulation results

This table summarises the results of the calculations:
It displays the peak temperatures, energy consumption and peak energy demand. These data are not empirically measured but calculated with the assumptions as mentioned above.

Attached house	max Temp °C	min. Temp °C	peak demand in kW	MJ/ m² a	energy efficiency
row existing without ceiling insulation	30.9	12.1	10.1	35.4	1.0
row + ceiling Hardboard	28.3	13.2	5.5	18.5	1.9
row + ceiling SISALATION	28.8	13.0	5.8	19.9	1.8
row + ceiling EPS 15 mm, AS 100 mm	27.2	13.7	4.8	14.0	2.5
insulation on outside wall	28.5	13.3	5.4	17.5	2.0
no cavity walls	28.7	12.7	6.2	21.2	1.7
Detached house					
existing design without ceiling insulation	40.0	8.8	13.1	55.7	1.1
low cost option 1	37.0	9.0	14.0	58.2	1.0
low cost option 2 light walls)	40.1	8.4	14.2	59.7	0.97
low cost option 3 (foundation)	37.0	9.0	13.2	58.2	1.0
low cost option 4 (cavity walls)	36.7	9.5	12.0	49.8	1.1
low cost option 5 (ceiling HB)	31.1	10.5	9.1	36.0	1.6
low cost option 6 (SISALATION)	31.5	10.3	10.0	38.1	1.5
low cost option 7 (ceiling EPS, HB)	29.0	11.1	8.0	30.5	1.9
low cost option 8 (EPS & wall insul.)	29.1	11.6	7.0	21.7	2.7
low cost option 9 (LCO 8, NW window)	30.5	11.3	7.0	24.6	2.3
low cost option 10 (LCO 8, insul. outside)	27.6	12.7	6.0	19.2	3.0

More detailed summaries are included in the chapter 'Project Devon street'.

8.4 COSTS AND BENEFITS

Cost benefit analysis indicates the most cost effective options:

Sisalation and expanded Polystyrene ceilings indicate benefit cost ratios above 5. The payback times for these investments range from 2 to 4 years, depending on the interest rate and future energy increase. Hardboard ceilings indicate a benefit cost ratio of 4 and payback times of 4 years. Insulating the outside walls is less cost effective: Benefit cost ratio is 2 and payback times are from 5 to above 8 years. Sensitivity analysis illustrates that payback times for an EPS ceiling used in attached houses can be predicted between 1 and 4 years. The payback time of a Sisalation ceiling in detached houses varies between 2 and 6 years.

The benefits for the energy utility Eskom are significant: For example: The benefit cost ratio of investing in an EPS ceiling insulation in detached houses is 1.5 and causes a positive net income. In comparison to the investment in peak power which indicates a benefit cost ratio below one: 0.15. This causes negative net income. (The calculations are discounted over 30 years)

Other options (orientation, roof colour and arrangements of openings) which improve the thermal standard may not cause extra first costs and are highly effective.

Other benefits which do occur as thermal conditions improve are not expressed in financial values:

- Decreasing costs for medical support
- Decreasing costs for transport
- Improving air quality and decreasing pollution problems
- Regional and global environmental benefits

8.5 STRATEGIES

Passive design options have to be considered right in the beginning of the planning process: These include site selection, orientation, solar control, thermal capacity, window size, surface colour, insulation and building materials.

- Layout

This study shows that in Cape Town row houses are advantageous to detached houses: Sharing walls causes reduction of building costs and energy consumption.

The thermal performance of row houses is better than detached houses even without improved design:
The maximum indoor temperature in summer is 10 K lower in row houses. The minimum temperature in winter is 3 K higher without heating. Energy consumption drops 5 kWh per square meter floor area, year in attached houses (30% less than detached houses).

- Improvements

The following table presents the type of improvement and the reduce in energy :

Option	Energy consumption in detached houses in MJ/ m^2 a	energy consumption in %
Light construction wall	59.7	+ 3 %
Cavity wall	49.8	- 14 %
Sisalation Aluminium foil ceiling	38.1	- 34 %
Hardboard ceiling	36.0	- 38 %
EPS and HB ceiling	30.5	- 48 %
Foundation	58.2	- 0 %
EPS ceiling and wall insulation	21.7	- 63 %

Energy consumption can be reduced to 50 % through ceiling insulation. 63 % can be saved using ceiling and wall insulation.

- Peak temperature

This table indicates the improvement of indoor conditions in detached houses:

Option	max. temp. in °C	reduction in K	min. temp. in °C	increase without heating in K
Light construction wall	40.1	+ 3	9	+ 0.2
Cavity wall	36.7	- 0.3	9.5	+ 0.7
Sisalation Aluminium foil ceiling	31.5	- 5.5	10	+ 1.2
Hardboard ceiling	31.1	- 6	9.1	+ 0.3
EPS and HB ceiling	29	- 8	11.1	+ 2.3
Foundation	37	- 0	9	+ 0.2
EPS ceiling and wall insulation	29.1	- 8	11.6	+ 2.8

Peak temperatures in summer can be reduced by 8 K. Minimum temperatures in winter increase by 2.8 K.
Further improvements can be achieved by ventilation, roof colour and shading:

- Ventilation

Through improved ventilation indoor temperatures in summer can be reduced. Increasing the airchanges per hour from 2 ACH to 7 ACH the maximum temperature drops 1.5 K.

- Roof colour and shading

Significant drop of maximum temperature in summer can be achieved by using light roof colour and shading the roof. The difference of maximum indoor temperature in summer between a dark colour and a white roof is almost 10 K.
Shading 30 % of the roof will decrease the indoor temperature another 2 K.

8.6 FURTHER RESEARCH

The following areas have been identified for further research:

- Develop the simulation program as discussed in the section 'limitations'
- Examine the effect of condensation and moisture to health and building structure
- Examine the energy use in relation to outside air temperature and humidity
- Validate simulation results of thermally improved houses
- Socio- economic studies on benefits of thermally improved houses in perspective of the energy utility and the national perspective

8.7 POSTSCRIPT

After having gone through the process of this study I want to comment on the following:

❀ Working at EDRC

Researchers and support staff at EDRC made me feel comfortable and welcome. I experienced an open, creative research atmosphere and enjoyed the four months worked in the Institute.
Coming from a technical university it was a novel experience, working at a policy orientated research Institute. The research methodology differed and the objectives of research were not only technically based. Therefore it was difficult in the beginning not to focus too much on policy and social aspects of my research, but on engineering based studies.
I and other students at EDRC had problems with their supervisors (mentioned below). During the stay we compiled a paper on 'Student policy at EDRC' to reorganize and improve the relationship between students and supervisors and set up clear policy for future students.
The relationship between students was productive. Weekly postgraduate meetings were held and a representative attended the weekly Management Committee meeting. On regular Wednesday meetings EDRC researchers were invited to provided a forum of exchange ideas. Projects and general issues (Methodology, Information systems, Development aid ...) were discussed.

❋ Study process

Start up:

When I first came to EDRC in November the project was not yet defined. To specify my area of research I held meetings with my supervisor once a week and discussed the research needs. Scanning through literature, project reports and through discussions we determined what research was required. Thermal efficiency was not considered in low cost housing in South Africa. We found that the need for specifying options which improve the thermal energy efficiency of buildings in different climatic zones is an important issue. I started my research with this broad outlook.

The process:

My supervisor organized that I could attend a conference on 'Greening the RDP' in Johannesburg which encouraged me to go further in this particular research. During this time in Johannesburg we visited institutions involved in related subjects. I met Mr. Mathews from the University of Pretoria, Faculty of Mechanical Engineering, who made interesting recommendations. He referred to the simulation programme 'quick' which I used for simulating houses in Cape Town.

The facilities to do literature research at UCT were excellent: CD roms were available and the library staff was helpful. The literature research was successful and I started collecting design options according to the different climatic zones. Another useful source which I have used was the CSIR library in Pretoria.

