THERMAL EFFICIENT DWELLING DESIGN: BALI, INDONESIA

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Ciptadi Trimarianto

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(CARDO)

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University of Newcastle upon Tyne

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PREFACE

In the name of Allah (God),
The most gracious and the most merciful.

A thesis dedicated to;
my honourable **Parents,**

my beloved wife,
Kenny Suaraningsih,

my lovely sons,
Rakhmadhanyta Mariantisna,
Rahmantogusnyta Mariantisna.

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THERMAL EFFICIENT DWELLING DESIGN: BALI, INDONESIA

ABSTRACT

In the warm humid tropical climate of Bali, Indonesia, overheating and high humidity influence occupants' comfort, indoor climate and the comfort of their homes, both directly and indirectly. The traditional way to deal with these problems, using natural ventilation, was ecologically sound and acceptable.

However, development of tourism in Bali has had a positive impact on people's earning, causing cultural pressure, migration and a rapid rise in the urban population, as well as increasing housing demand. In urban areas, the methods of climate modification have moved away from natural ventilation, and comfort is now more often achieved by installing air conditioning. This has caused increasing energy use and had economic impact. As world-wide energy consumption will continue to increase, the use of more energy will have more impact on global warming. In these circumstances, energy efficiency is paramount, particularly in the dwelling designs for new housing development in Indonesia.

The study focuses on the design of a thermally comfortable dwelling in the warm humid climate of Bali, Indonesia, with emphasis on the energy efficiency of the naturally ventilated and air-conditioned dwelling.

Using a computer program and energy conservation strategies, a dwelling design was simulated. A model dwelling was adopted from a standard house type for people on a middle class income, based on the family size of a couple with two children. Such units are built by the National Housing Authority of Indonesia. A comprehensive study of the computer-simulation outcomes, survey research, previous works undertaken and literature reviews were carried out, to develop a thermally comfortable dwelling design. This new thermally efficient dwelling design was simulated to draw the final conclusions of the research.

The research discovered that the combination of both natural ventilation and air conditioning, integrated with the combined design of a compound-compact dwelling, are an intelligent response to the thermal comfort performance problems of a dwelling in the warm humid climate and architecturally adaptable to the culture of Bali. The study found that a combination of natural ventilation with air conditioning which is only used when necessary, coupled with insulation and shading devices, can significantly reduce energy consumption and achieve adequate thermal comfort.

In this respect, however, architectural design should come first, and be considered before an engineering solution. The reasons are that architectural solutions are more robust, and has a long duration of applicability, while the technology is perhaps the opposite, being prone to mechanical failure. When a less compact dwelling is designed, increased use of natural ventilation can be achieved. The use of airtight construction, insulation in the building envelope and shading devices are effective ways of reducing the air-conditioning load.

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Chapter One

INTRODUCTION

1.1. BACKGROUND

Within Indonesia (Figure 1.1), Bali is an attraction for people from other parts of the Indonesian archipelago, and visitors from all over the world. Their impact on Bali is both economic and environmental. Indonesians come to this region, to service the tourist industry and earn higher incomes than elsewhere. The influx also puts pressures on culture, urban development and increases the demand for accommodation. Since the national policy stated that equal distribution of the housing development in Indonesia should be applied, Bali can expect more consideration in this respect. This development needs to reflect the architectural background of Balinese dwellings, whilst considering culture sustainability, land availability, climate and energy consumption. The accommodation that forms this development needs to learn lessons from Bali's traditional dwelling pattern, which respects the culture and climate of Bali.

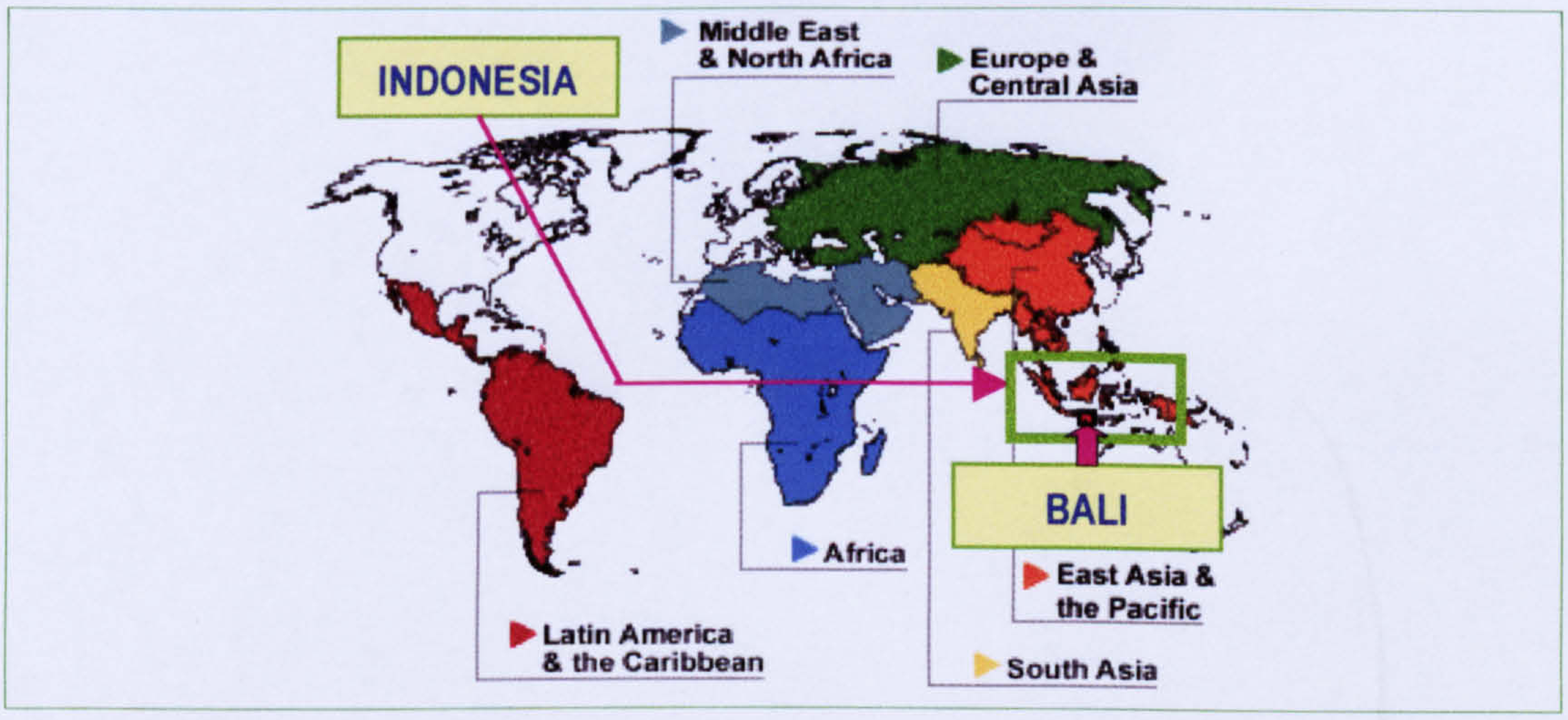

Figure 1.1. Indonesia in the World
Source: http://www.lib.utexas.edu/

However, indoor climate of dwellings in the warm humid climate of Bali is not easy to handle, especially in compact dwellings built in an urban area, with high density and limited land availability; a mechanical solution is an easy practical way to achieve comfort, but at the same time high energy consumption is created.

To achieve thermally comfortable conditions in these compact dwellings requires air conditioning.

However to achieve energy efficiency, cross ventilation is necessary.

These two strategies conflict with each other, therefore a combination design incorporating both strategies is required.

1.1.1. Indonesia

The island of Bali is one of the most important elements in the development of Indonesia as a whole. It is important to give a brief general introduction of facts about Indonesia that may have impact on the design development of dwellings in Bali.

1.1.1.1. Geography

Geographically Indonesia, where the small island of Bali is located, has a total area of about 2 million Km^2 (736,000 m^2) and oceanic area around 7,900,000 Km^2 (Figure 1.2).

Figure 1.2. Indonesia
Source: http://www.lib.utexas.edu/

This is the world's most expansive archipelago, stretching almost 5,000 Km from East to West and stretching North and South of the equator for a total of 1,800 Km.

The capital city of Indonesia is Jakarta. The country has both large and small islands that are located in a beautiful harmony of coastal plains and mountains.

Bali, with its capital city Denpasar is the most beautiful island in Indonesia. Sustainable development applied to the dwelling design in this region would help to maintain the beautiful island of Bali.

1.1.1.2. Climate

Straddling the equator, Indonesia including Bali has a warm humid climate all year round. The only two seasons which can be distinguished are the wet and dry seasons. The wet season falls between October and April, and the dry season occurs between May and September.

With the warm humid climate, the temperature throughout the year averages between 22° to 30°C with a high humidity which averages about 75%. The North coastal plains are usually hottest, up to 34 °C during the day in the dry season. The South coast is cooler than the North coast, and it is even cooler in the mountainous Highlands. The sun rises at 05.00 a.m. and sets at 06.00 p.m. Precipitation is of course most common during the wet season and shows an average of over 4,000 mm (160 inches) of rain a year on the highlands, while the North-East coastal tip has a rainfall of only 900 mm (35 inches).

This climate characters affects dwelling design and energy conservation strategies.

1.1.1.3. People

The Indonesian population is approximately 206.6 million with an annual growth rate of 1.68%, approximately 3.5 million per annum. The government has a family planning programme, in that a couple is recommended to have no more than two children. Religions of the population are mostly Islam with 87%, Christian 9%, Hindu 3% (e.g. most of the Hindu people live in Bali), and Buddhist 1%. Education is compulsory for 9 years with enrolment comprising 92% of eligible primary school-age children. Agriculture employs approximately 50% of the workforce, service industries around 30% and manufacturing about 20% (Indonesia Central Bureau of Statistics, 2001).

The family size recommended above is the most important point in relation to the dwelling design in Bali.

1.1.1.4. Economic

The gross domestic product (GDP) in 1995 was US$ 197.8 billion, with an annual growth rate of 7.5%. Income per head of population was US$ 1,013. Natural resources (8.4% of GDP) are: oil and gas, bauxite, silver, tin, copper, gold and coal. Agriculture (17.2% of GDP): products include timber, rubber, rice, palm oil, and coffee. Manufacturing (24.3% of GDP): garments, footwear, electronic goods, furniture and paper products. Trade: exports amount to US$ 45.4 billion including oil, natural gas, plywood and manufactured goods (Indonesia Central Bureau of Statistics, 2001).

The recent economic crisis in Indonesia has caused a rethink of how national resources are going to be developed in future.

However, the economic situation in Bali is better than in other parts of Indonesia, and foreign exchange earnings help local government to sort out the financial problems of housing development and other such sector industries.

1.1.1.5. Urbanisation

Indonesia's urban areas have expanded considerably. The process of rapid urbanisation started in the early 1970s. In the past 20 years, the urban population has increased 2.5 times, from 22.6 million in 1970 to 32.8 million in 1980, to 55.4 million in 1990. Indonesia's urban population was estimated at 28 percent in 1995. To put this into perspective, with an annual urban growth rate of 4 percent, the country's urban population will comprise 48 percent of the entire population of the country by the year 2000 (World Bank, 1995).

Bali has one of the largest urban areas within Indonesia. Along with its growing prosperity, this rapid urbanisation coupled with rapid migration to Bali has consequences for the local housing authority which is responsible for providing accommodation.

1.1.1.6. Tourism

Indonesia, and especially Bali was keen to expand the number of tourist visitors from the year 2000, and the government determined to promote the 'Visit Indonesia Decade' (Turner et.al. 1995).

Tourist revenues are expected to generate international exchange earnings of approximately US$ 8.9 billion, approximately 5% of GDP.

In 2001, domestic tourism increased by 1.6% per year, while international tourists increased by 1.8% to 5.4 million and foreign exchange earnings totalled US$ 5.3 billion (Ministry of Culture and Tourism of Indonesia, 2001).

Global development carries an international style into the traditional culture of Bali, and makes a widening economic development to the region and the country.

There are many advantages from wealth generated by international tourism. Indonesia, especially Bali, can expect some of this investment.

Bali is one Indonesia's main assets, and tourism development has increased the income of local people, increased migration, increased urbanisation, and increased demand for accommodation.

1.1.2. Bali

As part of Indonesia, Bali (Figure 1.3) can be categorised as a densely populated island that has an area of 5,620 square Km, measuring approximately 140 Km East-West by 80 Km North-South and lying just 8 degrees south of the equator. Denpasar is the regional capital city (Fast Doc Database, 1997).

Regarding climate, the hottest months of the year in Bali are generally between November and March, with an average temperature around 30°C (86°F) and the coolest months of the year are generally June, July, August and September with average temperature around 28°C (82°F). That is much like its near neighbour Java.

This characteristic warm humid climate is one of the important points to be considered in achieving comfort performance in the dwellings of Bali.

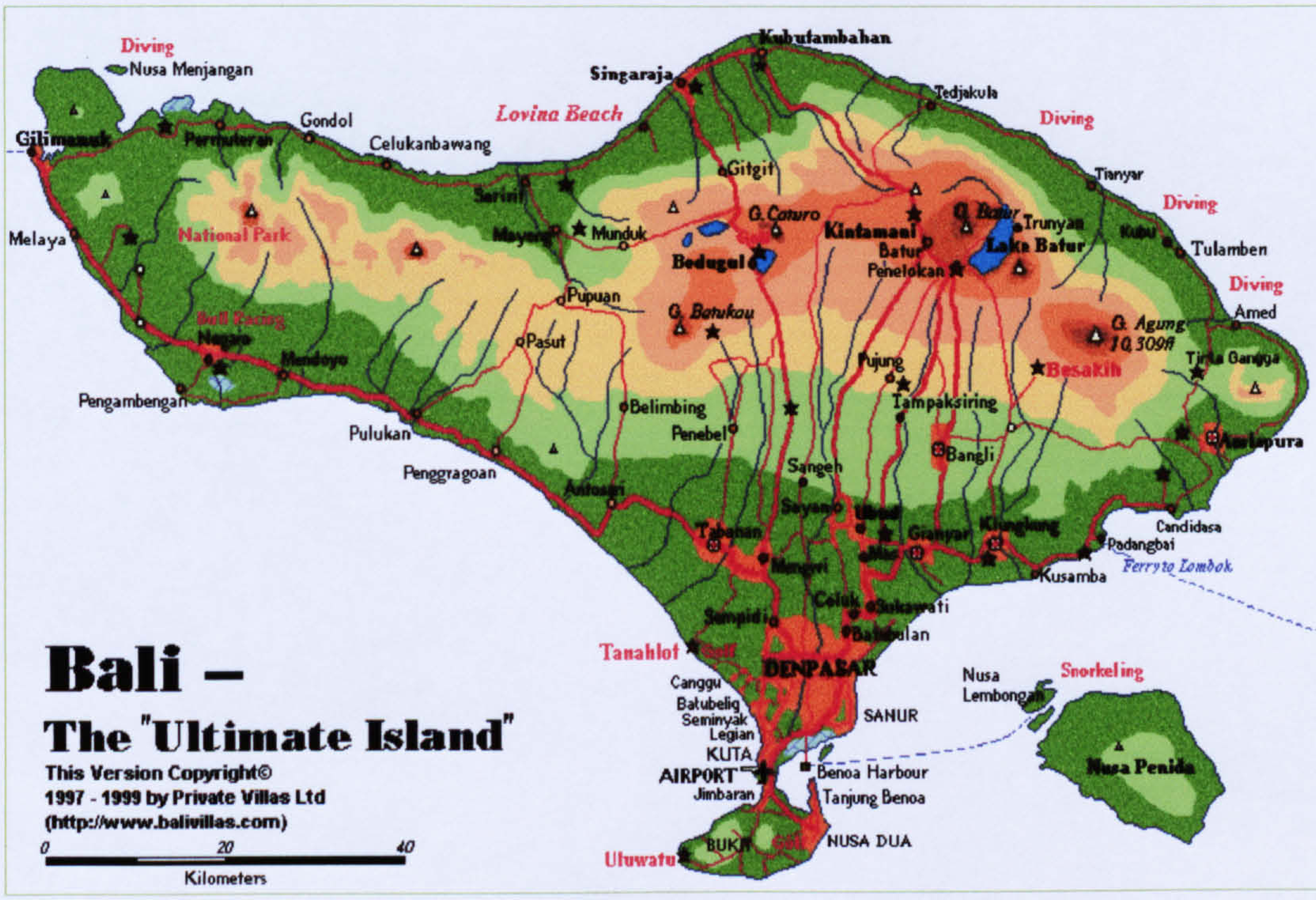

Figure 1.3. **Bali**
Source: http://www.balivillas.com/map.html

Bali is divided into 8 district regencies. Badung in the South is the most densely populated district and located with in it is Denpasar, the provincial capital city with a population of around 1,000,000. Image of Bali can be described:

> *"The countryside paints a rich tapestry of colours and textures, with a contrast between verdant rice terraces and volcanoes; white-sand beaches and tropical rain forests; peanut and palm fields; ancient temples, traditional dwellings and village factories where artisans hammer, carve, cut, colour and weave local materials into handicrafts fit for sale to visitors."*
>
> Bali Paradise, 1997.

This beautiful nature and architecture help visitors to enjoy holidays in Bali, and the people have risen to the challenge offered by tourism.

Bali's 4.5 million population is spread through the regencies that take their names as well as their boundaries from the island's old Hindu kingdoms. The resident population is almost entirely Indonesian, plus a number of more permanent visitors amongst the international tourists in Bali (Bali Statistic Bureau, 2001).

The uniqueness of Bali is that traditional Hindu ceremonies take place among the daily life activities of the Balinese people. These are interesting and attractive to other Indonesians and tourists, giving another added value to this island.

However, despite those advantages above, there are other points that have to be considered in such urbanisation. In the migration of people to Bali, the majority come from other islands of Indonesia but some come from another countries.

This influx into Bali has increased demand for accommodation, especially within urban regions. This accommodation must be designed to meet the particular requirement of Bali.

To protect the essential beauty of Bali, government regulations do not allow buildings to be higher than four storeys, and horizontal development may also be restricted.

As has been previously described, tourism has played an essential role in the Balinese economy. In other words, given the economic influence of tourism, the impact of development on the environment of Bali is unavoidable.

1.1.3. Housing Issues in Indonesia

As in other developing countries, housing is a problem in Indonesia. Presently it is experiencing a large urbanisation drive, and houses must be built to alleviate the problem. Bali has not only the urbanisation drive but also migration forces, because of the economic impact of tourism. Currently, most of the houses being erected could be described as a standard compact house for middle class incomes, which do not demonstrate any cultural respect, accommodating the couple with two children which is based on the national family planning policy of Indonesia.