Problems on the way:

There were some start up problems with hardware and software: In the first two month I was not connected to the local network. I could not print out nor communicate by email. After I had invested in a network- adapter life got easier. I joined the local EDRC network for exchanging useful internal information and contacted other international network groups (energy efficient building group in USA, Southern African Weather Bureau).

During the process of reviewing the literature I had to decide how detailed my research would be. I decided to review the passive design options and specify these on a particular low cost housing project in Cape Town. I always felt some dissatisfaction with not deepening these options. To examine very detailed physical phenomena was not the intention of my supervisor nor there was support for this.

I spend time on studying the various climatic zones in S.A. This could have been shorted to a minor part of the study. In the beginning I thought, it would be necessary to examine in relation to climate responsible design. Now I have a good overview of the various climatic zones in South Africa which require appropriate applied building design.

After getting into some detailed research I realized the need for deepening some aspects of the thermal efficient design options. I had to decide to do this or do simulations on a particular project. Because of the demand for information on the effects of improved design I choosed to examine the Devon Street Project.

Interesting aspects of improved buildings was to examine the costs and benefits of these and study the economic benefits in perspective of the end users and the energy utility. I had contact with a lecturer, Tony Leiman, of the School of Economics at UCT who is involved in cost benefit research and got some good advice. I found that the economic evaluation in different perspectives could take another half year of study.

✿ Involvement in projects

In the beginning of the projet I contacted non- government organisations to ask for information on existing building design of low cost housing. In discussions with various architects I realized that there is little understanding and awareness of thermal efficient design. The opinion is that insulating houses is viewed as a luxury. In discussions with people from the street I realized people appropriate this kind of research. An extract of my study was handed to the architect and the investors of the Devon Street Project. They were pleased to get this kind of information. It will encourage then to force the development of thermally improved design. The economic evaluation provide arguments for investing in insulating houses.

Companies producing insulating materials were very interested in my study and were pleased to provided their information.

In the end of my study there were some requests of a organisation called 'Development Action Group' who are organizing a 2000 house project in Cape Town, for consulting and monitoring energy related issues.

An abstract of this study was sent to a conference 'Household energy for developing countries' in July 1995 in Pretoria, S.A.

APPENDICES

A ORGANISATIONS AND INSTITUTIONS

(contact, field of expertise)

Baynham & Théron
Architecture, Planing and urban design
73 Hertzog Boulevard
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Building management
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(visit, building materials)

Center for Experimental and Numerical Thermoflow
Dept. of mechanical and aeronautical engineering
University of Pretoria
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(development of quick)

Development Action Group
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Tel:012-2902943
Fax: 012- 2902958
(climate data, information)

B NOMENCLATURE

symbol	name	unit
A	area	[m^2]
A_0	annual amplitude of $T_{(s)}$	[°C]
a	year	[-]
c	specific heat	[J/ kg K]
C^*	permeance	[kg/ N s]
C_{sav}	fuel saving costs	[R/ a]
D^*	diffusion coefficient for water vapour	[m^2/ s]
d	thickness of the wall, material	[m]
d	discount rate	[-]
d_e	effective thickness	[m]
$d_{e, ass}$	effective thickness	[m]
EIF	energy increase factor	[-]
F	damping factor	[-]
f_{CB}	benefit/ cost ratio	[-]
Gr	Grashof number	[-]
G_v	vapour flow	[kg/ m^2 s]
g	acceleration due to gravity	[m /s]
h_o	outer surface coefficient of heat transfer	[W/ m^2 K]
I_s	intensity of incident solar radiation	[W m^2]
I_d	discounted Investment	[R/ a]
i	inflate rate	[%/100]
k^*	vapour permeability	[kg m/ N s]
k_a^*	permeability of air	[kg m/ N s]
k	conductivity	[W/ mK]
L	length, thickness	[m]
N_d	day number	[-]
N	number of years	[-]
PT	payback time	[years]
PWF	present worth factor	[-]
Q	actual heat flow through wall	[W]
Q_0	heat flow with zero thermal capacity	[W]
q_{os}	heat flow entering the outside surface	[W/ m^2]
R_v	gas constant for steam	[kJ/ kg K]
r	reflectance	[-]
ΔT	temperature difference	[K]
$T_{(s,z,N)}$	soil temperature on the day N at depth z	[°C]
$T_{(s)}$	annual average of soil temperature	[°C]
$dT_{(z)}$	temperature range at depth z	[K]
$dT_{(0)}$	earth face temperature range	[K]
t_0	time period of the variation	[s]
U_{aa}	air to air thermal transmittance value	[W/ m^2 K]
U_{dry}	heat transfer coefficient of dry insulant	[W/ m^2 K]
U_{water}	Heat transfer coefficient of water	[W/ m^2 K]

U_a	Heat transfer coefficient of air	[W/ m^2 K]
U_b	Heat transfer coefficient of solid component	[W/ m^2 K]
U_{wet}	Heat transfer coefficient of wet insulant	[W/m^2K]
V_a	Volumes voidage of air	[%/ 100]
V_{water}	Volumes voidage of water	[%/ 100]
V_{air}	Volumes voidage of air	[%/ 100]
z	depth	[m]

Greek:

α	absorptivity of surface	[-]
α_{dif}	thermal diffusivity	[m^2/ h]
β	coefficient of volumetric expansion	[1/K]
ϵ	emmissity	[-]
$\theta_o - \theta_{os}$	outdoor air/ surface temp. difference.	[K]
θ_{sa}	sol-air temperature	[K]
$\theta_{sa} - \theta_i$	sol-air/ indoor air temperature difference	[K]
κ	diffusion resistance factor	[-]
τ	time lag	[h]
τ_z	time lag per meter depth	[d/ m]
μ	dynamic viscosity	[kg/ m s]
σ,ρ	density	[kg/ m^3]

SI- units

Quantity	Symbol	unit
Mass	kg	M
Length	m	L
Time	s	T
Thermodynamic Temperature	K	Θ
Luminous intensity	cd	-
Mol-mass	mol	N
Electric current	A	I

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D ENERGY FOR DEVELOPMENT RESEARCH CENTER (Profile)

EDRC is a university based research centre and its main goals are:

- To study energy and development problems and needs in Southern Africa and possible ways to address these
- To contribute to the achievement of improved social equity, economic competitiveness and environmental sustainability in the energy sector
- To develop human resources to respond adequately to energy and development needs

EDRC is committed to timely, high quality research aimed at generating knowledge and understanding, directed towards improved energy polices and practical implementation. Research is consolidated into five main research clusters: energy and urban development, energy efficiency and environment, energy and rural development, energy information and planning systems, as well as electricity. Each research cluster is headed by a project leader. One of EDRC's bigger research projects, Energy Policy Research and Training Project, funded by the Dutch government and the CEC has just been completed and is making a significant impact on the development of new policies aimed at widening access to basic energy services for the urban and rural poor.

EDRC places a high value on facilitating the transfer of research findings to user groups and is committed to close interaction with all key participants in the energy sector and the communication of relevant knowledge in an accessible form. The Centre provides a consultancy service and disseminates information to communities or organisations, enabling them to tap the expertise of the Centre and enabling EDRC to be more attuned to the needs of such groups. EDRC has hosted many visitors, including delegations from energy departments of Zambia, Lesotho, Zimbabwe and others from abroad.

Graduates from EDRC's Masters programme have begun professional work in the field of energy and development in an number of institutions ranging from the National Energy Council to non-governmental development organisations, or as private consultants. In addition good students have been drawn into research positions at EDRC. The bridging programme piloted at EDRC last year, attracted seven black trainees, most of whom have been offered jobs in the energy sector. In an effort to continue this contribution to the development of human resources for the energy sector, EDRC envisages a suite of training courses and programmes over the next 3 years: a Masters and Ph.D, a bridging programme, a specialist programme for civil servants and energy managers and shorter specialist courses for civics, unions, non-governmental organisations.

EDRC has developed a strategic plan which clarifies its goals and established clear priorities and programmes. This proposal seeks support for two aspects of this plan (a) training and (b) staff development/ affirmative action.

EDRC receives no money from the university and is entirely reliant on research and training grants from off-campus constituencies.