1.1.3.1. Housing Programmes

The aim of housing development in Indonesia is to meet the needs of the population for shelter, not only in terms of quantity but also quality, in order to provide a healthy environment.

The objectives of housing development in Indonesia are:

- *"Better planning and distribution of housing and infrastructure, with affordable quality and basic services.*
- *More efficient and effective management of housing development, to be sustainable and supportive of the environment; improved community participation, including co-operatives and the private sector.*
- *Improved business and employment opportunities in industries that support housing development.*
- *The creation of proper housing and its environment, that are clean, healthy, secure and provided with all necessary facilities.*
- *The policy adopted is the development of affordable housing for the community on a large scale, as well as the development of housing that is responsive to the environment and sustainable.*
- *The design of housing to take account of spatial planning and interrelationships as well as the integrity of the cultural environment."*

Department of Information of Indonesia, 1996.

These statements indicate that to be part of a housing development in Indonesia, a dwelling needs to respect the integrity of the cultural environment, be affordable, be efficient, be achieve a standard of quality and be responsive to the sustainable environment.

1.1.3.2. Housing Needs

Comprehensive and rapid development in urban areas has caused people to migrate from rural to urban areas.

The phenomenon was shown in that during 1985, the composition of the population was 26% urban and 74% rural while by the year 2000, it was 48% urban and 52% rural (Department of Public Housing of Indonesia, 1996).

Those figures indicate an increasing demand for urban housing. Because of this urbanisation and the migration drive, Bali needs more new dwellings than other parts of Indonesia.

According to a survey of domestic expenditure in urban Indonesia in 1989, 40% of the population can be classified as having a low income, 40% as middle income, and 20% as high income.

The middle urban population can be classified as 50% low-middle income and 50% high-middle income. Most of the urban population (80%) belongs to low and middle income groups (Indonesia National Housing, 1996).

This indicates that the housing need for middle class income groups in Bali is very important when considered as part of the overall housing development of Indonesia.

1.1.3.3. Housing Policy

Development of housing that is affordable for most people, sustainable and environmentally oriented is desirable.

Support is provided by giving access to bank facilities, with the establishment of housing ownership credit through the State Savings Bank (BTN) to help people obtain basic standard and medium-quality houses.

Legal support is the development of ready-built areas and ready-built environments within the framework of urban renewal projects, as well as legal support for the occupancy of apartments and condominiums (Department of Public Works of Indonesia, 1996).

Housing policy support research, and development of appropriate technology for housing and building as well as the development of local materials are essential for reducing costs. These housing policies recommend that in this context, the dwelling design in Bali should be affordable for the most people, and demonstrate respect for the natural environment and materials available locally for sustainability.

1.1.3.4. Housing Development

The programme is developing approximately 500,000 standard houses, allocating the construction to National Housing Corporation (225,000 units), Real Estate Indonesia (REI) (250,000 units) and co-operatives (25,000 units).

In the past period 1995 to 1999's development, low-cost walk-up flats and rental houses were also built 12,000 flats/maisonettes by private developers, in the development of reasonable houses of medium and high quality.

While national housing developments are equally distributed throughout the whole country, Bali as one of the primary islands contributing significantly to the tourist Gross Domestic Product (GDP), needs special consideration on housing development for people migration to Bali.

Housing improvement programs consist of urban housing refurbishment and rural housing renewal programs (World Bank, 1995).

Indonesian cities are changing rapidly and some housing is on potentially valuable urban real estate. The rising demand for prime land and for urban land in a rapidly growing economy is driving housing into the modern market place. The redevelopment of settlement land into commercial and up-market residential real estate is becoming increasingly common. This is placing additional pressure on urban development.

1.1.3.5. Institutional Housing Development

The National Housing Corporation (PERUMNAS) is a government enterprise, established under the Ministry of Public Works. Real Estate Indonesia is an association of professional organisations of developers. The State Savings Bank (BTN) appointed by the Government, and the non-bank financial institutions organise funding for housing construction, as well as providing housing ownership credit for the public.

1.1.3.6. Standard Housing Development

According to the Ministry of State for Housing, a standard house is a detached, single-storey building with a floor area of 36 m^2 (Type-36).

This is built on the area of not less than 60 m^2, up to 200 m^2. The standard price construction for the house should be around 500,000 rupiah (US$ 60) per m^2.

In this research the standard house, especially the standard dwelling Type-36, is adopted to accommodate the standard family in Bali, two adults with two children.

The reasons are based on the following considerations:

- The dwelling is affordable for most people, who generally have middle-class incomes.
- The dwelling can be made affordable for those people with less than middle-class incomes, by providing loans.
- The dwelling will encourage people with higher incomes, including tourists who live permanently in Bali, to make adaptations to this standard dwelling rather than build more luxurious accommodation.

1.1.3.7. Balinese Real Estate Development

Recently, tourism has had impact upon real estate development, and many people see their dwelling as a promising investment. The owner can use the property as private accommodation and let it during the holiday season, to visitors organised by a professional agency. This will support housing development, and impacts on the dwelling design.

While this study focuses on Bali, with respect to each local culture and environment, the ideas and designs to be put forward are applicable to development throughout Indonesia. This is one reason for the selection of Bali.

1.1.4. Economic Environment

1.1.4.1. The Indonesian Economy

This section will discuss the economic situation in Indonesia regarding greater international investment, and a warning about the energy demand which for Bali, is an integral factor concerning this investment.

Indonesia has a free-market economy that is dominated by the private sector.

However, the government still plays a significant role in the economy through state-owned firms and the imposition of price controls on selected industries.

According to the Fast Doc Database (1997):

- Indonesia's international debt in 1995 was about US$ 95 billion, of which approximately US$ 65 billion was official. In 1997, an international financial institution adjustment implemented a broad range of liberalisation for international trade investment, allowing greater private sector participation.
- In 1993, the coal sector was opened to international investment and by the end of the decade coal production was in the range of 70-80 million tons. The state owns oil and mineral rights and international firms participate through sharing production and work. Including exports of 27 million tons, total coal production reached 41 million tons in 1996. The value of domestic investments grew 65% in 1995 to a total of US$ 31 billion, while international investment increased five-fold to a total of US$ 40 billion.
- The United States is the largest participant in the oil and gas industries. Japan has traditionally been the leader in terms of value of investment and remains the biggest international investor, followed by the United Kingdom as the second biggest investor. Others international investors include Singapore, Hong Kong, Taiwan and South Korea.
- Oil and gas constitutes about 10% of GDP, with output averaging 1.6 million barrels per day in 1995.

With domestic demand for petroleum fuels expanding, Indonesia will become a net importer of oil by the next decade unless new reserves are found.

It is clear that despite these investments, prosperous economic development needs to consider energy conservation. Furthermore keeping Bali beautiful, while generating economic revenue, is paramount. With economic investment, the need for standard accommodation will increase. This must not increase energy demand.

1.1.4.2. Recent Economic Situation of Indonesia

In recent times the economic situation has weaken, with impact on the country's industrial development, including the housing industry. Only the tourism sector being buoyant in Bali could relieve the country's economic suffering.

According to the Indonesia Central Bureau of Statistics (2001);

- Between July and August 1999 inflation declined by 0.93%. Annualised inflation during the month was 5.77%, compared to the government's 1999 inflation target of less than 6 %. Indonesia has continued to enjoy deflation since March 1999, after the economy suffered hyperinflation of more than 77% in 1998 when the economic crisis heightened.
- Housing prices had dropped by 0.11% in August 1998. Inflation for the first eight months of 1999 was 0.71%, while inflation for the first five months of the 1999/2000 fiscal year ending in March 2000 was minus 3.24%.
- Exports in July 1998 increased by 11.56% to US$ 3.97 billion from US$ 3.56 billion in June 1998, but exports in January-July 1999 were down by 12.09% to US$ 25.62 billion, compared to the year 1998.
- Non-oil and gas exports in July 1998 increased by 8.17% to US$ 3.26 billion from the previous month, but non-oil and gas exports in January-July declined by 13.43% from the same period in 1998. Imports in July 1998 rose by 3.63% to $1.96 billion from $1.89 billion in June 1998.
- Imports in the first seven months of the year 1999 were down by 14.28% to US$ 1.02 billion compared to the same period in 1998. The importation of consumption goods in the 1999 January-July period jumped by 36.04% to US$ 1.02 billion, from the 1998 January-July period.

However, the consumption of goods only contributed 8.87% to overall imports.

The largest contributor to the overall import figure was raw materials, which contributed 78.04%.

This means the industry is moving very slowly. The importation of raw materials in the first seven months of the year 1999 was down by 5.54%.

However, the report added that the importation of capital goods fell by 50.03%. This means that there were practically no new investments.

Tourist arrivals in July 1999 increased by 23.09%, to 379,500 tourists, from 308,400 in June. The cumulative tourist arrivals figure for the first six months of the year 1999 was 2.24 million, a 10.86% increase from the same period in 1998.

With the traditional economic activities of Indonesia suffering difficulty, this rise in tourism with Bali at the centre is an important stabilising influence.

1.1.4.3. Bali Economy

From the economic point of view, Bali has the highest economic resource potential for local development, as part of the national development in Indonesia. With this in mind, Bali is where new housing development will take place, and research is vital to this development.

Tourism plays a considerable role in the Balinese economy, both in providing accommodation and other service industries. Tourists and general demands have been growing rapidly and there is a need to balance adaptation between them within international development.

The people of Bali are born into a way of life in which ceremonies are necessary, and have been since time immemorial. From an economic view, the Hindu people should be sure to conduct ceremonies on an appropriate scale, and not let proceedings escalate to the level of party blitz. Everything should be according to its time, place and occasion. Only this attitude will ensure a future for the economy of Bali (Bendesa, 1999).

Bali's economy traditional activities are agrarian and fishing, which coupled with the daily life ceremonies mentioned above has provided a unique environment and widening culture.

On the other hand Denpasar, the capital city of Bali, has been growing as an international tourism business centre.

With its distinctive landscape and culture, and competing development pressures Bali, Indonesia offers a microcosm to test the concept of sustainable development. Bali is encountering significant challenges in the promotion of policies to encourage vigorous economic development, while simultaneously enhancing traditional culture and protecting the integrity of the natural environment (Knight et.al. 1997).

This is one of the reasons why Bali has been able to weather the storm of the economic crisis so well. Bali is even enjoying something of a 'boom' despite the crisis, as noted by Newsweek (1st February 1999) where it was compared with the unemployment-stricken Java, which is otherwise the most developed island in Indonesia.

1.1.5. Energy Issues in Indonesia

1.1.5.1. Political Economy Energy of Indonesia

Indonesia is confronted with an increasing tension between the need to export oil to secure its international currency inflow, and the country's rapidly growing energy consumption. With current rates of growth now 8% yearly, oil consumption should surpass oil production somewhere between 2000 and 2010 (Barnes, 1996).

The fundamental issues in delaying this are encouraging the exploration and production of new oil reserves, and sustaining the life of currently productive fields. This includes the substitution of other sources of energy for oil, and an expansion of the export of coal and natural gas; other sustainable resources, and conservation of energy.

1.1.5.2. Geothermal Energy

According to Greeman (1997), Indonesia has more volcanoes than any other country and despite huge oil reserves, it is investing millions of dollars developing geothermal power.

In Java for example, scientists believe that drilling into its side will let out valuable high-pressure hot water, which is trapped between 1,000 metres and 3,000 metres below the surface, and in turn be "flashed" into steam pressure for driving turbines.

The water comes from a complex geological hot water field and is relatively free of minerals, which makes it particularly useful for power generation.

The field has produced 110 MW of power since the first elements came on stream in 1994, and it is now being expanded to produce 330 MW. The output from this project, and Balinese geothermal energy together will put Indonesia into fifth place in the world for geothermal power.

1.1.5.3. Geothermal Energy in Bali

Bali Energy has built and operates a geothermal power facility at the Bedugul Bali. The project involves construction of a series of geothermal power plants with an initial total generating capacity of 220 MW. This may be increased later to 400 MW. They will own and operate the plants for 30 years, after which they will be transferred to the Indonesian State Oil and Gas Company.

The plant uses two combustion turbines supplied by Westinghouse, the lead firm in the consortium which contracted to build the station (World Digest Indonesia, 1995).

1.1.5.4. Solar Energy

Although not yet economical for most middle-class families in industrial countries, solar technology is already the best buy in electricity for millions of households in the developing world (Flavin and Molly, 1997).

The use of solar energy in Indonesia is suitable to any area, solves the problem of unavailability of electricity energy power, and is simple to install.

As a warm humid climate tropical country, the energy contained in the sunlight that falls on a rooftop exceeds the electricity needed, and dwellings in Indonesia could benefit from solar power. Solar photovoltaic (PV) cells are semiconductor devices made of silicon similar to, but far less expensive than, the chips used in computers. They convert the energy from sunlight directly into electricity, thus avoiding any need for the costly and environmentally-compromising mechanical turbines and generators that provide most of the world's electricity today.

The model programmes of Indonesia offer lessons. The government aimed to increase the share of villages with electricity from 49 percent in 1994 to 80 percent in 1999.

However, the geography will not allow this goal to be reached solely by extension of existing electrical grids. Only Java and Bali, the two most populous of Indonesia's islands, have extensive electrical grids and even they do not extend to many mountainous areas.

According to the UNESCO Courier (1997), by 1992, a government programme to install more than 3,000 household solar systems through village co-operatives was complete. By 1995, Indonesia had satellite offices in a network of about 50 regional service centres. Its total portfolio of 5,000 loans was valued at US$ 1.4 million, and had a remarkable payback rate of 100 percent. By 1996, the customer list had grown to 8,000, and still there had been no defaults.

A recent US$ 44 million World Bank loan to Indonesia is the first to solely target solar home systems. The finance includes a US$ 25 million grant, which does not need to be repaid from the Global Environment Facility (GEF), which can be tapped for projects that mitigate global warming. Solar technology, of course, offers an alternative to coal or oil-fired power plants that emit large quantities of carbon gases.

However, both private banks and international aid agencies seem more interested in financing energy projects that increase dependence on fossil fuels, and damage the environment. One reason is the relative ease with which private capital is attracted to large projects.

1.1.5.5. Energy Conservation

> *"The challenge to industry and the engineering professions is to satisfy the growing demands for material, processing and manufacturing by using fewer environmental resources."*
>
> Dowd, 1999.

A recently important issue in the habitat development of Indonesia is a sustainable environment with energy efficiency, for the next generation as well as the world beyond. Incorporating tropical climate environment and energy efficient usage patterns, integrated design, natural ventilation and air conditioning in the housing industry must receive special consideration.

The design should achieve a high standard of human thermal comfort and energy efficiency, by well-configured architectural features, thermal insulation, and the occupancy scheduling of the dwelling.

1.2. THE PROBLEMS

1.2.1. Introduction

There are four main problems indicated which are; pressure on housing, finance related issues on housing, impact of tourism on housing and impact of urban climate on energy air-conditioned dwellings. All of them are then summarised below into a specific conclusion related to the focus of research in Bali.

1.2.2. Pressure on Housing

Due to national development, the process of urbanisation in Bali will continue to increase with more than half the population living in urban areas (see also previous section 1.1.1.5). This not only influences their environment but will also create a variety of housing, economic and energy problems in urban areas.

In housing and human settlements, development is aimed at meeting the needs of people for shelter as well as improving both the quantity and quality of housing within a comfortable environment.

Nowadays the situation is continuously becoming reversed; most domestic development investment comes from the private sector (Department of Information of Indonesia, 1996).

There is still a gap between supply and demand in housing. The urban areas continue growing and there is an urgent need to improve conditions, because most of these areas are increasing without any improvement in the quality of the houses or their environments.

The land available for housing is decreasing and insufficient to cope with the need for new dwellings. The lack of land for housing in urban areas is causing an escalation of land and building prices.

1.2.3. Finance Issues on Housing

Other problems relate to housing finance mechanisms, and relatively low involvement by the private sector in housing development programmes.

The budget for housing development depends upon the government, but the capacity to provide funds for housing is limited. Nationally, the international investment business community has been actively involved in real estate, contracting and building services.

Nevertheless, it is expected that 70% of investment will come from private sources, locally and overseas.

As housing demand is increasing every year in Bali and other islands in the Indonesian archipelago, there is an urgent need to allocate funds for housing development and to reduce building costs.

However, due to the limited budget of the government, the private sector is required to meet this. In Bali, the revenue generated by tourists should be harnessed to overcome some of the cost of development.

The first area of funding, is the housing development funding needed to meet land acquisition costs and construction costs, those being land development costs and building costs. Constraints come in the form of limited resources and high interest rates.

The second area of funding, which is merely to help increase affordability for people with lower incomes, consists of the housing loan and the grant for advance payment. The housing loan provides lower interest rates, while the grant for advance payment can help overcome advance payment obstacles.

Affordability for low-income people is decreasing, because construction costs are increasing faster than income.

1.2.4. Impact of Tourism on Housing

The development of tourism will be geared towards strengthening the sector in order to enhance its ability to generate employment opportunities, increase income, expand regional and national government revenue and improve foreign exchange earnings by developing tourism areas nationwide, and broadening the participation of the community in tourism development activities (Department of Information of Indonesia, 1996). Yet, Rapoport and Hardie (1991) noted:

> *"In the present context, however, these developments and modernisation above are seen as equivalent to cultural change. More specifically, one is dealing with a form of acculturation since the changes are clearly seen to be due, in major part, to intercultural process contact, interaction, and conflict between the local traditional culture and the modern Western culture."*
>
> Rapoport and Hardie, 1991.

Balinese architecture is an expression of traditional culture for the country, and has been recognised as an asset for tourism development.

However, since Bali is known all over the world as an international tourism centre, there has been some 'culture-selling' of an image of Bali and this has shaped the building design.

Balinese architecture is the unity between religion and culture based on the power of nature. Tourism has to grow, whilst still keeping the balance that is an integral part of the island.

The problem is how to accommodate the need to preserve Balinese architecture, yet meet the demands of modern culture.

Housing and settlement pattern then should be organised to accommodate these requirements in a combined dwelling design.

1.2.5. Impact of Urban Climate on Energy Air-Conditioned Dwelling

Climate and durability are not always the most obvious matters. Building materials and construction technique may be more or less determined by the local situation. The goal should be to consider all the factors, and achieve the best comfort for the dwelling.

With tourism building designs which follow international trends and the architecture of temperate countries, architects rely on engineers to fix a comfortable indoor climate. This can be done, but at a high annual cost for energy and maintenance.