(1994)

E DRAWINGS

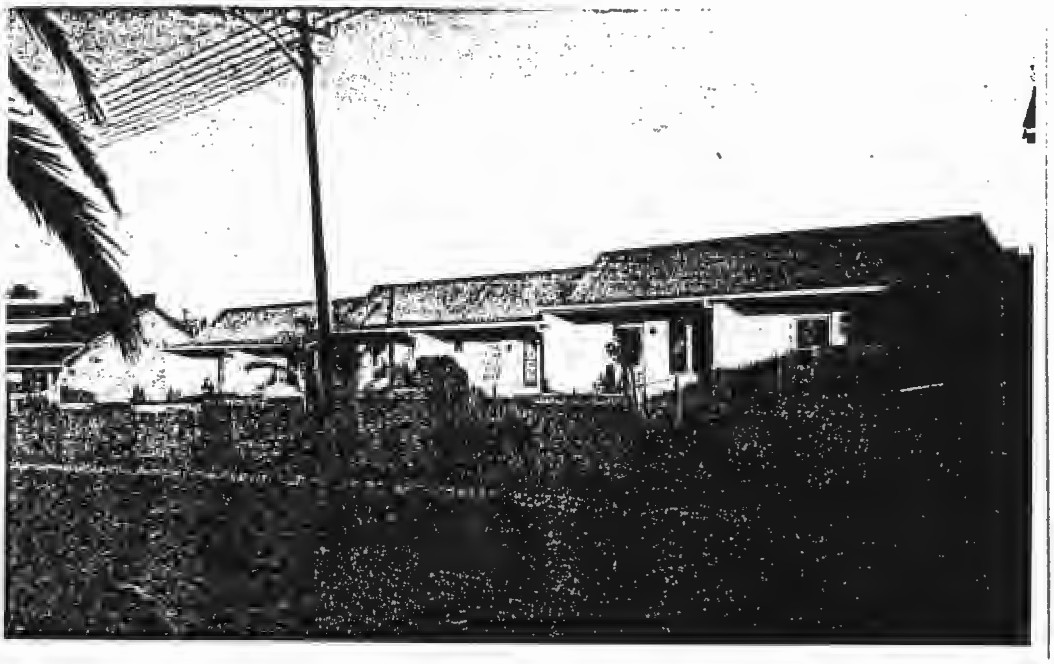
Project: Devon Street, Cape Town	scale	date
Construction Drawing- Roof plan	1:50	Sept. 1994
Construction Drawing elevation section	1:50	Aug. 1994
Construction Drawing elevation section	1:50	Aug. 1994
Construction Drawing - plan	1:50	Aug. 1994

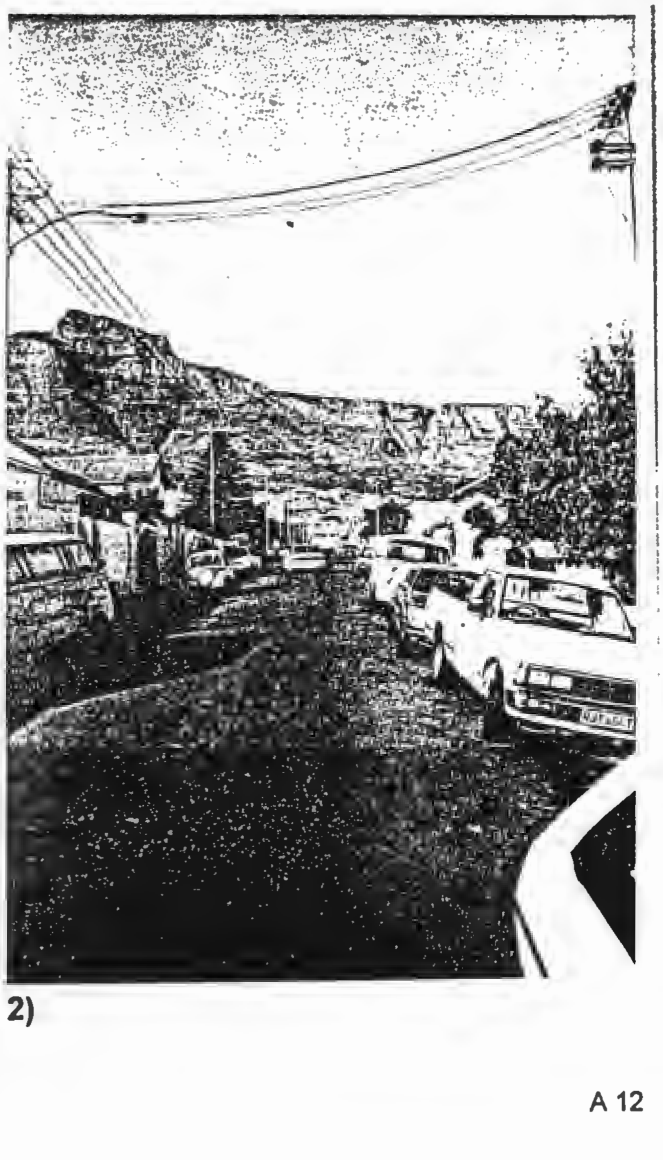
Copyright © 1994 by Beynham and Théron
(the drawings are not in scale but photo reduced by 50 %).

F PHOTOGRAPHS

Nr.	date	title
1)	10.3.95	West view of six row houses in Devon Street, Cape Town
2)	10.3.95	South West view of Devon Street
3)	10.3.95	North East view of Devon Street
4)	12.3.95	North West view of two houses
5)	12.3.95	North view of six row houses
6)	12.3.95	East view of six row houses

1)





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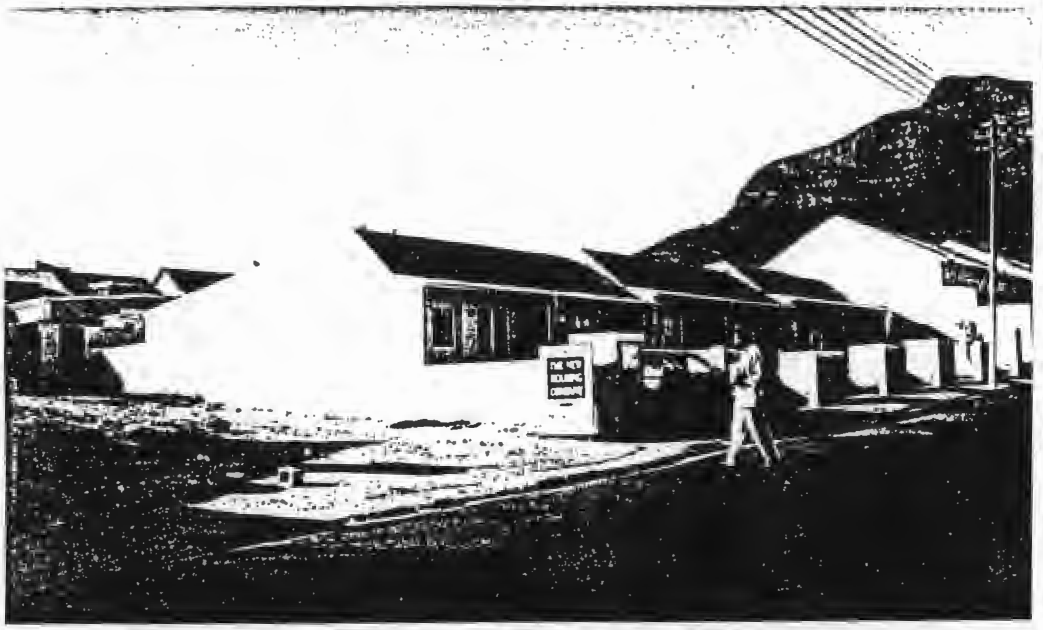