Designs for temperate climates are not always applicable to the tropical climate, especially for the problems of heat and humidity. In temperate countries, the design of walls and roofs assume lower temperatures outside than inside, while in air-conditioned buildings in tropical climates, the situation is the opposite.

In warm humid climates, power-cuts and mechanical breakdown of air-conditioning equipment, which is technically complicated, commonly affect the indoor climate in air-conditioned dwellings. In this respect Adamson and Aberg, (1993) indicated:

> *"In the meantime, the indoor climate can be almost unbearable if the house is not designed to give the best possible climate without any air conditioning."*
>
> Adamson and Aberg, 1993.

There are situations where the installation of air conditioning is often required for human comfort, especially in warm and humid tropical climates. That means investment in cooling equipment, higher annual energy costs and maintenance costs during operation.

The investment and recurring costs of air conditioning are influenced by aspects of building design such as the thermal insulation of wall and roof, airtightness of the building, window design, ventilation, cooling and occupancy strategies.

A common problem in warm humid climate due to the high relative humidity is the requirement to increase energy demand for air conditioning.

Recently demands for comfort have increased, and are often provided by air conditioning equipment installed in existing buildings or single rooms. This is the worst case from the view of energy conservation, for human comfort, health and for the building itself. Electricity consumption will be very high and the building fabric may be heavily damaged. Therefore, an adaptation of the building to complementary air conditioning is necessary. For energy conservation, the design of the building envelope should be adapted to the ambient climate and the required indoor climate.

The goals of national energy development in Indonesia are to increase the share of non-oil energies, and to minimise oil dependency. In Bali, Indonesia there is very often a shortage of electricity, causing shorter or longer power cuts, and this warrants limiting the need for electricity for air conditioning.

A problem in building design is poor understanding of the differences and similarities between an actively cooled house and a passively cooled house.

The upper limit of thermal comfort in a tropical climate is technically defined as 28 °C (Antaryama, 2000). In the actively cooled house, the occupants set the thermostats to a desired temperature, often lower than the upper comfort limits, to keep the indoor temperature within comfort limits. The building envelope has to be designed to give the most economical investment and annual cost.

1.2.6. Summary of the Problem in Bali

Increase in population especially of Bali, couple with tourism impact on people migration to Bali, has given pressure on housing supply. In turn, this pressure also influences the finance issues on how to achieve affordability of housing over the range of energy conservation issues prevalent in urban areas.

Accordingly, the current response from the government to address the problems was to build houses to standard forms and sizes, typical compact dwelling.

However, this response does not reflect traditional architecture of Bali that was commonly built around comfortable compound dwelling.

The typical densely standard compact dwellings above puts more pressure on limitation energy and resources, because of the high reliance on air conditioning to enable thermal comfort.

The relevance implications if nothing is done are the depletion of energy resources and lost of cultural and environmental forms of housing in Bali.

Therefore for that reason, there is a need a design dwelling solution that reflects cultural and environmental needs for housing, with high thermal capability and energy efficient, be able to increase on supply of housing by maintained current plot and dwelling sizes, and it is not heavily reliance on energy consumption.

In these respects overall, housing design should consider the cultural, environmental, physical, social and economic factors related to energy conservation that inform dwelling design, to support the goals of national energy development in Indonesia.

1.3. OBJECTIVES

The main objective of the research is to discover a thermal-efficient dwelling design, for a middle-class-income family with two children living in the warm humid climate of Bali-Indonesia, that is thermally comfortable and environmentally acceptable.

It is hoped that the findings of the research will be able to contribute design guidelines for housing development in Indonesia, with the objectives of improved housing in a sustainable environment and the creation of a decent quality, standard dwelling that should be comfortable and affordable.

In relation to energy saving features, the study is a step towards meeting this challenge and is focused on research into a thermally comfortable indoor environment, in association with energy efficiency for a dwelling in a warm humid climate.

Development of housing must respect the needs of the people of Bali and its tourist trade. The former seeks to respect the advantages of the traditional dwelling while the latter demand a more technology-based solution to be adaptable to the indigenous architecture. For these developments, to provide a suitable thermally comfortable indoor environment whilst addressing energy efficiency is important.

More specifically, to gain a better understanding of the climatic response of dwelling;

- To identify the characteristics of a thermally comfortable dwelling.
- To examine the thermal performance of the dwelling in relation to the required thermal comfort.
- To examine and evaluate the characteristic indoor climate of the dwelling.
- To examine the influence of the physical properties on thermal performance.

The results of identification and examination will be used to design a dwelling, with architectural features as the main consideration to achieve a better thermal comfort performance for dwellings in Bali, Indonesia.

The dwelling design is intended to be suitable for the majority of the people of Bali, in particularly those with middle class incomes, and with the possibility for those on lower incomes to afford it by providing soft loans.

At the same time it is to encourage those with higher incomes, including visitors living in Bali, to adapt this standard dwelling and thus to avoid the construction of exclusive luxurious dwellings that are expensive and consume more energy.

1.4. RESEARCH METHODOLOGY

1.4.1. General Research Methodology

> In a general perspective, *"research aim is to re-orientate thinking, to pose a question what to think, to do and to know, and to focus on new aspects of the complex reality."*
>
> Phillips and Pugh, 1994.
>
> Specifically, *"the primary research involves a constant interplay between observation, and explanation, collection of further facts to test the explanation, refinement of explanation and so on."*
>
> de Vaus, 1996.
>
> Scientifically, *"this can be generated by two common types of research methods, the quantitative and the qualitative approaches."*
>
> Ragin, 1994, Patton, 1990.

In order to achieve objectives of this research, the research is mainly focused on the simulation study, and the result of simulation is comparatively analysed with the following approaches are;

- the survey research by means of questionnaire's result analysis,
- a comparative study to the previous field researches and a simulation study, undertaken in the warm humid climate of Indonesia, and
- the literature studies.

Comprehensive results between them are analysed to draw conclusions which are used to produce a design of dwelling. This dwelling finding is then simulated to achieve a significant final goal of the research.

In this respect, the research aims are to tackle the problem of dwelling design and to achieve satisfactory human thermal comfort and energy efficiency in the warm-humid-climate housing of Bali, Indonesia.

Exploring the research by the activities of intelligence gathering using the very important descriptions, questions, and analysis.

Data theories are explored using the relevant literature resources both literal and electronic, to find out more about the subject of the research.

The related studies are widely researched from literature, electronic information, survey research and reviewing the previous research and field studies undertaken in the warm humid climates e.g. in Bali, Surabaya and Jakarta, Indonesia.

Focused on thermal comfort, the thermal performance studies may be conducted in one of two ways: actual field researches, or using computer simulation studies. Each has its advantages and limitations. The method chosen influences the survey research adopted.

In this thermal comfort research, computer simulation is applied. Using a computer program (e.g. Hevacomp Design Database Version 15, 1998) a model dwelling of standard design built by the National Housing Authority of Indonesia was taken for the building specification data input simulation.

The survey is conducted electronically to indicate preferences for a thermally comfort dwelling, energy consumption pattern of dwellings, and an idea of the ideal comfortable .dwelling in Bali, from the Indonesian people who have the experience of living in this warm humid climate.

According to the literatures, the two major approaches to the scientific research in architecture that have been broadly identified are the architectural morphology of dwelling design non-climate related studies, and various environmental aspects of architectural climate-related studies with the help of the tools of building science. The latter can be used to highlight the relationship between form and performance (Antaryama, 2000; Hawkes 1996, 1981, 1980; Steadman, 1983).

All these theoretical approaches are brought together with other research methods to achieve the research objectives and to use the findings of the study as guidelines for the dwelling design in the particular climate of Bali, Indonesia.

1.4.1.1. Dwelling Design, Non-Climate Related Studies

In this approach, the study discusses and explores in brief the macro context of the dwelling design, studies from the cultural background and architectural background of both traditional and contemporary dwellings in Bali.

According to Antaryama (2000), the descriptions architectural morphology of architecture form, may refer to the relations between an architecture form and their associated properties; the very general, (Lawrence, 1990, 1987; Oliver, 1987; Aksoylu, 1987; Rapoport, 1969, 1986; Prussin, 1969), to morphological characteristics in descriptions of house form aspects (Mills et.al. 1995; Mills, 1992; Brown and Steadman, 1991; Steadman et.al. 1991; Chapman 1990; Periainen, 1969). These are commonly established based on the architecture plan; a rectangle (Steadman, 1983; March and Steadman, 1971), an adjacency and access (Van Leusen 1994; Brown and Steadman, 1991; Steadman, 1976, 1983), a vertex and contiguities and connections between rooms of dwellings, (Lawrence, 1987), and a relationship between spatial patterning, social and cultural function (Brown, 1990; Chapman, 1990).

1.4.1.2. Dwelling Design, Climate Related Studies

In this context, the research explores and investigates the more specific matter about the dwelling design, climate-related studies from the climate background, thermal comfort, and the technical terms of both traditional and contemporary dwellings in Bali, Indonesia.

From a previous study by Antaryama (2000), the following general descriptions of a building are normally considered sufficient for qualitative studies of the influence of climate on the building (Yeang, 1987; Yuan, 1987).

This also applicable to studies that focus more on thermal performance (Hyde and Docherty, 1997; Malaina and Sharples, 1996; Hyde, 1995).

This usually focuses on a comparison between the performance of different forms to indicate their effects on the indoor airflow, and evaluating the geometrical response of a building to particular climate conditions (Pearlmutter and Etzion, 1993; Saleh, 1989).

Perhaps the most widely used measure with regard to heat loss and gain is the ratio of surface area to volume (Steadman, 1992; Markus and Morris 1990; Gupta 1984, 1987), where the thermal performance of simplified geometrical models of different shape and form were compared.

Markus et.al. (1972) proposed measurement of plan and mass compactness ratios. When the proportion of a building façade is considered in relation to orientation, the aspect ratio (particularly) is generally used (Burberry, 1978; Wilson, 1976; Olgyay, 1963).

More extensive measures were employed by Steadman and Brown, (1987) theoretically to estimate the exposed surface area of dwellings.

These encompass ratios of exposed surface area (wall and/or roof) to floor area, and glazed area to wall area.

Maltreya (1991) used similar measures, i.e. ratios of openings or window area to floor area, to determine the impact of fenestration on the thermal performance of a building.

On the same theoretical ground aspects Steadman & Brown (1987), and Al-Hussayen (1995) employed measures of ground coverage, elevation length (perimeter), and proportions of width to length, and width to height to explain the environmental aspects of a building.

In the study of natural ventilation in building, measures of site-related characteristics such as spacing among buildings (i.e. ratio of distance to height) and ground coverage (or density) are commonly considered (Lee et.al. 1980; Santosa, 1988).

In more detailed studies, such as those by Santosa (1988) and Givoni (1969), measurement of openings ratio (i.e. openings area to wall area) was included.

Effects of opening area on the distribution of wind velocity inside a building were also studied by Givoni (1969, 1965) through a measure of proportion of window to wall widths.

However, in computer-generated designs (e.g. generation of plan layouts) adjacency requirements of rooms have been included as one aspect of the constraints (Reynold, 1993, 1980; Brown, 1990; Lee, 1977; Mitchel, 1977).

The adjacency of rooms to the exterior, for example, can indicate the constraints imposed by certain room adjacencies on the possibility of placing doors or windows in those rooms, either for the propose of gaining direct access from outdoors, natural ventilation and light, or a view (Steadman, 1983, 1976; March and Steadman, 1971).

This in turn offers a guide to the environmental performance of the building. Such a description, therefore, can provide an insight into the interaction between building form and its surrounding environment.

The foregoing has shown that many of the methods of describing dimensional characteristics of architectural form have also been applied to climate-related studies.

1.4.2. Computer Simulation

The computer simulation studies are extensively discussed and analysed in Chapter Seven and Chapter Nine. In this stage, a general introductory of the computer simulation methodology and the method chosen are given below.

In this method related to Chapter Seven, the standard dwelling chosen is simulated in term of air conditioning energy use by inputting dwelling design specifications.

Firstly, by inputting data of the latitude and altitude locations of Bali into the simulation program, the whole year monthly weather data could automatically be available for computer simulation.

Secondly, by selecting and inputting design data of the rooms of the standard dwelling into the simulation program, the results and the graph of the monthly energy pattern during a year calculation will be generated automatically by the computer program.

Thirdly, the same simulation technique is also applied for this standard dwelling over a range of energy conservation strategies.

The results of simulations are then compared and analysed to draw conclusions.

This simulation technique is chosen for the main way to do this research, due to the advantages of computer simulation on thermal comfort studies (Hyde and Docherty, 1997; Hanna and Simpson, 1996; Maltreya, 1991; Santosa, 1988) and the disadvantages and constraints as well as the criticism of the fieldwork in thermal performance studies (Turner and Szokolay, 1982).

However, the outcome of this computer simulation is also comparatively analysed to the previous works undertaken; computer simulation and field studies in Bali by Antaryama (2000), a field study in Jakarta by Karyono (2000), and an experimental study in Surabaya by Funo and Silas (2000), all are located in the same warm humid climate of Indonesia.

According to Antaryama (2000), the computer simulation method offers three major advantages;

First, the computer allows predictions to be readily made for any variation or alteration in building-related parameters, such as form, materials and ventilation rate, and for any given conditions. This is particularly useful in the early stages of design before the building is finalised and built, or experimental studies.

Second, it allows the effect of certain variables, e.g. form, on thermal performance to be especially evaluated, holding all other things constant.

Finally, a computer simulation allows predictions to be made not only for a particular month but also for the entire year, something that could take a considerable time using field studies or scale experimental models.

On the other hand according to Robin et.al. (1998), there are of course general disadvantages on the computer simulation method e.g;

- Computer simulation cannot, in truth, come close to the character and complexity of the reality.
- It only represents reality as seen through the eyes of the designer.
- Simulation cannot necessarily invoke the affective reactions that occur when tackling real problems.

The computer simulation analysis of studies in thermally comfortable dwellings can be either using fundamental geometrical models to predict thermal responses or performances under given conditions, and/or of actual performance of buildings to provide various aspects of building forms and building materials.

In these respects, thermal performance is conducted with passive and active cooling of the building, which corresponds to the pressure and outdoor conditions to achieve an adequate and continuous comfortable indoor temperatures.

Recently, many thermal comfort simulation programs have become available. Most of them, however, are intended primarily for proposed engineering and mechanical air conditioning manufacture, making them very expensive.

Actually, only a few computer programs for thermal performance studies are readily applicable and give brief descriptions that designers and architects have produced in the developed countries.

In this terminology, the selection of an appropriate program for building design or research is a program that provides either a prediction for long term energy demands of air conditioning, or a daily temperature profile for cooling the building.

The main considerations are the applicability of the program for more variations, to be user-friendly, suitable for a wide range of thermal performance conditions and types of buildings, with more precise accuracy of the prediction.

This has led to a development of programs that are cheaper and reliable. All of those evaluated fall into this category (Ahmad, 1998; Williamson, 1983).

In Chapter Nine, this simulation study is also applied for the dwelling-design finding which come from the comprehensive analysis of the studies.

1.4.3. Survey Research

In this approach, the study concentrates on the respondent feedback's analysis in away of their experiences on thermal comfort sensation in their current dwelling and reviews their idea and expectations of an ideal dwelling design which is then, the result can generates the conclusions of this research.

The survey research was performed by electronic mail (e-mail) with some reasons will extensively be discussed in Chapter Five and one particular reason is explaining below.

Examining the social lives of families and the way that they customise their lifestyle requires great effort, especially in most such conservative Hindu environments where privacy in the home is part of everyday life. Even with a high level of response, the process of generating a firm conclusion will always be attended with uncertainty.

One of the advantages of conducting the survey by e-mail is that a relationship between interviewer and interviewee is not established, the interviewee is corresponding to a computer screen and the answers given are a more honest reply to the questions. Such uncertainty is exists in the survey would result from the attitude of respondents. While respondents would have given due care and thought to their responses, it may be that some were concerned to deal with the matter quickly or unevenly.

Perhaps some might give responses that they thought the researcher wished to receive, as a way of showing courtesy. That is a very common social custom. There must, therefore, remain some small element of uncertainty about field survey results.

1.4.4. Comparative Study from Previous Researches

In this approach, the previous studies undertaken by other researchers in Bali, Surabaya and Jakarta, Indonesia are reviewed and their findings compared with the result of this research.

In the thermal performance studies, field observations and one combined with computer simulation were conducted.

The field study was intended to obtain and analyse the real thermal performance of a dwelling under current normal occupation and climatic conditions (Antaryama, 2000; Hyde and Docherty, 1997; Santosa, 1996; Maltreya, 1991).

In addition, *"the study is also pointed out to assess the occupants' response and willingness to obtain a satisfactory comfortable dwelling"* (Hanna and Simpson, 1996).

Despite its advantages, however, using this method may face limitations and constraints.

The use of such methods allows daily changes in the internal environment, to be monitored and recorded on site.

Ideally, this should be based on long term monitoring, in order to assess the overall performance of the building and satisfaction responses.

Another main constraint imposed by this method is that it requires sophisticated and expensive equipment and, more importantly, that it may interrupt and disturb the normal life of the occupants. In addition, as Turner and Szokolay, 1982 criticised:

> *"One further criticism is that this method would not be appropriate if comparison is to be made in the study, because user behaviour can dramatically alter the thermal performance."*
>
> Turner and Szokolay, 1982.

In these respects, to generate this research and to present a finding that is widely researched, the following three studies of thermal comfort in warm humid climate of Indonesia were reviewed;

- A field study and computer simulation study of house form transformation and climate in Bali, by Antaryama, (2000).
- A field study on thermal comfort and building energy studies in Jakarta, by Karyono, (2000).
- An experimental study of a passive design of housing for a warm humid climate in Surabaya, by Funo and Silas, (2000).

To support the research simultaneously, the previous studies undertaken are extensively discussed and analysed in Chapter Six.

1.5. THESIS FRAMEWORK

Chapter One introduces the general background, the problems, objectives, methodology, and thesis framework of the research.

Chapter Two covers the socio-cultural and architectural background of traditional and contemporary dwellings in Bali, Indonesia.

Chapter Three is focused on geographical, climatic context of environmental setting and thermal comfort of Bali, Indonesia, which considers overheating as well as human thermal comfort and bioclimatic analysis.

Chapter Four reviews the specifics of basic thermally comfortable dwelling in the warm humid climate, and it considers housing development and problems associated with such development in Bali, Indonesia; energy requirements, growth of air conditioning and energy demand, as well as architectural features or strategies developed to modify energy use.

Chapter Five discusses the aims and objectives of the survey research; it continues with survey design and framework, methodology of data collection and the survey analysis outcomes.

Chapter Six reviews the quality of indoors thermal conditions, energy consumption patterns, thermal comfort indices and economic analysis of the previous studies.