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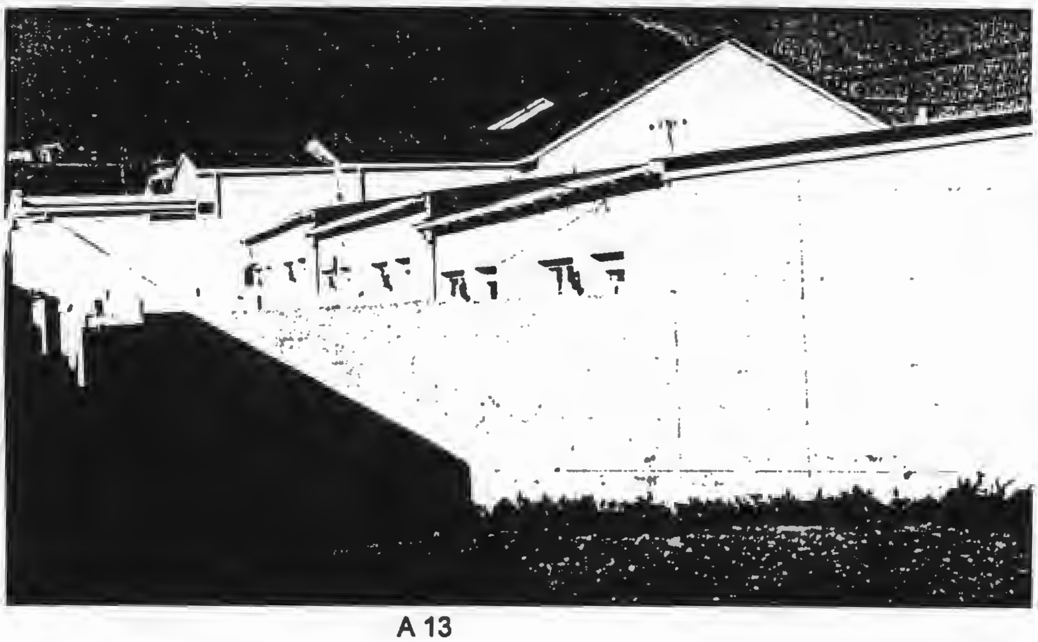


Present worth of fuel costs savings

inflation rate in %	i =	10
saving fuel costs for 1 st. year in Rand	C saving =	160
years of calculation	N =	20
interest rate in %	d =	20
energy saving investment in R	I =	308
present worth factor	8.25	
payback period [years]	2.5	
interest rate for Eskom	i, eskom=	7
factor (1+d)/(1+i)		1.09

years	Fuel savings	total PW of cost saving	cost saving	factor 1/PWF	annuität	present worth factor (N,i,
1.00	160.04	133.37	(174.63)	1.20	369.60	0.8
2.00	176.04	255.62	(52.38)	0.63	192.83	1.6
3.00	193.65	367.69	59.69	0.44	134.06	2.3
4.00	213.01	470.41	162.41	0.34	104.79	2.9
5.00	234.32	564.58	256.58	0.28	87.31	3.5
6.00	257.75	650.90	342.90	0.25	75.73	4.0
7.00	283.52	730.02	422.02	0.22	67.52	4.5
8.00	311.87	802.56	494.56	0.20	61.42	5.0
9.00	343.06	869.04	561.04	0.18	56.72	5.4
10.00	377.37	929.99	621.99	0.17	53.00	5.8
11.00	415.10	985.86	677.86	0.16	50.00	6.1
12.00	456.61	1,037.07	729.07	0.15	47.53	6.4
13.00	502.28	1,084.02	776.02	0.15	45.47	6.7
14.00	552.50	1,127.05	819.05	0.14	43.74	7.0
15.00	607.75	1,166.49	858.49	0.14	42.26	7.2
16.00	668.53	1,202.65	894.65	0.13	40.99	7.5
17.00	735.38	1,235.80	927.80	0.13	39.89	7.7
18.00	808.92	1,266.18	958.18	0.13	38.93	7.9
19.00	889.81	1,294.04	986.04	0.12	38.09	8.0
20.00	978.79	1,319.57	1,011.57	0.12	37.36	8.2

Input / output to economic evaluation

inflation rate	10	%
interest rate	20	%
energy saving investment	308	R
energy consumption	58.2	MJ/ m² a
house area	40	m²
improved energy consumtion	38.1	MJ/ m² a
improving factor: in %	35	%
years of calculation N =	20	a
increase of fuel price index	1.5	[-]
peak demand saved:	1	kW

Fuel	percentage of use in %
Electricity	10
Coal	10
Paraffin	20
Anthracite	20
Gas	20
Wood	20

ESKOM Input data

electricity generation price	11	c/kWh
investment cost for 1 kW in R,	5000	
availability factor	0.8	
real investment costs for 1 kW	**6250**	**R**
electricity net income per kWh	0.038	R/kWh

benefit cost rate 2.0

Output of calculation

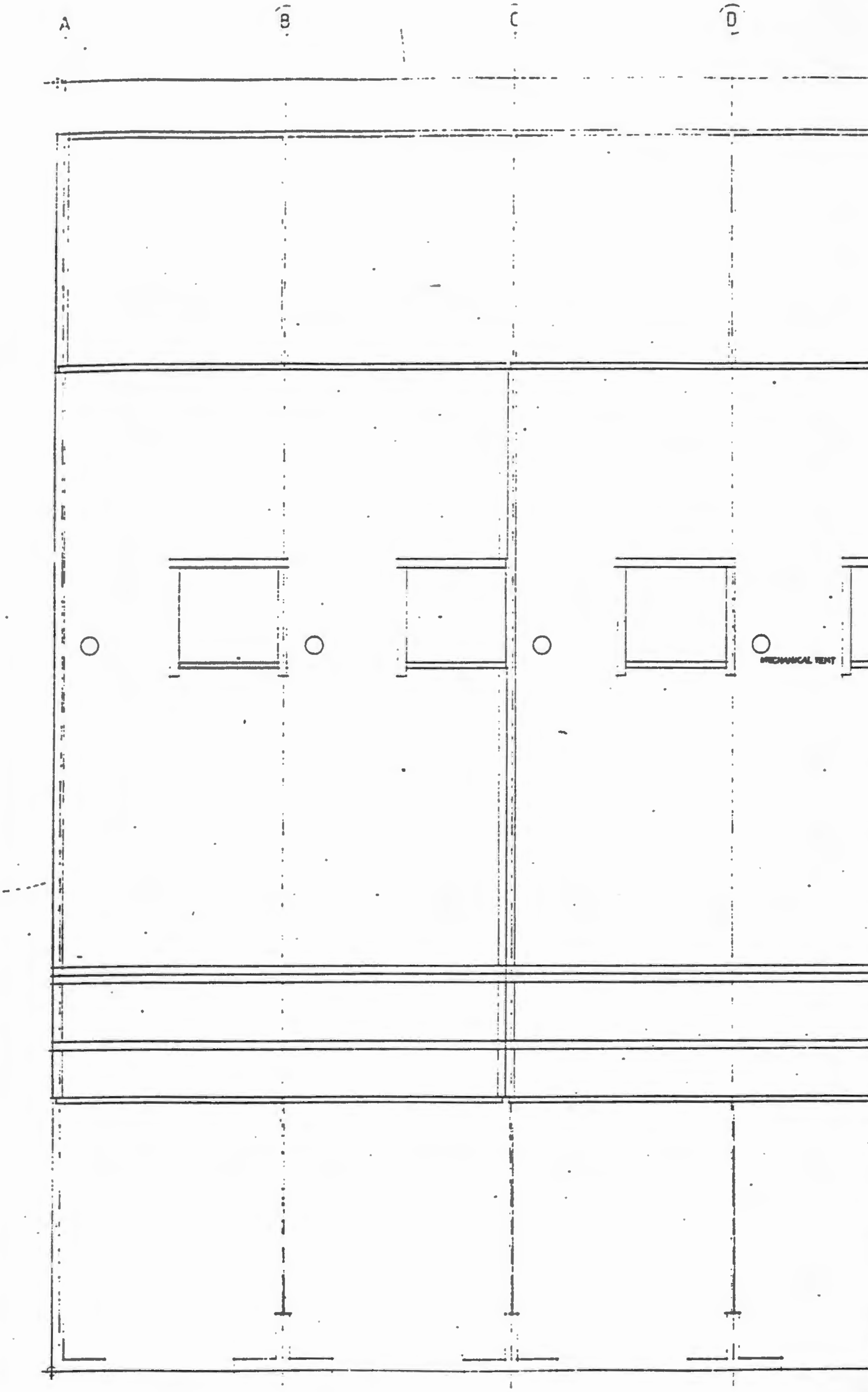
payback time PT	**6.0**	**years**
total energy costs in R	**218**	**R**
difference in R	**75**	**R**

fuel saving benefit

after 10 years	130	R
after 20 years	314	R
capital costs of investment per year	**37**	R/ a