Chapter Seven focused on the technical background, gives a description of the analysis techniques, theoretical model analysis and outcomes computer simulation of thermal performance of the standard dwelling.

Chapter Eight describes the design of a combined dwelling; insulation, air conditioning and natural ventilation strategy.

Chapter Nine analyses the simulation of the combined dwelling design; comfort consideration, strategy for the integrated dwelling design and outcome of the simulation.

Chapter Ten of the research is the summary, conclusions, and recommendations are made to apply in Bali and to other developments in Indonesia. Limitations and further research are also discussed here.

1.6. CONCLUSION

Resolving housing demand, migration, urbanisation, and city development is important for all the cities of Indonesia. This can be achieved not only by funding housing, reducing construction costs through technological innovations, use of local materials, but also by understanding comfort requirements and energy conservation in residential buildings.

Bali is an important part of developing Indonesia. The national housing policy focuses on middle cost houses, which account for 60% of housing development.

Economically, it is not feasible to build typical Balinese traditional houses in the current situation.

Such is the pace of development that the traditional Balinese house may be replaced by a modern contemporary dwelling.

However, it has to be recommended that a combination of vernacular architecture and modern technology have great potential to produce an economic, comfortable solution for the housing needs of Bali.

The climatic response of traditional and contemporary architecture houses, therefore, remains a study of great relevance and interest. The traditional house is more responsive to the local climate than is the contemporary dwelling. Though clearly shaped according to social and cultural needs, the traditional house is also very well adapted to the physical environment. The contemporary house is much more shaped by modern life-styles and requirements, and problems imposed by rapid development in the city, all of which often outweigh climatic considerations.

The recent political and economical situation in Indonesia has made conditions difficult, and has had an impact on international and national investors who are interested in housing development in Indonesia.

In Bali, however, the presence of a significant tourist industry provides a vehicle to generate higher incomes and encourage investment. There are plenty of accommodation development opportunities, while the occupants demand dwellings that are more comfortable.

Chapter Two

CULTURAL AND ARCHITECTURAL BACKGROUNDS OF BALI, INDONESIA

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Chapter Two

CULTURAL AND ARCHITECTURAL BACKGROUNDS OF BALI, INDONESIA

2.1. INTRODUCTION

Figure 2.1. Traditional Bali Dancers
http://www.saradbali.com

Before discussing the architecture of dwellings in Bali, it is important to briefly introduce the Balinese culture (e.g. Figure 2.1, Figure 2.2, Figure 2.3, Figure 2.4, Figure 2.5 and Figure 2.6), since this cannot be separated from the daily activities which take place in both traditional and contemporary dwellings.

As has been described in the previous chapter;

> Bali, a paradise island, *"with its distinctive landscape and culture, is encountering significant challenges to encourage vigorous economic development, while simultaneously enhancing traditional culture and protecting the natural environment."*
>
> Knight, et.al. 1997.
>
> They further recognised, as is already happening, *"development and tourism pressures have led to fragmentation and degradation of ecosystems, modifications, deposition and regeneration processes, and inequity regarding access to natural resources, especially for local people relative to their traditional activities."*
>
> Importantly relevance to the research, they reached a conclusion, *"an integrated approach is recommended to protect and rehabilitate linked ecosystems within the context of cultural policies."*

Figure 2.2. **Art and Environment of Bali**
http://www.saradbali.com

Furthermore examples, as can be seen in Figure 2.2;

> *"Bali, a tiny jewel in the Indian Ocean, offers emerald green rice paddies, turquoise waters, palm-lined, white sand beaches, sunrise, sunset, and the misty mountains where the real soul of Bali is to be found, enough natural beauty to satisfy the most cynical of world travellers. Yet this is not all the island has to offer, Balinese culture is an equally powerful attraction. Because Bali's rich volcanic soil easily supports two rice crops a year, the local people always have time left over for the arts. Music and dance, painting, sculpture and woodcarving are staples of Balinese life."*

MMC, 2002

From the historical point of view, migration to Bali both from Indonesia's archipelago and worldwide, has occurred throughout history. Within the beautiful natural environment, Bali has developed cultural artistic activities which have made the island interesting to visitors, and inspired a revolution in Balinese art.

2.2. CULTURAL AND ENVIRONMENTAL BACKGROUNDS

2.2.1 Cultural

> *"The idea of balance is central to Balinese philosophy and way of life; nature and man meet and complement each other."*

MMC, 2002.

There are a series of ceremonies and rituals in Bali, which contribute to the rich and varied activities in the daily life of people in Bali (Figure 2.3 and Figure 2.4).

Figure 2.3. **Bali Ceremony**
http://www.saradbali.com

Figure 2.4. **Art Ceremony**
http://www.saradbali.com

The ceremonies of the Balinese start from birth, and accompany the stages of childhood and puberty. Marriage is the next important ceremony (Figure 2.5), and the biggest ceremony is cremation (Figure 2.6). They are amazing, spectacular, colourful, melodious and exciting events.

Figure 2.5. **The Wedding Costumes**
http://www.saradbali.com

Figure 2.6. **Traditional Cremation**
http://www.barongtours.com

All of these cultural ceremonies attract the people and visitors to Bali.

2.2.2 The Village

> *"The villages are hidden behind the same mud walls, there will be the same red tiles of the same family pavilions with, again thirty meters apart, the same thatched puppet houses: the family temples. A big tree, two slit logs hanging from its branches, with a couple of shrines under its shade and a nearby the neighbourhood community hall. An atmosphere of calm, order, and collective belonging prevails."*
>
> MMC, 2002.

The basic Balinese territorial unit is the village, whose surface covers both the wet land of the rice fields and the dry land of the compounds; with related gardens, temples and roads.

However, the village in Bali has changed, combining it natural panoramic view with the built environment, to gain more income for its people by providing commercial accommodation for visitors (Figure 2.7).

The Balinese village is typically host to a set of three village temples, the mother temple located towards the mountain, the social temple located in the centre of the village, and the temple of the dead, located below. Besides these territorial temples, there are also the neighbourhood's temples; rice fields temples, each of which has its own calendar of festivals.

Figure 2.7. **Accommodation with Vernacular Attraction Environment**
http://www.villas_bali.com

The community is a group of anything between fifty and two hundreds individual compounds. The word community originally referred to a row of houses, thus to the physical clustering of compounds into a neighbourhood, with a temple and a community. The basic social unit of the community is the couple.

2.2.3 Temple

In the temple there are several small compounds housing holy constructions for worshipping the spirits of deified ancestors and supporting buildings. These are varied in number, name, types, and architectural style (Figure 2.8 and 2.9).

However, in general the temple can be divided into three areas:

The outermost area of the temple, where there is a place for the traditional wood drum, which is usually beaten when a ceremony is going on, and the big common building which is a place where people can get together. The kitchen can be part of the common building or separated. In this area there is also a building where people can rest.

The middle area of the temple, there are buildings for playing traditional instruments and also the long building. A fence with the gate divides the outermost area through the middle area of the temple.

The head area of the temple; in this area there are several shrines whose number, name and type are determined by the Hindu Gods of the temple, or by the kind of job and the ancestry of the guardian of the temple (Yudiata, 1999).

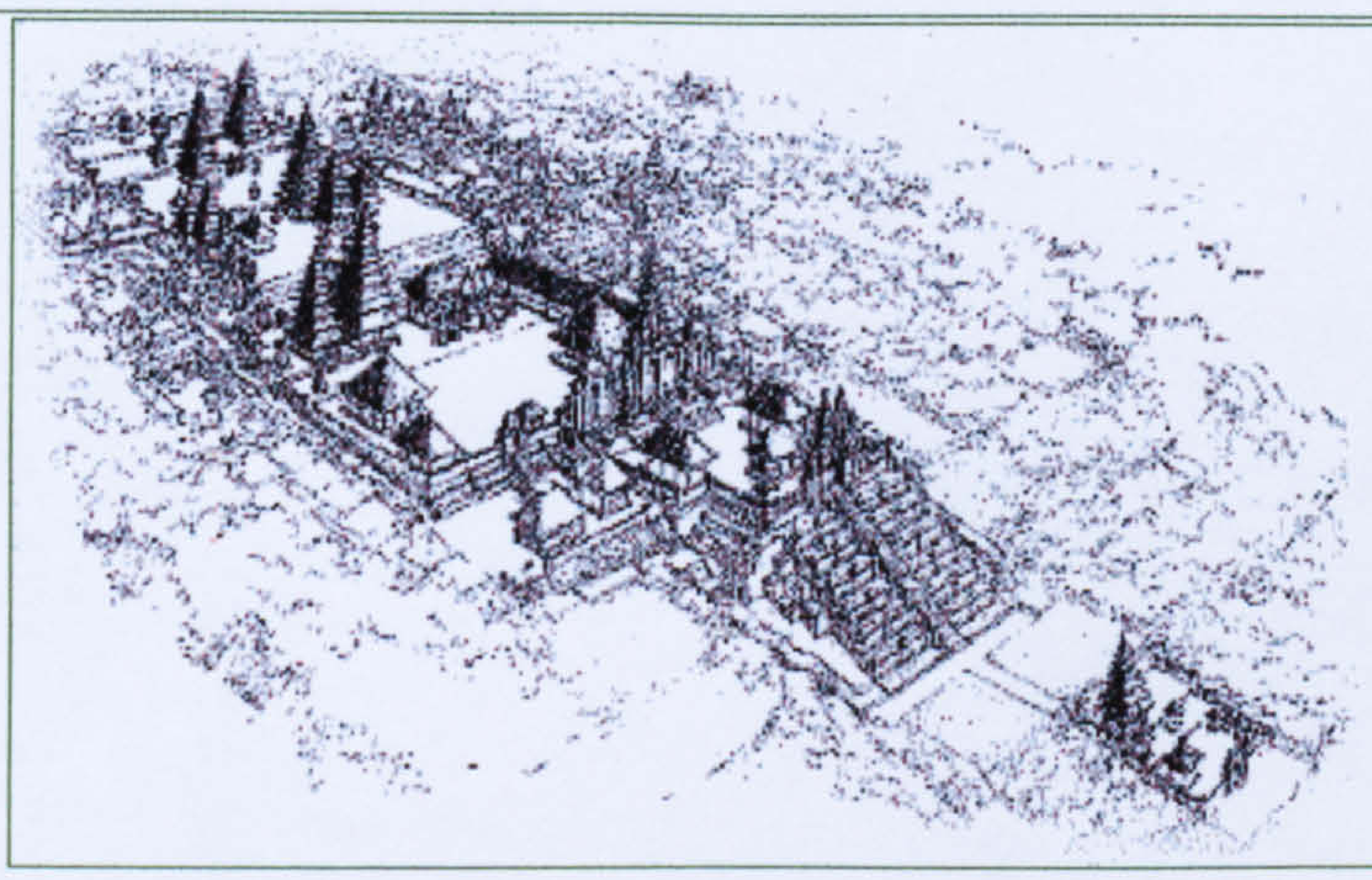


Figure 2.8. The Mother Temple of Bali <Besakih>
http://www.saradbali.com

Figure 2.9. The Mother Temple of Bali <Besakih>
http://www.wright-photo.com

2.3. ARCHITECTURAL BACKGROUND

> *"Historically, an essential function of the dwelling was to protect its inhabitants from the severity of external forces such as climate. Tied to the prevailing belief and value system, the design principles were handed down from one generation to the next as a tradition."*
>
> Crowe, 1995.

In Bali, the culture of Hindu Java has a strong influence on Bali's traditional architecture. Indeed, Antaryama (2000) indicated the following descriptions.

As cultural life grew, related activities and requirements increased, and at this point, the dwelling was no longer built primarily for the purpose of staying alive; it had to accommodate many other purposes.

However, since the residents of a given place normally shared the same image of life and world view, the dwelling of a particular period then came to adopt similar but varying forms.

However, since the residents of a given place normally shared the same image of life and world view, the dwelling of a particular period then came to adopt similar but varying forms.

From the form and simple construction employing the limited materials available (i.e. Balinese Dwelling), the house has been made more elaborate in response to a great variety of current social and cultural needs (i.e. Modern House).

> *"The modern dwelling form, therefore, has to serve not merely the simple purpose of a house but also the complex demands of modern life."*
>
> Gardiner, 1975.

Today, the increasing number, complexity, and difficulty of problems have greatly accelerated the pace of change in various aspects of society and culture, the development of technology and the availability of materials. The development of the house occurs through time and space, and parallels and reflects people's changing needs and expectations. Alexander (1964), who recognised this situation noted that conditions have forced change faster than ever before. The situation consequently offers man no alternative but to adjust himself and adapt to it; change becomes inevitable. The development of new technology, materials, and construction techniques has resulted in a wide freedom of choice in the design of modern houses. This coupled with the need to accommodate more complex requirements, has led to new and more varied forms of house design. Therefore, the house tends to be shaped to express individual needs and tastes rather than to reflect what is believed by most of the traditional community.

The forgoing shows that, *"nothing seems to be immune to change, nothing is permanent, everything is in constant flux and change including house form design"* (Zuk and Clark, 1970).

In principle, due to cultural impact, the form of house design is in a continuous process of change. Even vernacular buildings such as the traditional Bali house, which was normally based on old styles, have been transformed to contemporary patterns. *"Instead of being built in the traditional way, it now commonly employs modern techniques and form"* (Dawson and Gillow, 1994; Rapoport, 1969). *"The exception can be found such as the proponents of eco-tourism may contribute to a positive, symbiotic relationship between conservation and tourism"* (Linberg and

Hawkins, 1993), *"and the situation where tourism has appeared to receive and give added value to cultural expression"* (McKean, 1989).

Environmental impacts of tourism often occur in the forms of architectural styles. Tourism impacts on the design building in Bali began with foreign visitors camping and staying in the traditional home of residents, then moving towards the guesthouse and the bungalow, followed by hotel development.

The plan has been complemented by policies encouraging the use of indigenous styles of architecture.

"However, the implication is that it will be necessary to manage change, recognise, and monitor the consequences (Nelson et.al. 1992), *where Bali was recently designated for world tourism development"* (Wall and Dibnah, 1992).

> *"The modern movement in architecture, which regarded function as paramount, has exercised a strong influence on building design."*
>
> Steadman, 1975.

"It is commonly viewed as having no regard to the natural world or to regional characteristics, representing instead a pure and universal response to technology and society" (Jones, 1998).

The battle for styles in housing is made more complicated by architects who consider that their architecture should be both modern and Indonesian. There is commonly an open pavilion whose form is a copy of indigenous architecture.

"However, it employs European methods and techniques for wooden construction" (Priyotomo, 1996).

Indonesian modern architectural movement as described by Fordham (1996) *"meant by modern architecture is modernising indigenous architecture; not Indonesian of European modern architecture".*

A point is made of the sensitivity in the integration of modern technology of construction, philosophy of indigenous architecture of Bali, and the richness and uniqueness of indigenous forms.

Silaban (1991) noted: *"current Balinese house is an architecture that emerged from utmost warm humid climate climatic utilisation, not a copy, and imitation of indigenous form"*, so that may mark the modernity of dwellings in Bali.

Housing should be designed in the modern spirit of architecture, in a typical building that the term modernises copy is refused, or, is interchangeable with modernisation and but also designed a new vocabulary of indigenous form: a modernised indigenous form.

Most house building financed by the government now appears with geometric forms for the body, and distinctive indigenous roof forms as their top.

However *"unfortunately, most of them are not sensitive to composition so that the top and the body do not integrate to each other"* (Priyotomo, 1996).

Certainly many projects have used indigenous forms, but have been designed by international architects.

Today, environmental impacts on traditional dwellings in Bali can be defined as a challenge of climatic response for thermal comfort, when moving from a traditional to contemporary house design that reflects in part the prevailing society and culture. Waterson (1990), Knapp (1989), Dumarcay (1987), Oliver (1987), Yuan (1987), Prussin (1969), and Rapoport (1969) noted that as a warm humid climate architecture, at the same time they implicitly or explicitly embodied a response to the physical environment, i.e. climate, topography, and natural resources.

Modern houses by contrast are often considered as lacking any local references. *"They tend to be alien to their environment due to the ideas underlying the design are frequently derived from imported abstract knowledge, which is applied without consideration of the cultural or climatic conditions"* (Cofaigh et.al. 1996; Yuan, 1987).

> *"Hence, there will always be the possibility that form implicit in a new building will respond either well or badly to climatic conditions."*
>
> Cofaigh et.al. 1996.

Figure 2.10. Traditional and Contemporary Architecture Adaptation

However, as indicated in BRE (1980) and by Rapoport (1987), *"not all traditional forms were successful in this respect".*

Conversely, new forms, which tend to give priority to the needs of modern lifestyle rather than climate-responsive design, may nonetheless be well adapted to their surrounding physical environment.

Though in reality the form of current houses might be far from ideal in environmental terms, the design may in some way take the climate into account.

Thus, *"it is necessary to choose suitable values for gaining control of the cooling in buildings. Accordingly, suitable indoor comfort can be maintained; the energy efficiency of the cooling systems will be maximised; and the lifetime of cooling will be prolonged"* (Qiunghua, 1999). This is especially true where the indoor environment is concerned, whether it relies on natural means (i.e. the use of a passive system), combination as hybrid (i.e. uses a passive and an active system) or provides full air conditioning (i.e. the use of an active system).

> *"However, the widespread tendency to suppress the inevitable interactions between a building and its environment with expensive and unnecessary mechanical means, provides lessons that have to be learnt."*
>
> Goulding et.al. 1993.

In terms of a climatic conscious dwelling design, an increasing awareness of energy-efficient building has led architects to turn to more environmentally responsive designs (Fordham, 1996; Yeang, 1996; Littler and Thomas, 1984). The reason is an awareness of energy that in the recent past has frequently been neglected (Jamal, 1991; Fisher, 1982; Burberry, 1978).

In terms of a climatic conscious dwelling design, an increasing awareness of energy-efficient building has led architects to turn to more environmentally responsive designs (Fordham, 1996; Yeang, 1996; Littler and Thomas, 1984). The reason is an awareness of energy, that in the recent past has frequently been neglected (Jamal, 1991; Fisher, 1982; Burberry, 1978).

The importance of climate in the design of houses lies in the fact that energy consumption relates not only to the occupants and the building itself, but also to the prevailing energy system, i.e. the climate. This means that by taking climatic factors into account at the concept stage, it is possible to achieve a well-designed building that uses minimal energy but still maintains comfort (Goulding et.al. 1993; Yeang, 1987; Turner and Szokolay 1982; Konya, 1980).

In this way, one can hope to avoid the application of mechanical means to a more or less completed building, a practice that often leads to an increase in energy consumption.

This however, does not necessarily mean dispensing with them completely, as the environmental elements that aid us have their limitations.

Apart from its contribution to energy conservation, climate conscious design owes its importance indirectly to the fact that climate tends to remain more or less unchanged over time.

This is in contrast with cultural, economical, and political conditions that may readily change (Yeang, 1997; Behsh, 1993).

Hence, at a time when impacts on dwellings are occurring to meet changing requirements, climatic considerations remain critical in design, especially if only passive systems are to be applied.

According to the previous chapter, it was clearly indicated that, *"the pace of development in Indonesia and the impact of tourism as a whole have contributed to rapid change in Bali"* (Rahardjo, 1989), where architecture houses were included. This has had a significant impact on both the physical and social aspects of life over the last three decades (Pitana, 1994; Woods and Antaryama, 1994).

The Balinese dwelling then has clearly been subject to change.

However, many scholars, such as Windu (1977), Gelebet (1978), Sastrowardoyo (1983), Soetomo (1993), and Santosa (1996) have considered Balinese architecture, including the house, to be environmentally adapted.

That is to say, apart from embodying the socio-cultural life of the inhabitants, the physical characteristics of the traditional dwelling also reflect its response to the climate.

In term of simple climatic analysis, the traditional open plan and dispersed arrangement of dwellings clearly work in accordance with their surroundings. In the warm humid conditions, such open characteristics minimise resistance to light winds. This is particularly important, as the only natural way of ameliorating the problem of overheating in this type of environment is by providing ventilation and air movement.

> *"By contrast, the common use in the contemporary house of compact form, with complex multi-walled rooms, would seem to encourage uncomfortable indoor conditions due to lack of cross ventilation. The presence of internal partitions can block the flow of air, and thus considerably attenuate the effectiveness of openings."*
>
> Woods and Antaryama, 1994.

The effects might not be too serious if the building stood alone, but since contemporary buildings are often constructed close together as a result of the limited plot size, the potential area for opening is reduced and the resistance to airflow correspondingly increased. Where internal discomfort is experienced in new dwellings, this can necessitate the use of mechanical equipment such as fans or air conditioning, to maintain favourable indoor conditions.

However this is not a straightforward solution, especially when air conditioning is concerned, as the fact remains that provision of such equipment is expensive in equatorial climates.

The main reason for this was addressed a long time ago by Fry and Drew (1956), also by Atkinson (1960): *"in this type of climate, systems have to operate throughout the year, and if they fail, thermal discomfort is likely to occur because the buildings have been especially designed for their use"* (i.e. dwellings are built to a compact design plan).

The contemporary house, whatever the undesirable environmental consequences that might result from its design, has offered a solution to changing social and economic needs. Yet, it does not follow that they have to accept fully the new design concepts, nor revert wholly to the principles governing the traditional house.

Climatic-responsive design is important to the contemporary house, and the principles that were adopted, either consciously or unconsciously in the traditional dwelling may be judged well suited to local conditions.

The proposition put forward by many researchers (Keonigsberger et.al. 1974; Steadman, 1975; Supic 1982; Devey, 1991; Carter, 1993) is that *"traditional house design (which) commonly offers sound and ingenious solutions to climate problems is an important starting point in this respect".*

> *"On the other hand, understanding of climatic responses in both indigenous and current Balinese houses are, therefore, necessary as a guide to future dwelling design innovation."*
>
> Wall, 1996.

2.3.1. Traditional Dwelling

Marvels of nature and the built environment of Bali have become known all over the world. The climate can support a huge range of plants, and the Balinese love of beauty, architecture means that every possible space is landscaped. The style is informal, with a traditional pattern, with a rich variety of architectural features (Figure 2.11).

Figure 2.11. View of Traditional Bali House
http://www.guesthouse.com and www.purisantrian.com

Traditionally, architecture in Bali has taken advantage of the natural environment and primary factors such as the warm humid climate influences its dwelling design. Natural environment was united into the building characteristics, and this can be seen throughout the island as a unique pattern of vernacular architectural dwellings (e.g. Figure 2.12).

> *"The design takes advantage of the environment; use it to its full potential and protect the internal environment of the building from the undesirable external elements."*
>
> Kennet, 1998

2.3.1.1. Characteristics and Features

The vernacular house of Bali had been designed as a building compound, orientated to the courtyard, on a relatively square dwelling plot. This is divided into nine grid patterns with space and housing functions, as well as hierarchies.

The latter comes from the Balinese philosophical culture, with cross section orientations between the highest (North) to the lowest (South) of the Earth, and the highest (East) to the lowest (West) of the Sun.

In the traditional Balinese house, there are several small buildings such as shrines, the parents' bedroom, other bedrooms, the living room, kitchen, and granary.

Figure 2.12. Architecture with Nature in Bali
http://www.ritzcarlton.com and www.villas_bali.com

Each has an individual characteristic, a hierarchy of space, and certain functions. This compound is surrounded by a fence and has a main, roofed gate entrance, which is usually located at the area of lowest hierarchy (Figure 2.13).

The parents' enclosed chamber house is the north pavilion, the only building with privacy, and is the most important part of the dwelling after the shrines. It is built on the North side, facing South in the direction of the open space.

Spaces, semi-open for the son and daughter are oriented to the centre of the inner court of the house and are separate. The former is situated on the East facing West, and the latter placed on the South facing North opposite the parents' building.

Having a similar form to the children's bedrooms, a ceremonial, guest and living rooms are placed on the West area, facing East into open space opposite the sons' bedroom. The best place recommended for the kitchen is on the Southwest, facing North and as near as possible to the main roofed gatehouses. The granary, a 2-storey space, is constructed on the East side of the kitchen, facing West behind the daughter's room.

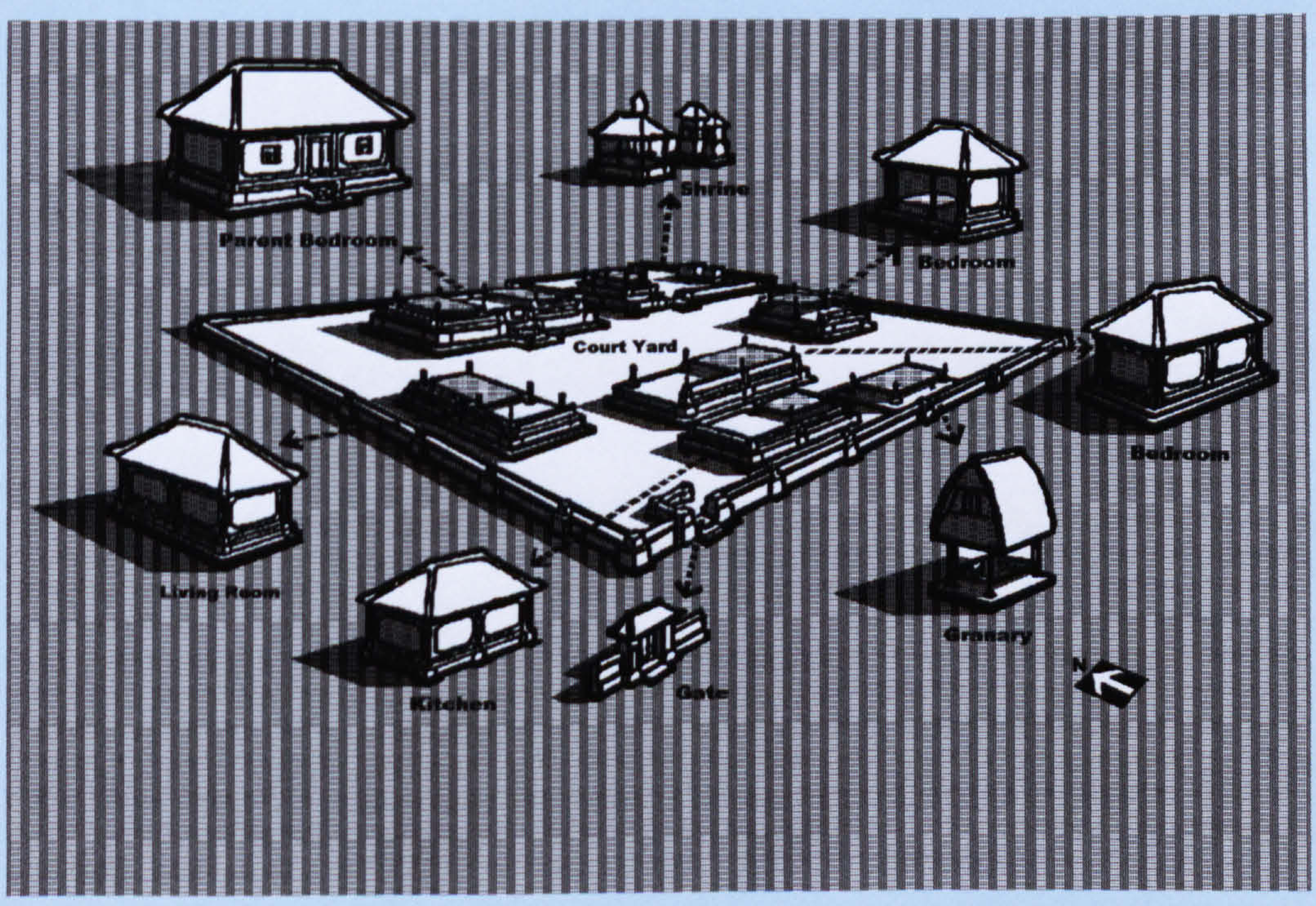


Figure 2.13. Traditional Bali House Pattern (Sulistyawati, 1998)

Following the Balinese beliefs about the way of life, the house can reflect this as part of the macro- and micro-environmental spaces. This bioclimatic response of the dwelling is not only to ensure harmony with nature but also that the environment remains within the house.

The space of highest hierarchy contains several small family temples and is used for religious activities, being located at the Northeast corner of the house site (Figure 2.14).

Figure 2.14. **Shrine (Family Temple)**
http://www.balisarad.com

2.3.1.2. Indigenous Climate Responsive Features

The house compound makes a remarkable statement about the uniqueness of the Balinese home (Figure 2.15).

This is the idea of a house where one lives outside, inside. Fenced in, from the front the street and neighbour houses but yet outside in an open space looking at the plants, birds and butterflies.

The compound consists of a series of buildings which are enclosed by a wall with gardens in between and all around them. That is the beauty of living in a warm humid climate, the opportunity to live in open spaces.

The small doorway, with an inviting gesture welcomes you inside. The entrance to any Balinese family compound is made as narrow as possible, narrow as the owners' body, and immediately behind it is another obstacle in the form of a low wall. The narrow entrance and the protective wall are important elements in the structure, for welcome and direction. This barrier is reinforced by carvings and ornaments in stone and wood and represents a strong tradition in the Balinese home.

The compound consists of a number of buildings of varying sizes, surrounded by a solid outer wall.

Figure 2.15. **Veranda of a Traditional House**
http://www.right-photo.com

The wall not only serves to ward off unwanted, invisible visitors but is also the visible symbol of the cohesion and solidarity of the Balinese extended family.

The wall and the gate vary in height and size. They reflect the wealth and the social status of the family who live behind them.

A simple farmer in a poor village may only be able to afford hedges to surround his simple compound, while a wealthy Balinese may enclose the large compound with thick and tall brick wall, and a richly carved gate. The wall serves the function to protect the compound against evil spirits or negative energies, and to provide a physical boundary as well as privacy. Like a human body, the compound is divided into three parts: the head, the body and the feet.

The head is the family temple; the body is the space where the family live; and the feet are represented by the backyard, where the family manage their waste. The family temple is used for worshipping the Gods and the Ancestors. The living space is used to sleep, eat, entertain, procreate, and conduct ceremonies related to the human life cycle such as birth, childhood, adolescence, marriage and death. In the past and in the villages, the backyard is used to manage waste, bodily as well as the waste from the rest of the compound. Here, they might keep pigs, goats, ducks, or chickens. Today, especially in urban area, it is difficult to find the backyards.

It was mentioned earlier that the island of Bali has a warm humid climate with unthreatening weather but *"Bali is in a zone of tropical storm and cyclone activity at an average of slightly less than one per year, and right on an average track line"* (World Map of Natural Hazards: Munich Re). Due to the global warming, the latter was nothing to occur but Balinese dwellings are adaptable to the climate.

The dwellings are designed with pitched roofs to deal with heavy rainstorms. The geography of Bali is sloping with terraces on the land contours from the mountains to the beaches, to avoid flooding. Strong winds that might happen only infrequently during the year are eliminated by high fenced walls, semi open dwelling design, brick wall partitions separated from structural buildings which are made of timber, and the gap between walls and roofs, which is good for cross ventilation. Earthquake experienced has been anticipated since a long time ago by non-rigid indigenous dwelling construction using timber materials. In fact, traditional dwellings built a hundred years ago still can be found. The extinct volcano of Gunung (mountain) Agung which has only once exploded, in 1963, is becoming a place of attraction for visitors.

Back to some of the reasons why Balinese live in a semi-open compound. The other reasons are of spiritual and practical significance. Spiritually, as part of Balinese Hinduism, people believe in the concepts of microcosms and macrocosms.

The former is a concept of seeing something or an entity as always consisting of three parts: a head, a body, and feet. The latter is a used as a way of classifying a space or a site, whether a family compound, a village or the island, into three realms: the abode of the Gods and Higher Spirits; living space for the human beings; and the living space for plants, animals and the lower spirits. Both microcosms and macrocosms are manifested in the family compound, by the Balinese consideration that the compound has a head (the family temple), a body (the living quarter), and feet (the service area). In addition to these concepts, the layout of the family compound is also based upon the belief in the influence upon the properties of certain cardinal directions.

For example the North and thus its subsequent complementary directions of Northeast and Northwest are considered sacred, because of their association with the sacred mountains of Bali. Thus, an appropriate place for the family temple is in the Northeastern part of the compound.

The South is considered the abode of the God of fire, and hence the Southern part of the compound is appropriate for the kitchen.

The compound system also has practical applications: it creates several small niches for different family members to conduct their respective activities; it provides spaces in between buildings to accommodate the Balinese Hindu ceremonies and the guests who come to attend them; and the compound's yard also serves as a productive system to supply some of the family's need for flowers for offerings; as well as fruits, spices and vegetables.

> *"As a result, living outside inside, in a compound house, where spiritual concepts and belief systems, as well as the consideration to create a productive system are integral parts of the design, is yet another unique feature of Balinese society."*
>
> Tisna, 1999.

Balinese family compounds are often similar. All of the entrances are on the same side, within the rectangular enclosure the inevitable family temple is always in the same position, and the various buildings are arranged in almost exactly the same pattern.

At first sight, it is difficult to see any real difference between one compound and another. Whether the family is rich or poor, the family temple, the living, and the sleeping apartments, the kitchen, a building that serves various ritual purposes are designed in the same broad plan.

The more prosperous homes will have higher quality wood and stone, larger buildings and finer quality carving and art.

The number of buildings which contain the living and sleeping chambers varies according to the size of the family. The largest building, always situated close to the family shrine, belongs to the parents, who enjoy the greatest respect.

The younger generation sleeps separately according to sex; sometimes unmarried girls and young women are accommodated in the parents' house.

2.3.1.3. Building Materials and Construction

Figure 2.16. Vernacular Dwellings
http://www.membertripod.com

The buildings are composed of local indigenous material such as limestone, bricks, timber, bamboo, wild grasses, etc. (Figure 2.16). Foundations are constructed of stone. From ground level to the floor brick level is surrounded by limestone, and used also to support the brick wall partitions from floor level to the roof. A space-frame structural system of columns and beams uses coconut timber for the main roof trusses.

Roofing material has traditionally been made from thatch wild-grass with exposed bamboo framing. This material is both aesthetic and practical, as it keeps the building watertight against tropical downpours and provides cool shading to the interior.

However, development has affected the roof finishes of traditional dwellings, which have more recently been of clay roof-tiles on timber frames.

Bali is rich with coconut timber used for the building material, particularly in traditional buildings as conservation for the built environment. Timber as building material is commonly used for doors, windows and roof truss framework in traditional construction.

In a structural dwelling, the non-rigid timber construction is important. Timber has a long history of use as a structural building material and finds its way into many varied applications, from architecture to civil and structural engineering. Various hardwoods can be used in production of structures, including old growth coconut wood and teak species. These types of wood are quite rare in other parts of the world, but are plentiful and easily found in Indonesia. This traditional material may be more practical and follows the code of harmony with nature.

Hand carved wooden components, such as decorative posts, as well as flooring, wall and ceiling panels can easily be produced to custom dimensions.

Bricks and roof tiles have been common used in Bali. Stone, especially the various types of indigenous stones, can beautifully complement the hardwood structures, either in a garden and residential setting.

These can incorporate stone-carved features in a traditional theme or to suit a preferred design. Stone relief carvings for exterior or interior walls, custom stone garden statues and hard-landscape can be provided in various quantities and dimensions.

All houses are custom designed to the qualifications for home garden living. It is considered in detail including local building codes and weather conditions.

All materials are carefully selected and examined for the highest quality. This also ensures that all materials are appropriately treated for boring insects, maximum durability, and that all wood is checked for suitable moisture content. (Figure 2.17).