Energy and fuel costs

Fuel	spec. energy	Price	Cost	
	MJ/ kg	[R/ kg]	[c/ kWh]	percentage of use in %
Electricity	-	-	14.80	10.00
Coal	23.60	0.20	12.90	10.00
Paraffin	46.70	1.66	21.00	20.00
Anthracite	31.70	0.48	41.10	20.00
Gas	49.10	3.12	30.20	0.00
Wood	18.10	0.50	36.60	20.00
average			22.51	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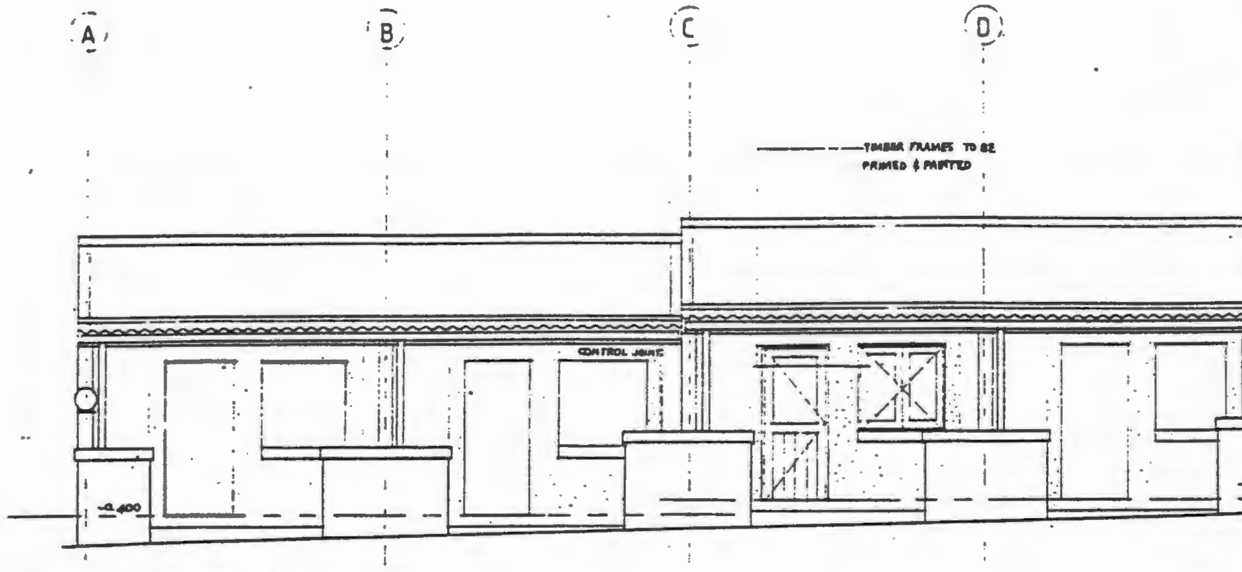
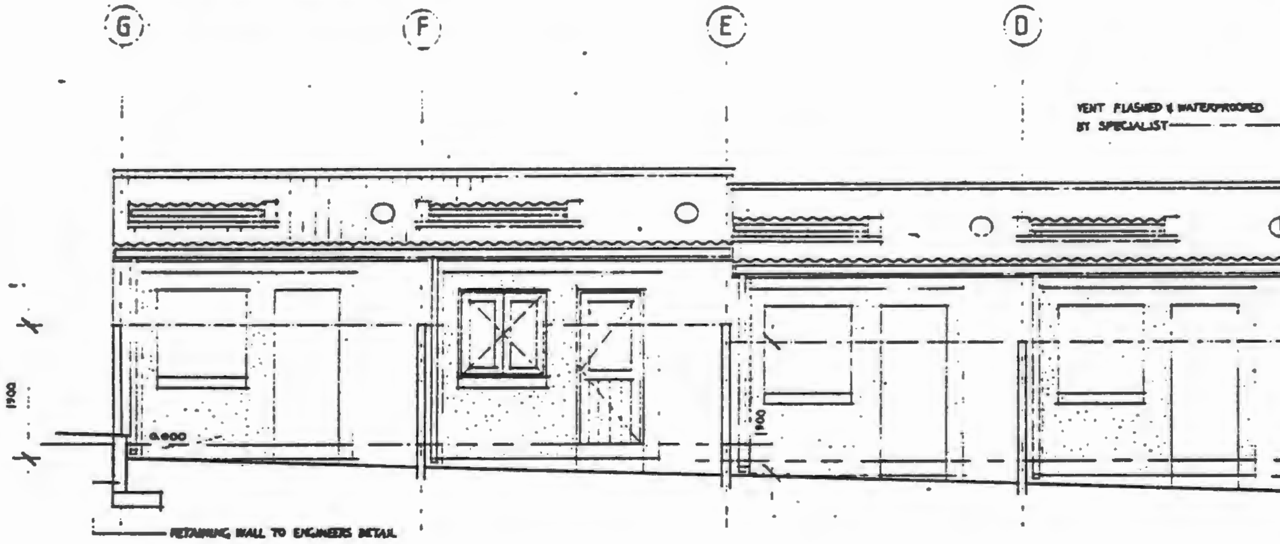
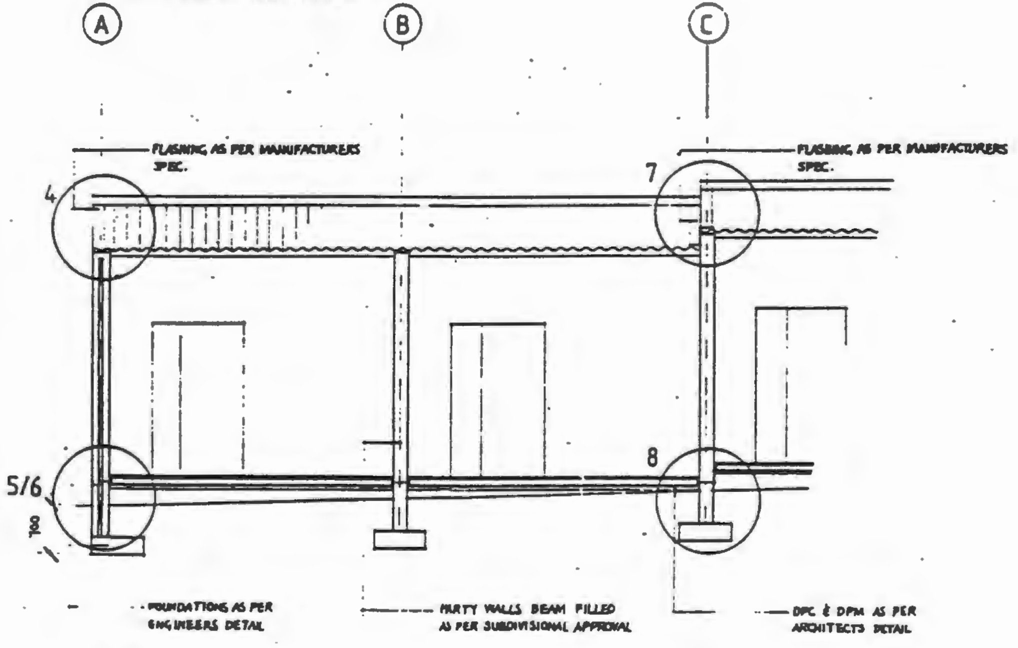


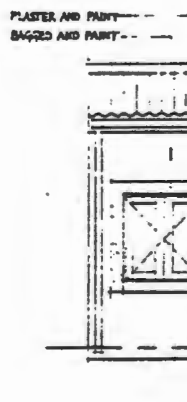
DEVON STREET ELEVATION



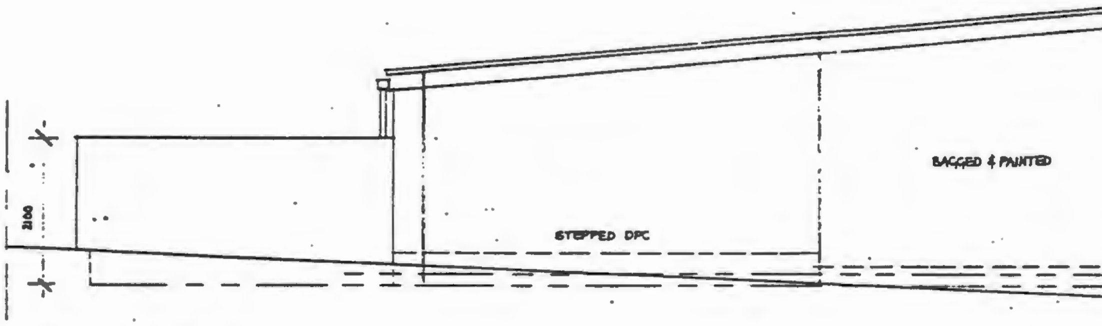
SOUTH EAST ELEVATION



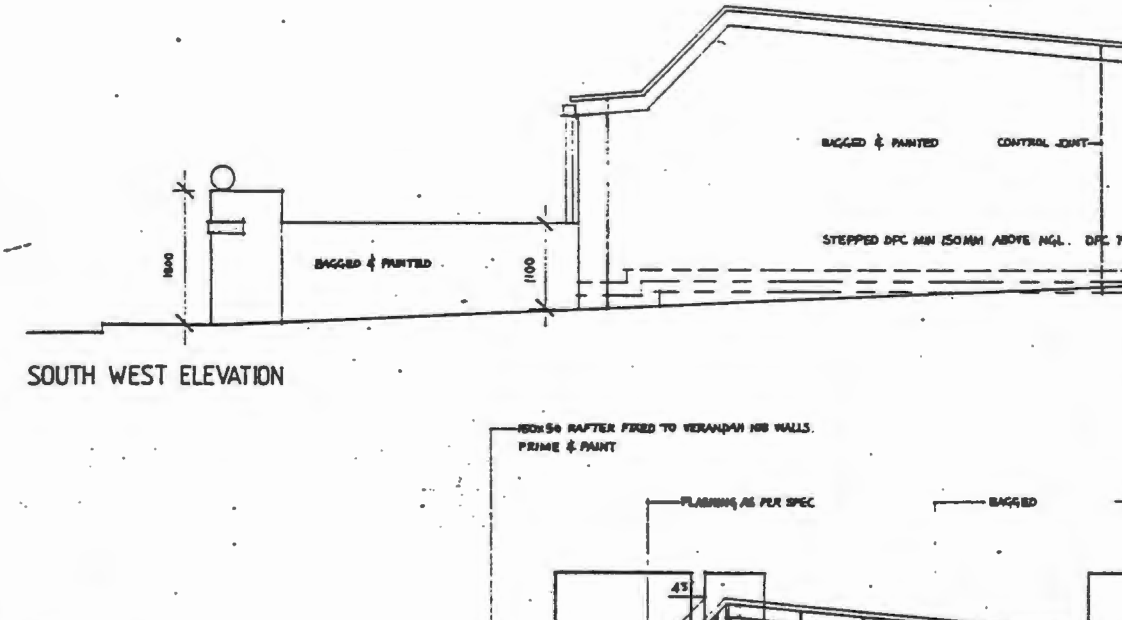
SECTION AA



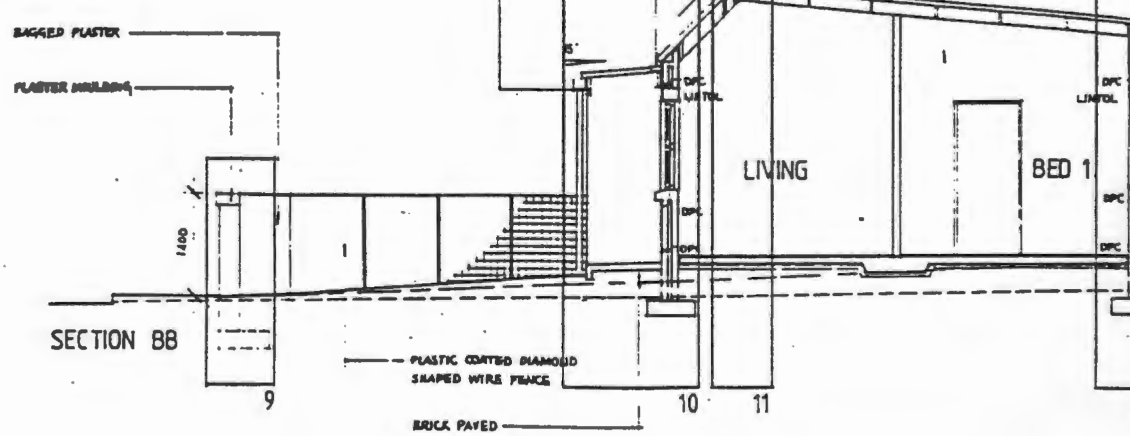
SOUTH EA
COURT



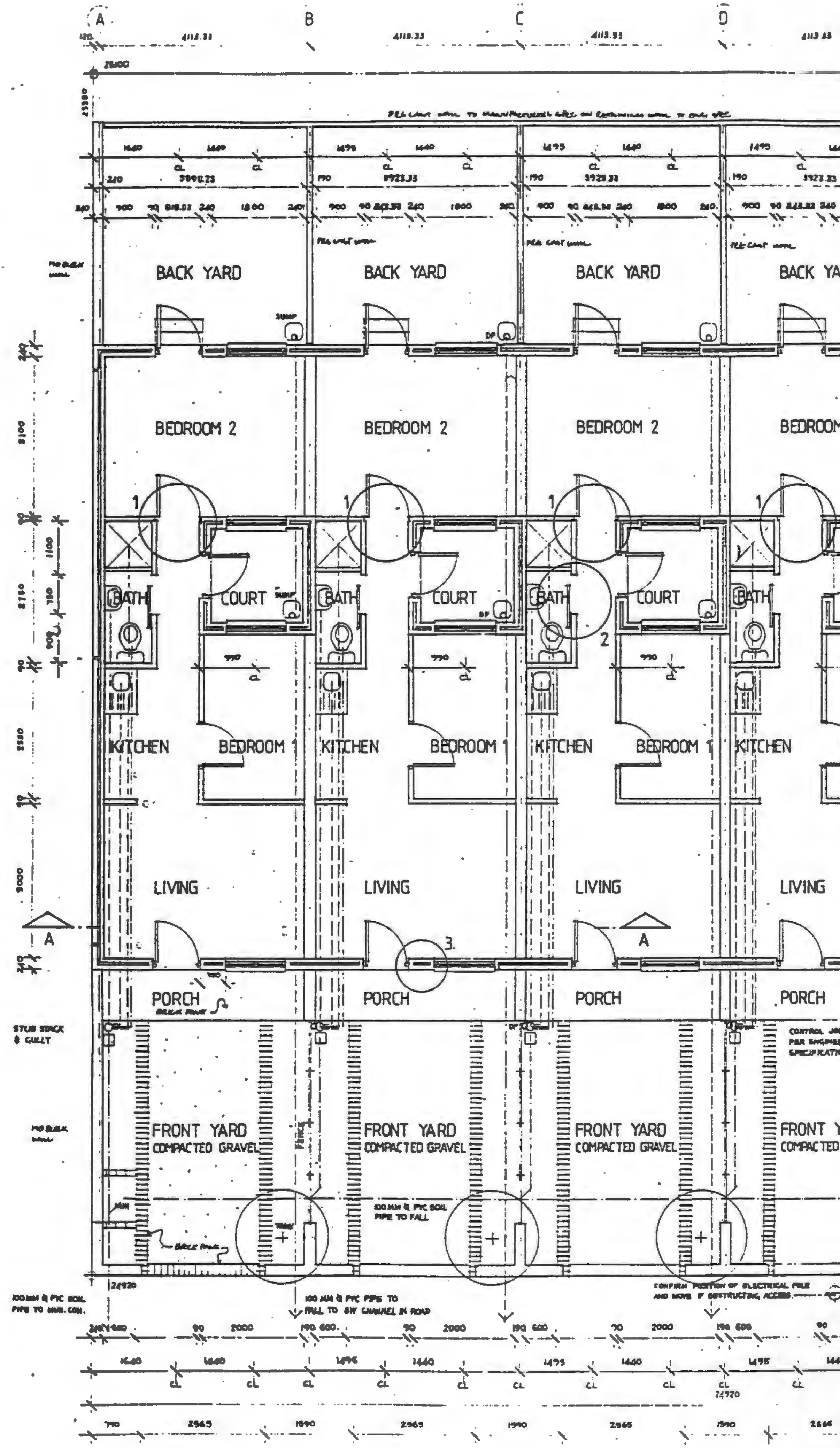
NORTH EAST ELEVATION



SOUTH WEST ELEVATION



SECTION BB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100 MM Ø PVC PIPE TO FALL TO SW CHANNEL IN ROAD
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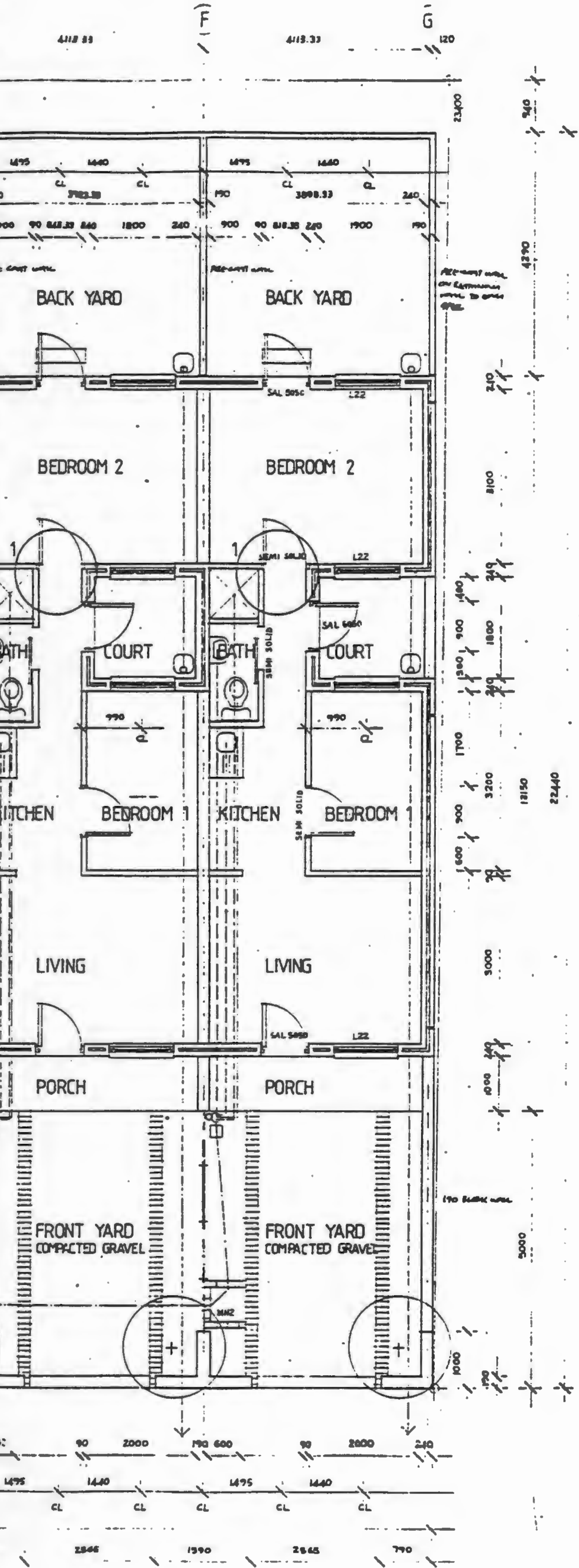

NOTES