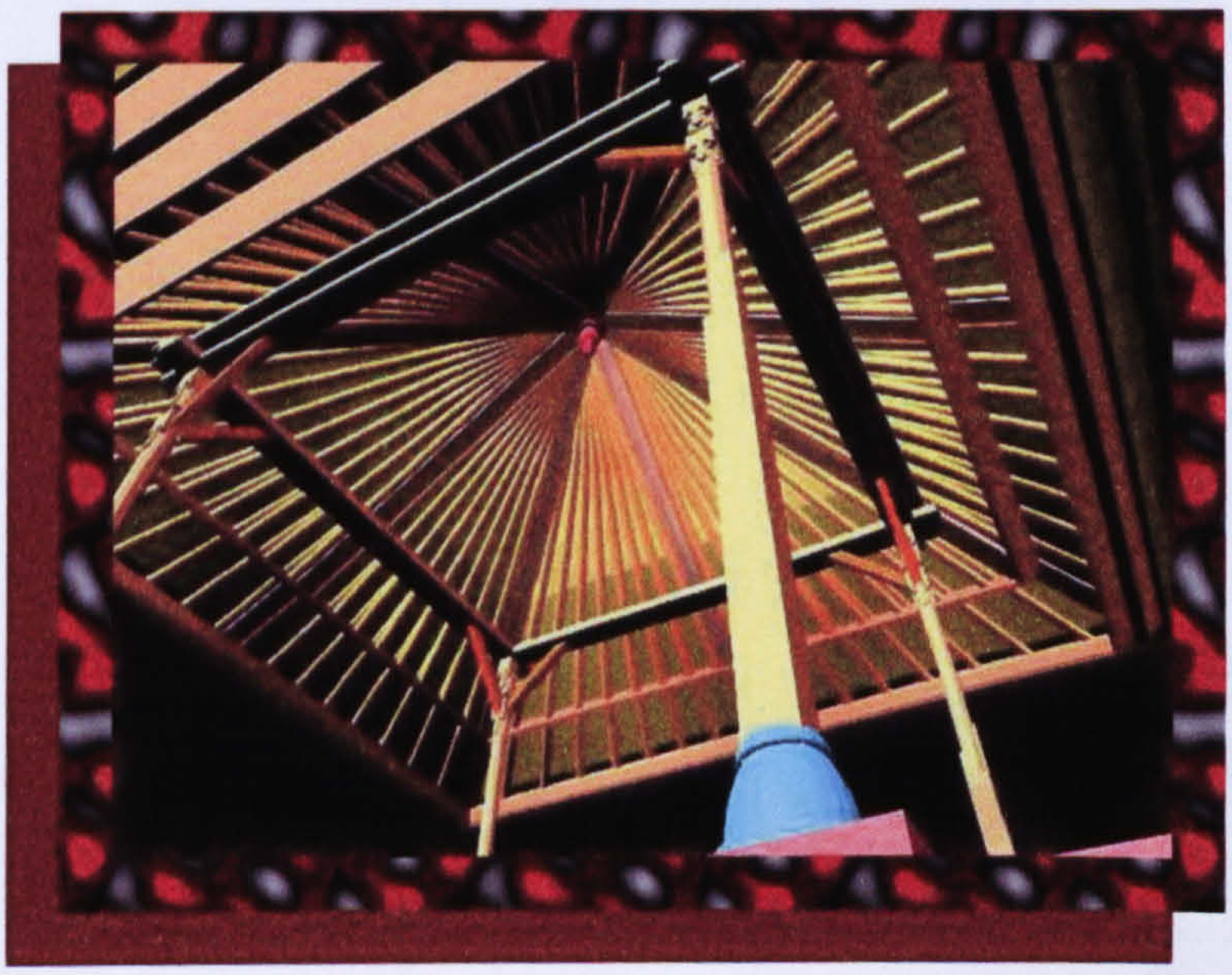


Figure 2.17. Traditional Bali Interior
http://www.bali-indo.com

When examining the history of the traditional dwelling in Bali, a great deal of development in both form and materials can be detected.

In this regard, Gill (1990) recognised that *"by this time building designs had merged with the indigenous architecture in such a way that should be suitable for the region's yearly pattern of dry and rainy seasons"* (e.g. warm humid climate).

Between the posts, there are built-in beds or platforms, made of wood with springs of bamboo. A clear separation between wall and roof characterises the construction of the dwellings. For the final touch masonry decoration and ornamentation are usually added, being mainly applied to pillars, and to the walls of the dwellings (Figure 2.18).

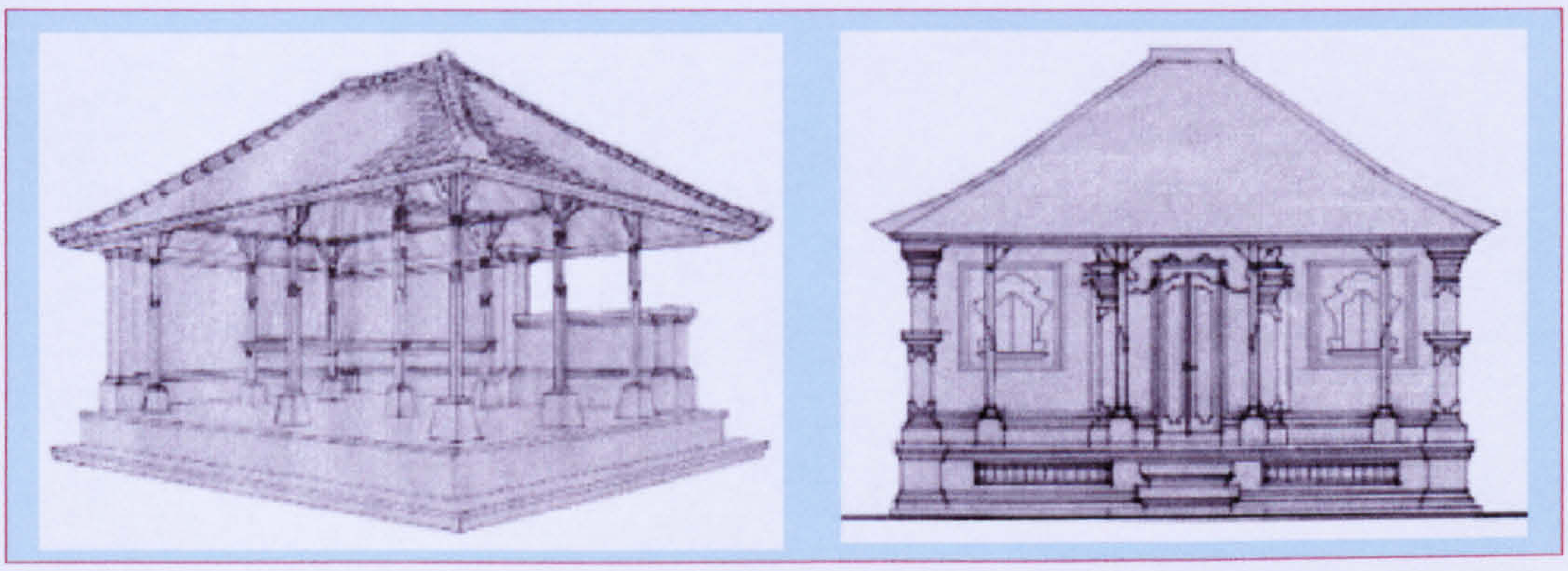


Figure 2.18. Traditional Architecture in Bali (Saraswati, 2000)

2.3.2. Contemporary Dwelling

2.3.2.1. Characteristics

In present developments, due to tourism and urbanisation, modern mass housing of compact design is built on small sites and without any respect for the indigenous pattern.

The housing characteristics today have changed from the vernacular open courtyard design on a large site, to modern, compressed, compact dwellings on small sites. The contemporary buildings have not only replaced traditional dwellings but natural building materials have also been replaced (Figure 2.19).

Concerning the building structure, reinforced concrete has been commonly used for the dwelling. Concrete is the principal building material in the structure, and has the added benefit of being a fire resistant material. It is contrast from the traditional compound which isolates the kitchen, to reduce the risk of fire to the whole compounds. The compact house is the defining image of any new settlement, being either of one or two storeys.

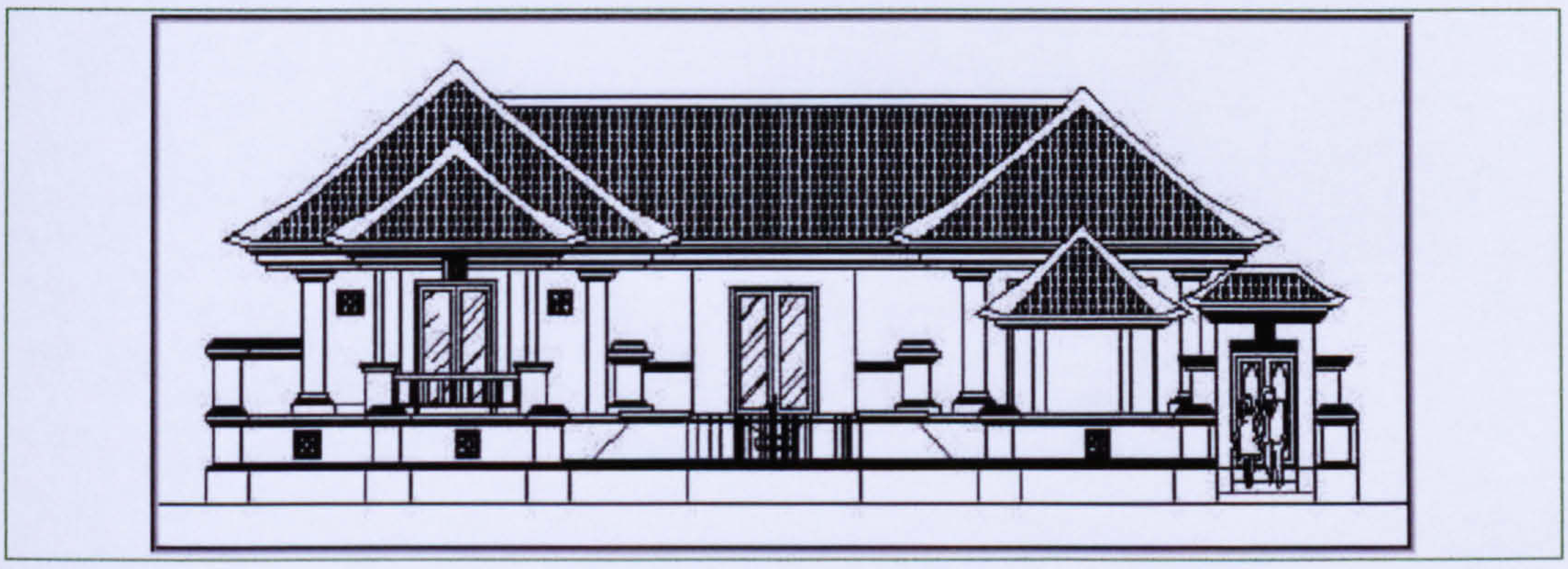


Figure 2.19. Modern House
http://www.membertripod.com

Recent dwellings have quite different physical characteristics from traditional ones (Figure 2.20). Orientation and cosmology are only rarely considered in the design. Although following traditional patterns, the decoration may be applied only to the façade of the house.

House development occurs through time and space, and parallels and reflects the Balinese changing needs and expectations.

However, *"the modern house has to serve not merely the simple purpose of living but also the complex demands of modern life"* (Gardiner, 1975).

Therefore, the appearance of the buildings in Bali is much the same as in other parts of Indonesia. The design may vary in size, but invariably they are materially similar.

External surfaces are enclosed by structural walls; every room has opening windows and opening doors, while roofs are sloped and has a suspended ceiling underneath. Building materials commonly used are terrazzo or ceramic tiles for the floor, and brick or concrete blocks (the most common) for the walls.

There is glass within a wooden frame for windows or openings, double sided plywood for doors, timber louvers for fixed openings, terracotta tiles for the roof covering and fibre cement or plywood for the ceilings.

"As the mainstream of dwelling is clearly rooted in the traditional vernacular forms" (Peter, 1998), the roof is also extended beyond the building perimeter to create an overhang to provide sun shading.

These houses are generally built in areas where the influences of economic development and tourism are the greatest, and this can be either within the city, or on its outskirts.

Figure 2.20. Current Contemporary Dwellings

Indeed, traditional housing performance can only be sustained by people with high incomes, and of course exclusive villas for tourists' comfort (Figure 2.21).

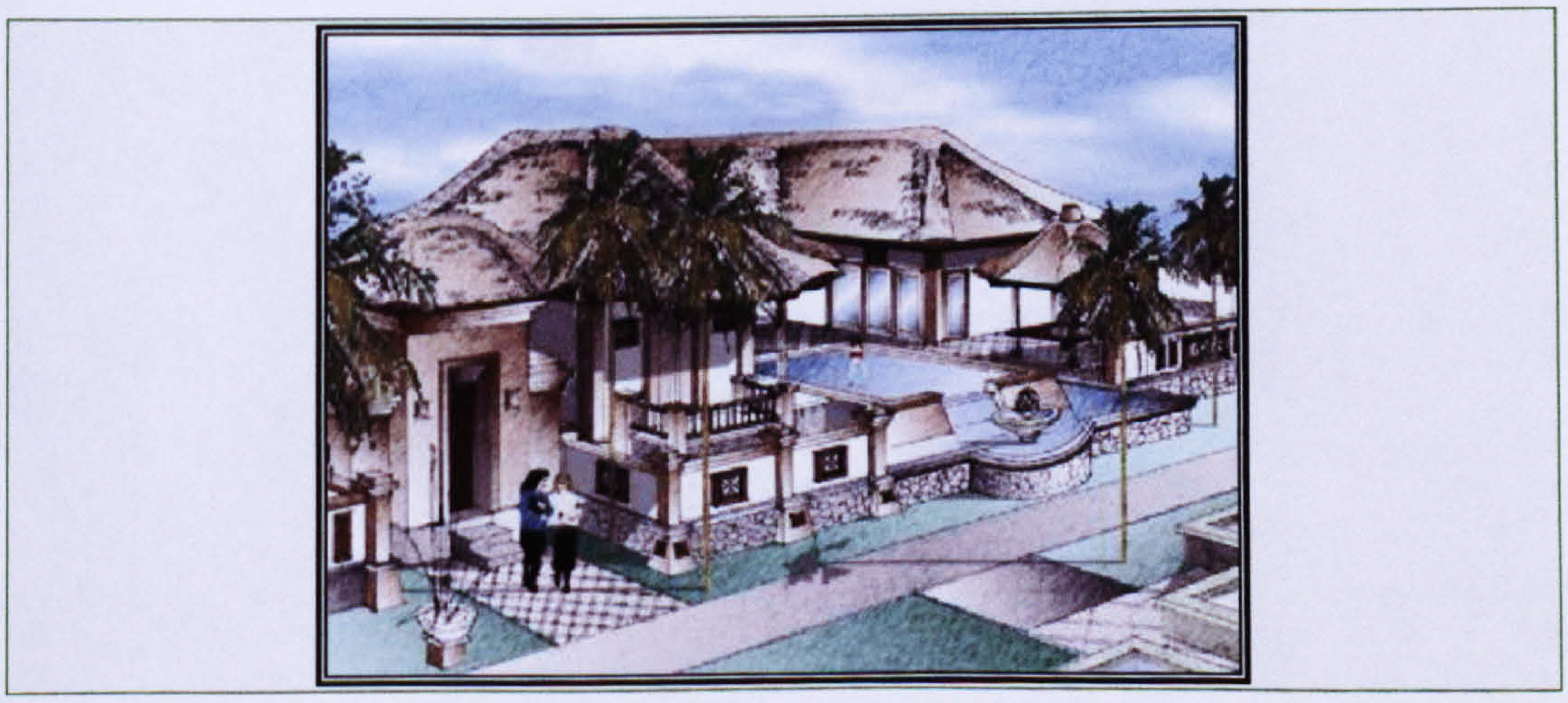


Figure 2.21. Exclusive, Traditional Villa
http://www.membertripod.com

For example, some delightful villas have been constructed in recent developments, each set in a charming village and enjoying spectacular, uninterrupted views of the environment such as rice paddy fields in the background and ocean and volcanoes in the distance.

The courtyard garden has been replaced by the private swimming pool. Balinese traditional building material is used to impress, rather than for performance. These houses comprise bedrooms with air conditioning, en-suite bathrooms, large open planned living/dining areas and kitchen, and include a landscaped garden.

Figure 2.22. is an example of a new plan Villa (Family Compound House).

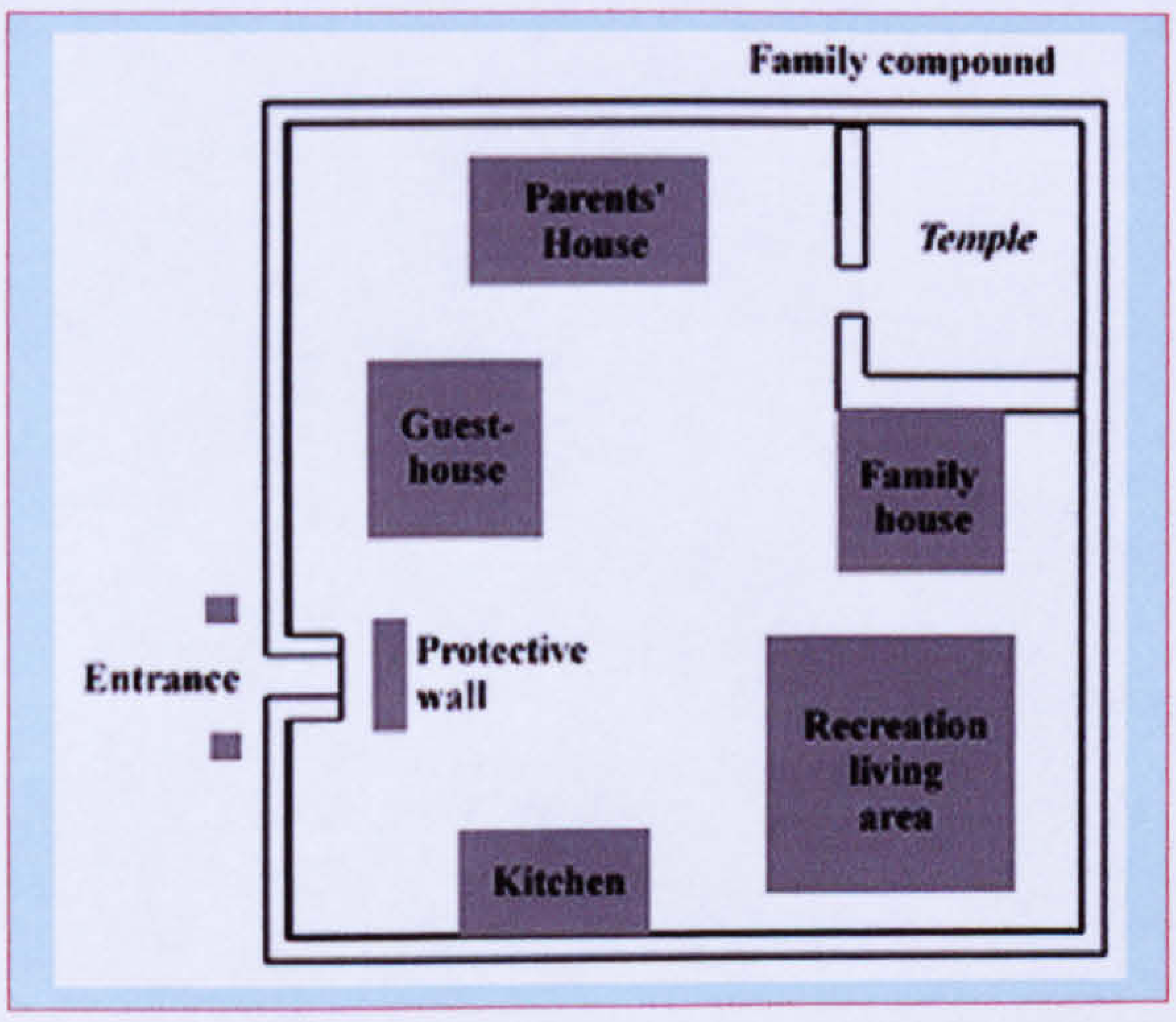


Figure 2.22. Villa (Family Compound House)
http://www.tradeia.co.id

2.3.2.2. Building Typology

The standard type of contemporary dwelling is commonly designed as a compact property to accommodate the typical couple with two children and a middle class income.

The size of the dwelling is approximately 36 square metres on a plot of 108 m^2; it contains two bedrooms, a living room, kitchen and bathroom.

It is important to discuss the reasons for selecting the particular building typology in this research.

This dwelling standard was designed based on the national government's family planning recommendation, which is that a couple should have two children. To encourage the success of this program, a couple with three children would receive social benefit from the government for only two of them.

With 80% of the urban population coming from the low and middle income bracket, (see Chapter One section 1.1.3.2. Dwelling Needs); this contemporary typology is suited to this 'standard' family size.

In this study, the research is concerned with the following considerations that: (see also Chapter One section 1.1.3.6)

- The dwelling is affordable for the majority of people, who mainly have middle-class incomes.
- The dwelling can be made affordable to the people below middle-class incomes, by providing loans.
- The dwelling will encourage those with higher incomes, including tourists who live permanently in Bali for some reason, to adapt to this standard dwelling rather than to build luxurious accommodation.

The configuration on the plot is 1-attached house, which has one side wall of the dwelling on the periphery.

The plan of the dwelling is presented in (Figure 2.23), and (Figure 2.24) shows the elevation and section of the dwelling.

Figure 2.23. Floor Plan of Standard Dwelling

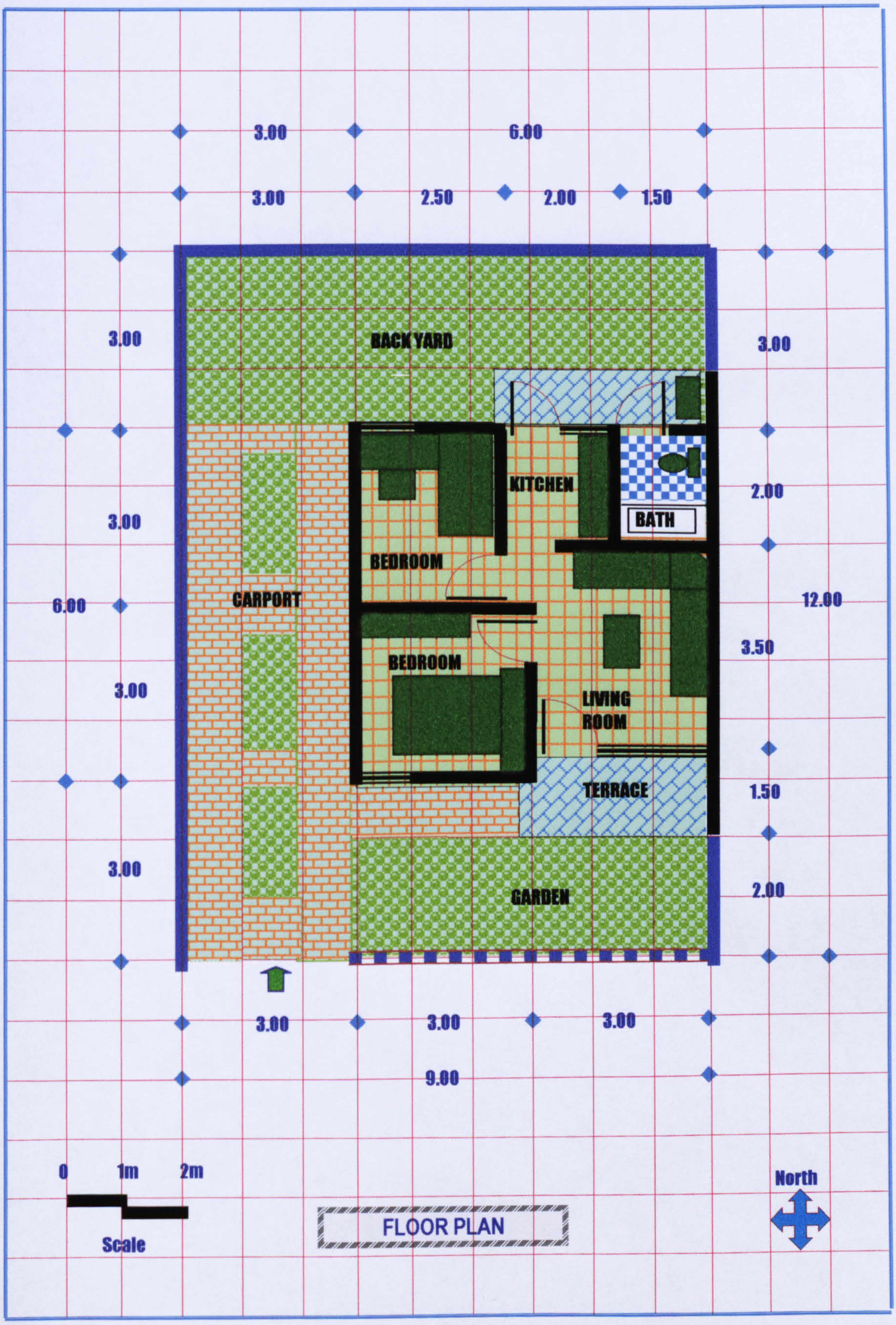
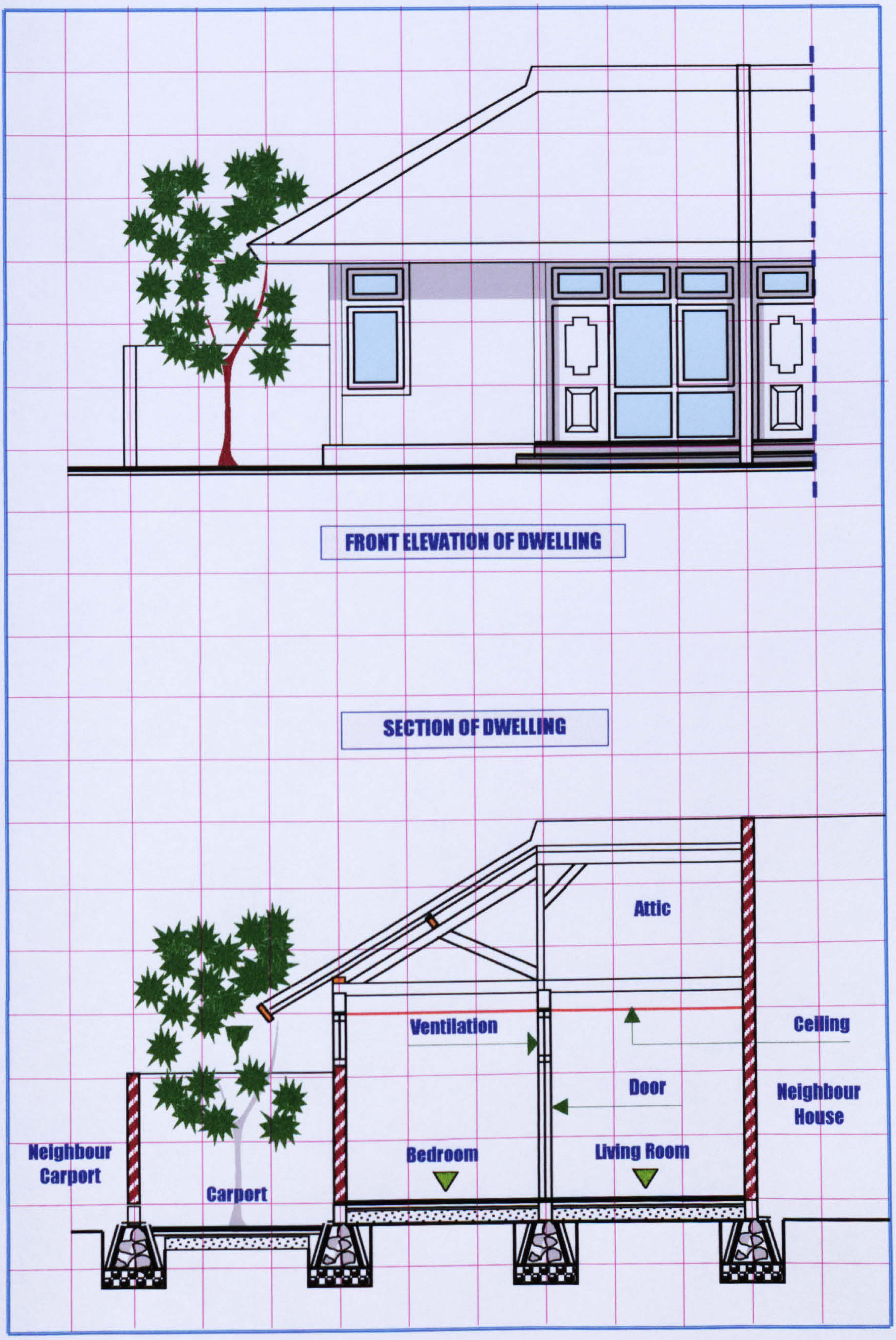


Figure 2.24. Elevation and Section of Standard Dwelling



2.3.2.3. Problematic Thermal Issues

At any time, the comfort of an individual in the rooms of the house has been recognised as the first, vital element in the building's arrangement.

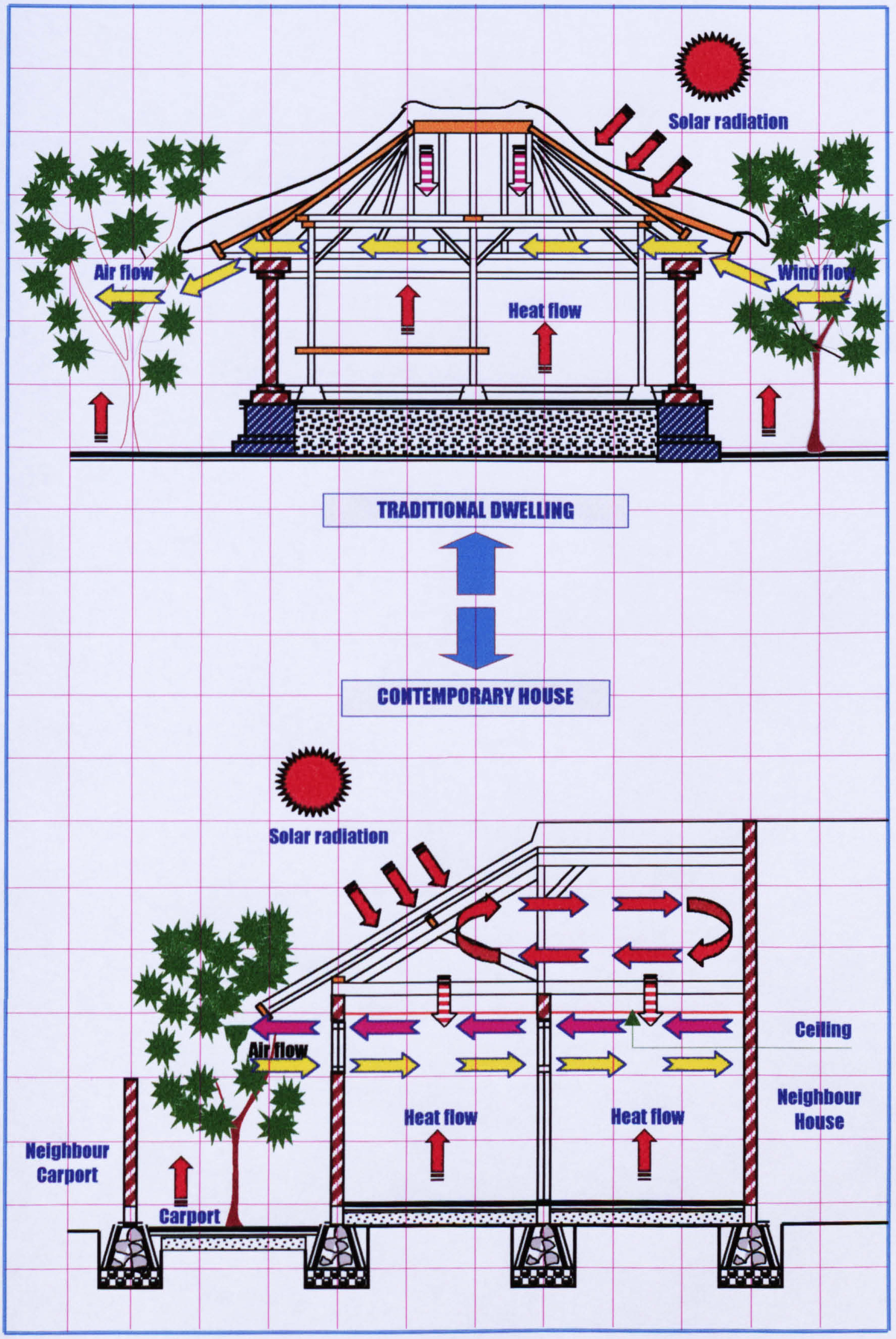
In the vernacular house, an open structure of buildings ensures comfort of the occupants. Spaces within spaces, and living inside outside on a large plot were the basic concepts of the house. Individual rooms within one building and the open layout system of the traditional house allowed free air movement. Natural building materials were adaptable, to maintain thermal building comfort conditions in the surrounding of the house. The pitched roof shading and its local materials were highly suitable to the climatic circumstances, and supported comfortable room conditions. Rooms without ceilings provided more volume and permitted fresh air circulation in the building. Natural ventilation and raising the floor above ground level decreased the high humidity of the warm climate (Figure 2.25).

The vernacular housing pattern of Bali was a small group of dwellings clustered together and buildings were commonly designed to take best advantage of the thermal comfort from the natural landscape, and solar gain.

Nowadays, most modern buildings have several rooms within one dwelling, and they have been compressed onto a small site. The typical design of closed spaces has affected the ventilating system in an unhealthy way, and prevents air movement in the house. The uncomfortable air temperature in the dwelling has been increased by solar radiation. The flat ceiling of the rooms reduces room volumes and increases room air temperature (Figure 2.25).

In the modern design, this natural pattern has been lost and dwellings are compressed onto sometimes unsuitable sites. Poor ventilation in most current houses has caused a trend towards installing air conditioning. That is good for indoor air, but it makes the outdoor air more inhospitable. The energy load used for room cooling in this unhealthy dwelling environment can be high and inefficient.

Figure 2.25. **Problematic Thermal Issues in the Dwellings**



2.4. CONCLUSION

The traditional dwelling architecture of Bali is an expression of Balinese culture, and one of the country's greatest assets.

The traditional compound dwelling pattern in Bali was constructed on a relatively large plot site, using local materials in harmony with nature. Being highly ventilated and thermally efficient, this was the proper dwelling design for warm and humid climatic conditions. It was designed on an open plan, with exterior and interior spaces being sometimes hard to define.

However, given the recent national economic situation and migration pressures, it has become difficult to build the Balinese traditional house. Compact, mass housing has been offered for the people to live in.

As mentioned in the introduction chapter, to achieve thermally comfortable conditions in these compact dwellings may require air conditioning.

However, to achieve energy efficiency cross ventilation is necessary. These two strategies conflict with each other, and a combined design incorporating both strategies is required.

The recent economic situation has led to the search for new and indigenous building materials, which are structurally suitable for thermally comfortable dwellings; whilst related to the warm humid climate, they must possess potential for energy conservation. For instance, coconut timber has been used for many years in the traditional dwelling and is well known as an efficient heat insulator that could be used in various dwelling interior designs.

For these conditions, special dwelling designs are needed, for the traditional dwelling to be sustainable and the use of energy resource should be as efficient as possible. Natural ventilation and air-conditioning can achieve these particular objectives.

In the traditional dwelling, the use of wide eaves, little external walling, a raised floor and separate shelters exemplifies the sophisticated range of environmental options offered by buildings within a compound.

The pitched roof, apart from functioning as a means of dwelling protection, provides shading for walls and floor, allowing minimum impact of high solar radiation.

Generally, each dwelling has few walls and separate spaces, giving maximum potential for air movement. Such plan layouts allow cross ventilation whatever the wind direction, even when the pavilions are close together, hence providing the possibility of internal temperature reduction. In the case of enclosed pavilions (parent pavilions), where thermal discomfort might possibly occur, cross ventilation may still be induced by the continuous ventilation resulting through a gap between wall and roof.

By contrast, the common use in the contemporary house of compact form, with complex multi-walled rooms, would seem to encourage uncomfortable indoor conditions due to lack of cross ventilation. The presence of internal partitions can block the flow of air, and thus considerably attenuate the effectiveness of openings. The effects might not be too serious if the dwelling stood alone, but since contemporary dwellings are often constructed close together a result of the limited plot size the potential area for opening is reduced, and the resistance to airflow correspondingly increased.

Contemporary buildings function in quite different ways (see Figure 2.24, and 2.25). Though a pitched roof form with wide overhangs is also employed to reduce the impact of solar radiation, the use of multiple spaces in a compact form may to a great extent diminish the environmental benefits that have been achieved through the design of the roof.

The use of internal solid wall subdivisions can prevent cross ventilation from taking place. Although there are windows along the perimeter, they may be ineffective due to such internal partitions.

In these cases, it is probable that the rate of ventilation will be insufficient to dissipate any excess heat from the building and will result in a considerable reduction of the air movement that is used for physiological cooling. Hence, there is the possibility of an increase in indoor air temperature.

Close proximity of building units, tight planning and often inappropriate building orientation are other factors characteristic of contemporary dwellings that may be have a negative impact on the internal conditions of the building, since they can deflect, obstruct and obviate the potential benefit of the wind.

Where dwellings are in closer proximity to one another such as in urban areas, similar problems are likely to arise due to the obstruction of the surroundings.

The tendency to occupy a very limited plot shown by current dwellings can actually pose a major obstacle, especially in promoting ventilation and air movement. On this point, it can be argued that the present house dweller is potentially at greater risk of suffering from thermal discomfort indoors.

Where internal discomfort is experienced in these dwellings, this can encourage the use of mechanical equipment, such as fans or air conditioning to maintain favourable indoor conditions.

In these respects, a mechanical comfort system addition to maintain internal discomfort indoor conditions in the modern dwelling, and adaptation to an air-conditioned building design will be necessary.

Climatic-responsive design is important to the contemporary house, and the principles that are adopted, either consciously or unconsciously, in the traditional dwelling may be judged well termed to local conditions.

An understanding of climatic response in both traditional and contemporary Balinese dwellings is, therefore, necessary as a guide to future building design.

The proposition put forward by many researchers that traditional dwelling design commonly offers sound and ingenious solutions to climate problems is an important starting point in this respect.