1. BEFORE COMMENCEMENT OF WORK, THE CONTRACTOR
THE ARCHITECT, IN WRITING, OF ANY DISCREPANCIES IN
OR SPECIFICATIONS AND SHALL NOT INFRINGE OR BRE
LAW BY COMMENCING WITH THE WORK PRIOR TO NO
BY THE ARCHITECT.
2. DO NOT SCALE, USE FIGURED DIMENSIONS ONLY.
3. ALL HEIGHTS PERTAINING TO DRAINAGE TO BE C
SITE PRIOR TO LAYING OF PIPES.
4. CONTROL JOINTS [illegible]

NEWHCO WEST CAPE

DEVON STREET

1770

DEVON STREET
WOODSTOCK

17 AUGUST 1994

BAYNHAM T

CONSTRUCTION DWG - PLAN

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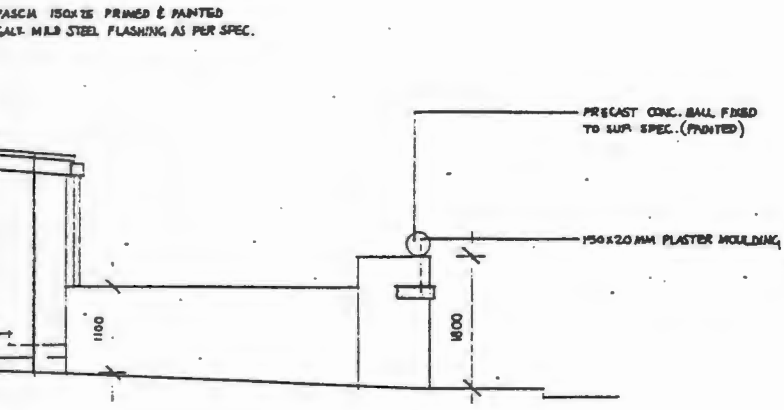

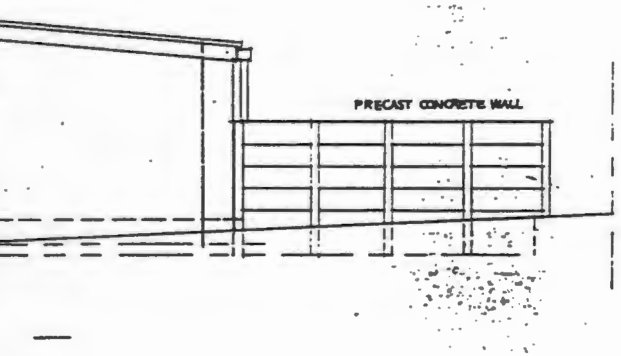

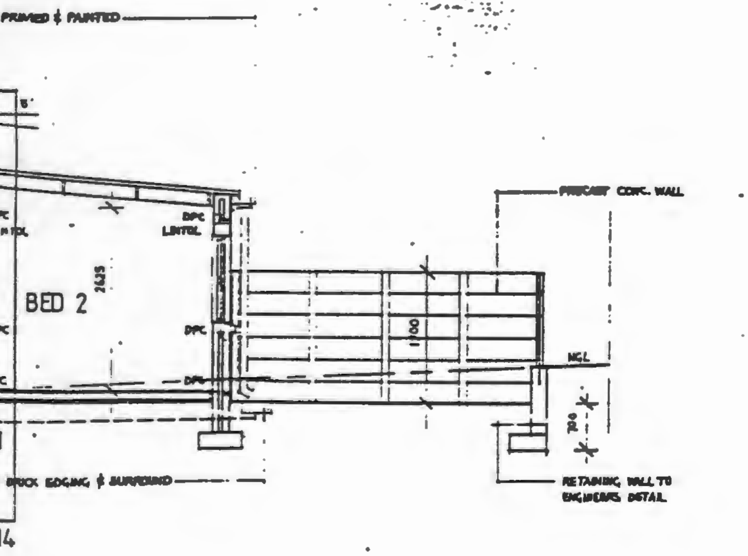

NOTES

REFER NOTES ON CONSTR. DWG. 02 01

THE NEW HOUSING COMPANY

NEWHCO-WEST CAPE

DEVON STREET

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DEVON STREET
WOODSTOCK

17 AUGUST 1994

BAYNHAM THÉRON

CONSTR. DWG ELEVATIONS SECTION

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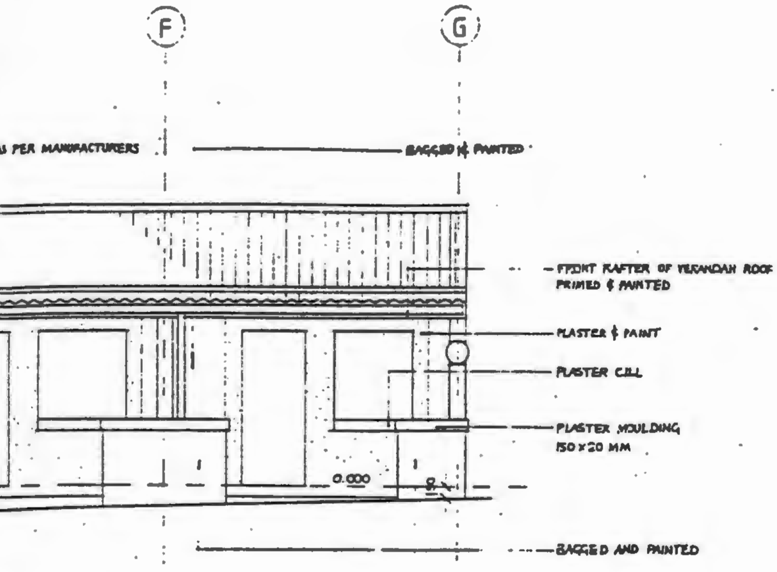
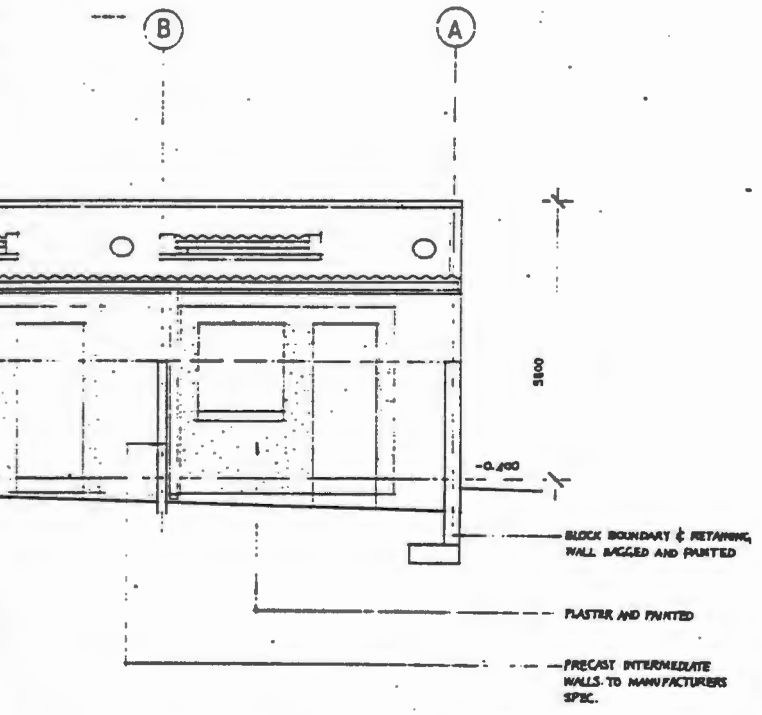
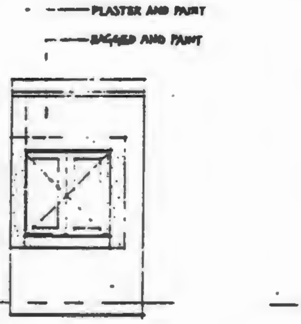
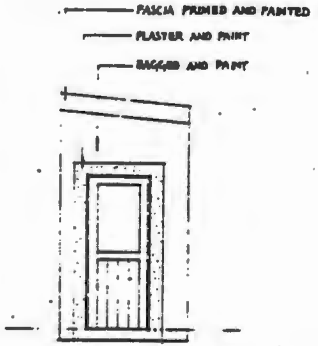
02







NORTH WEST ELEVATION
COURT



SOUTH WEST ELEVATION
COURT

NOTES

REFER NOTES ON CONSTRUCTION DWG 01 01
WEEPHOLES IN CAVITY WALLS AT 600 MM C.C ABOVE DPC.
ENSURE CAVITIES ARE CLEAN.

THE NEW HOUSING COMPANY

NEWHCO WEST CAPE

DEVON STREET

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DEVON STREET
WOODSTOCK

17 AUGUST 1994

BAYNHAM THÉRON

CONSTR. DWG ELEVATIONS SECTION

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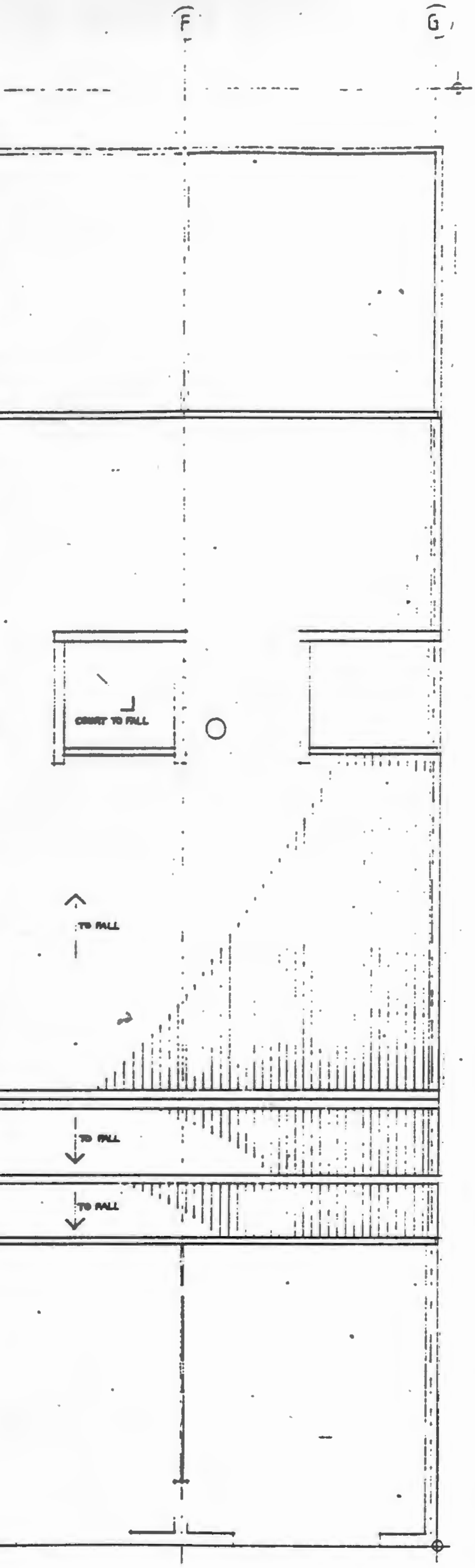

NOTES

REFER NOTES ON CONSTRUCTION DWG 01-01

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NEWHCO WEST-CAPE

DEVON STREET

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DEVON STREET
WOODSTOCK

17 AUGUST 1994

BAYNHAM THÉRON

CONSTRUCTION DWG-ROOF PLAN

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02