Unfortunately, due to the need for big plots and the high cost, it is impossible for this indigenous dwelling design to become the common dwelling type.

Heat was the main problem in these dwellings, causing uncomfortable internal conditions that could be too warm in the high humidity. This combination, coupled with high solar radiation created difficulties and high rates of ventilation and air movement were the only practical way of restoring comfort.

Chapter Three

ENVIRONMENTAL SETTING AND THERMAL COMFORT OF BALI INDONESIA

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Chapter Three

ENVIRONMENTAL SETTING AND THERMAL COMFORT OF BALI INDONESIA

3.1. GEOGRAPHICAL CONTEXT

Bali is a tropical island, situated at 08.45 degrees South of the equator. This small island has a mountain range in the centre, which is between 1,350 meters and 3,014 meters high. A plain, coastal region surrounds it.

Recently however, as can be seen on Figure 3.1, those beaches, plains, hills, and mountains that existed once in simple harmony with nature, have been changed towards being a tourist-oriented, built environment.

Around Bali is a beautiful landscape which stretches from the West to the East. The South part of the island, where Denpasar, the state capital of Bali is located, is more beautiful, with white sand beaches, artistic architecture and a green environment. There are lush tropical forests, pristine crater lakes, fast flowing rivers and deep ravines, picturesque rice terraces and fertile vegetable and fruit gardens. The North part of Bali is more adventurous, covered with grey or black volcanic deposits and warmer than the Southern area.

Figure 3.1. Changing Geography of Bali

Sources: http://www.wrightphoto.com, http://www.nusadua-niko.com, http://www.greengarden.com

> *"__BALI.__ The name itself summons up a host of images. A tropical island-lush vegetation spilling down volcanic mountainsides, sandy beaches, coral reefs and surf. A landscape sculptured by skilled hands over the centuries into a visually stunning hydraulic system of contoured terraced rice fields of every shape and size and all imaginable shades of green. Village tranquillity, urban congestion. Friendly people, smiling faces, laughter. A crowded island where Hindu ceremony is articulated daily, in ways which reflect a palpable, enduring culture. __PARADISE.__"*
>
> Bater, 1995.

3.2. CLIMATICAL CONTEXT

3.2.1. Introduction

From a previous study by Antaryama (2000), climate according to Trewartha and Horn (1980), *"is a synthesis of the daily values of the atmospheric elements within a specified area, over a long period."*

> *"The sum total of atmospheric variables, such as temperature, precipitation, humidity, wind, sunshine and any other meteorological events experienced at a given place for a brief period of time may be defined as the weather of a location. In this sense climate should also be regarded as the integration in time of weather conditions."*
>
> Koenigsberger et.al. 1974.

The variety of climates, which is practically infinite, is produced by the interaction of solar radiation with the atmosphere and with gravitational forces, together with the distribution of land and sea masses. These characterise the conditions of a given location, which is recognised as a climate zone.

A number of different classifications of climate zones have been developed by geographers over some 60 years, and have been used for different purposes. Most have been established based on detailed analysis of climatic data, of concepts such as evapo-transpiration, and the observed nature of natural vegetation (Koenigsberger et.al. 1974).

Warm humid climates are found in the latitudes near the equator, extending to about 15° North and South.

The defining characteristics of these regions are luxuriant, dense and quick-growing vegetation with both frequent rains and high temperatures.

Growth of fungi, rusting, rooting and the presence of insects are characteristic. Climate conditions are marked by small annual diurnal range.

Air temperature in the shade, reaches a mean maximum between 27 and 32° C during the day and mean minimum between 21 and 27 °C at night. Like temperature, humidity is also high during most of the year, even in the dry season. Relative humidity may vary from 55 to almost 100%, and the average is about 75%. Water vapour pressure remains steady in these regions with a value of 2500 to 3000 N/m^2 (BMG, 1995).

Precipitation, one of the dominant characteristics of this climate, is high throughout the year with an annual rainfall in excess of 1500 mm. The highest precipitation generally occurs during the warm season and may exceed 500 mm in a single month (Trewartha and Horn, 1980).

Sky conditions, which are fairly cloudy and hazy throughout the year, cause diffuse radiation. Although diffused the solar radiation is strong, causing sky glare. With a cloud cover of between 60 and 90 % accompanied by vapour content, the outgoing radiation from the earth and sea is not readily dissipated during the night. This is because the cloud water vapour contents prevent dissipation to the sky. Reflected radiation from the ground is low. If there is limited cloud cover and the sun is not hidden, the sky can be bright with a luminance of 7000 cd/m^2 or even higher (Antaryama, 2000; BMG, 1995).

As has been described in the previous section, Bali is a warm humid climate island, situated at 08.45 degrees South of the equator.

Figure 3.2. shows the warm humid climate within the Climatic Zones on the Psychrometric Chart.

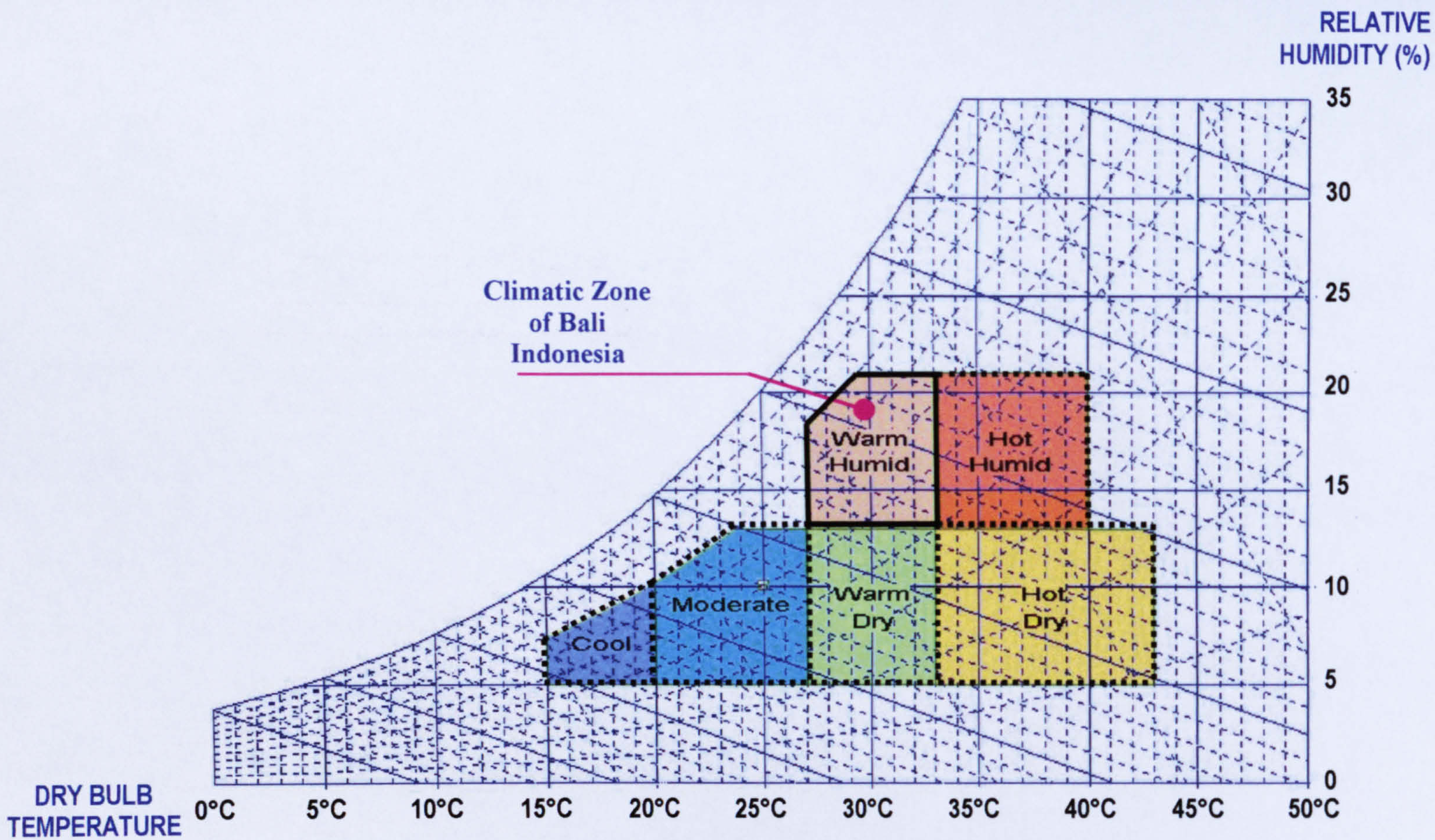

Figure 3.3. **Climatic Zones of Bali Indonesia on the Psychrometric Chart (Marsh, 1999)**

3.2.2. Climatic Analysis

Table 3.1. shows the daily average climatic conditions of Denpasar, Bali at the latitude 08.45 S, longitude 115.15 E, elevation 3 m, in the period between 1986 and 1995 (Bureau of Meteorology and Geophysics [BMG], 1995).

Elements of Climate	Monthly Mean											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Dry Bulb Temperature Daily °C												
Max	31.4	31.6	31.7	31.6	31.0	30.4	29.5	29.4	30.3	31.2	31.7	31.8
Min	24.6	24.8	24.6	24.5	24.1	23.9	23.6	23.5	23.6	24.2	24.9	24.9
Mean	28.0	28.2	28.1	28.0	27.6	27.1	26.5	26.4	26.9	27.7	28.3	28.4
Relative Humidity Daily %												
Max	95	94	94	94	94	93	91	91	92	93	93	94
Min	64	63	63	64	64	63	61	60	60	58	61	61
Mean	80	79	79	79	79	78	76	76	76	76	77	78
Precipitation Monthly mm												
Total	423	320	179	110	44	48	43	36	26	39	164	266
Sky Conditions Daily Duration hour												
Sunshine	6.1	5.9	7.4	7.2	8.6	8.1	7.8	8.6	8.3	8.9	7.3	6.8
Solar Radiation Daily Total Irradiation Wh/m2												
Global	5824	5775	6302	5815	5848	5383	5367	6126	6479	7051	6359	6089
Beam	3552	3497	4075	3743	3946	3594	3547	4149	4334	4789	4081	3825
Diffuse	2272	2278	2227	2072	1902	1789	1820	1977	2145	2262	2278	2264
Wind Daily m/s												
Mean speed at 0m height	2.4	3.0	2.2	2.2	2.8	2.9	3.6	3.6	2.9	2.5	2.0	2.4
Mean speed at 3m height	1.2	1.5	1.1	1.1	1.4	1.4	1.8	1.7	1.4	1.2	1.0	1.2
Prevailing direction	270°	270°	90°	90°	112°	112°	112°	112°	112°	135°	135°	270°

Table 3.1. Average Climatic Conditions of Denpasar, Bali, Indonesia
Source: Bureau of Meteorology and Geophysics (BMG), 1995, Climatic Data, Denpasar Station, Ngurah Rai Airport, Bali

3.2.2.1. Air Temperature

In the warm tropical climate, dry and wet seasons, Bali has an average air dry bulb temperature of over around 30°C, and there is very little difference in air temperatures between day and night, with diurnal variation of 6°C - 10°C. The dry season is warmer than the wet season, and indoor air temperature is hotter than outdoors. There is a vapour load from outdoors through to the air indoors.

Experience indicates that within the house, the room temperature is uncomfortably high which can decrease productivity.

3.2.2.2. Solar Radiation

The solar radiation on the building and environment is for approximately 12 hours every day. The sky is bright and glaring even with thin cloud cover, and the radiation is high. A high intensity heat index of 32°C occurs between 9:00 a.m. and 15:00 p.m. The sky conditions influence not only daylight radiation, but also long-wave radiation to the sky. This radiation has its wavelength within the infrared spectrum and is not visible.

The daily total global irradiation on horizontal surfaces is high in Bali. The average value over the year reaches 6,035 Wh/m^2/day. The maximum value of 7,050 Wh/m^2/day occurs in October, and the minimum value of 5,370 Wh/m^2/day in July. Around half to two thirds of this total global irradiation is diffuse, indicating a high non-directional radiation (see also Appendix - I).

Higher daily total diffuse irradiation of between 2,260 and 2,280 Wh/m^2/day is experienced from October to February. From March to September, values less than 2,230 to a low as 1,820 Wh/m^2/day occur (Antaryama, 2000).

3.2.2.3. Relative Humidity

At ground level, during the day, relative humidity (RH) rapidly decreases. If moisture is available in the form of water or rich vegetation, strong evaporation may increase RH. At night the situation is reversed; as the lowest level cools its RH rapidly increases, and condensation may occur if the saturation point is reached.

> *"The above problem has influenced the development of the traditional and modern house in the region."*
>
> Clark, 1992.

The humidity content is about 80%. The relative humidity varies with the air temperature; in the morning, the temperature is comparatively low and the relative humidity is high, possibly up to 95%. In the afternoon the opposite occurs; when it is warm, the relative humidity is lower, at about 60 - 70%. The exception is during the rainy season, when temperature and relative humidity do not vary much over the day.

3.2.2.4. Wind

Wind speeds of about 10 knots per hour, or about 4 m/s per hour are common (Figure 3.3). The wind velocities are low but strong winds may occur. At the coasts, there is a sea breeze during the day.

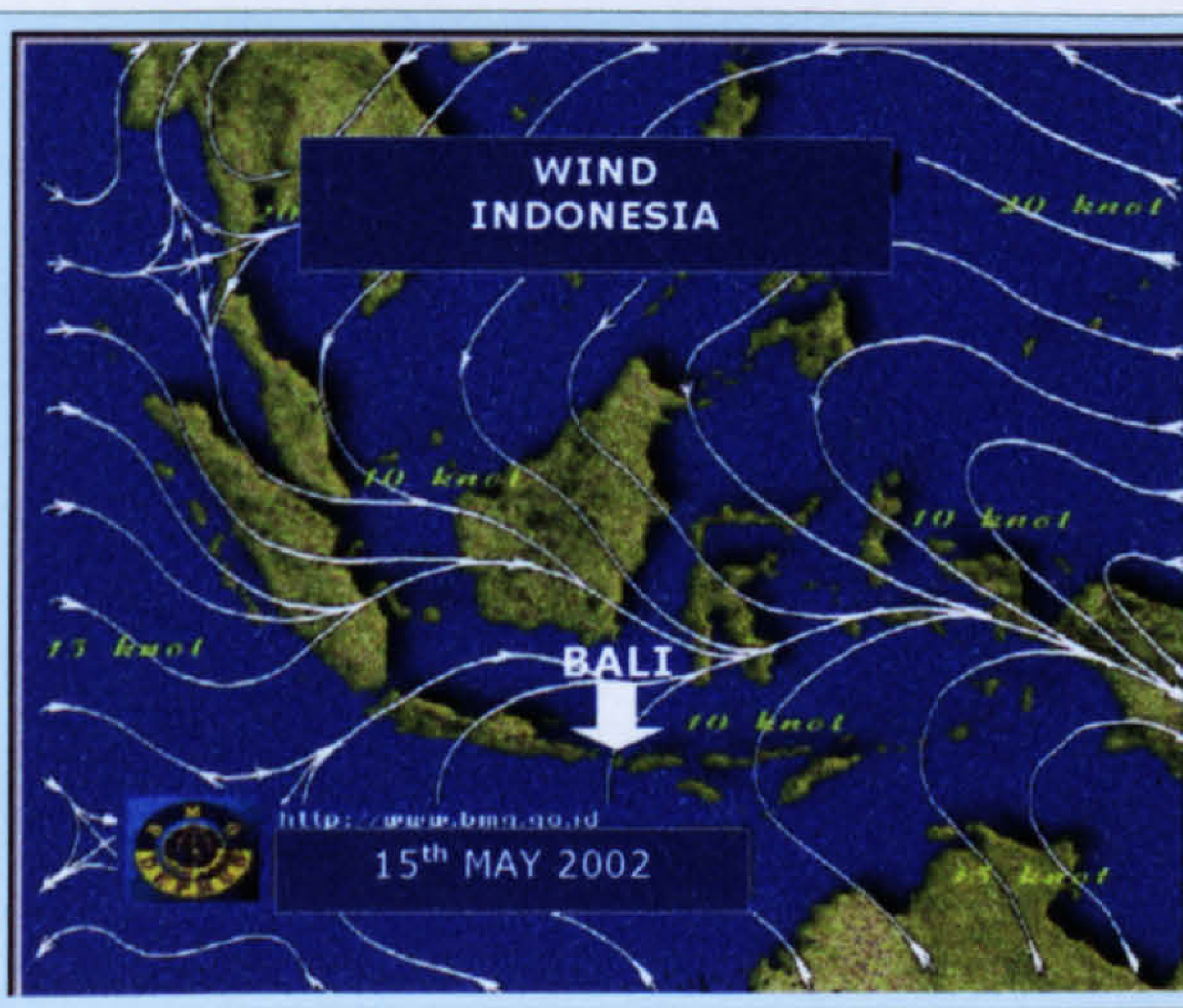

Figure 3.3. Wind in Indonesia
Source: http:/www.bmg.go.id

Typical wind speeds are low. At 10 m height above ground, a wind speed of 2.7m/s is experienced on average over the year, but this tends to be higher during the cool months (e.g. 3.6 m/s in July and August), and lower in the hot months (e.g. between 2-2.5 m/s from November to April with an exception in February, when 3 m/s is recorded). At 3 m height above ground these values are further reduced (BMG, 1995).

Over the year three wind directions, i.e. easterly (90°), south-easterly (112.5° or 125°) and westerly (270°) are dominant. Calm periods, however, also occur frequently throughout the year (about 27.7% of occurrence). From May to September the East South East (ESE) wind is dominant. This shifts slightly to a South-easterly (SE) direction, in October and November. From December to February, the prevailing winds are from the West. Easterly winds only occur in April, while in March there is a transition between the easterly and westerly wind, in which the easterly one proved slightly higher within the ten-year period 1986-1995. Calm periods are generally commonest during the hot months and are less frequent during the cool months (Antaryama, 2000).

3.2.2.5. Precipitation

From June to September it is pleasantly cool in the evenings. During this time of year, Bali's coastal areas have hardly any rain. However, in the hills and mountains one must expect cloudy skies and showers throughout the year.

Higher regions may also cool after sunset. Rains can heavily wet the external walls of the houses, and it takes time to dry the wall surfaces resulting in black mould as well as algae growth.

Total rainfall over the year is high, i.e. 1,500 mm. From November to May the conditions are generally wet, when a monthly total rainfall of well over 100 mm and may exceed 500 mm is recorded. From June to October the conditions are dry, with monthly average rainfall generally less than 50 mm. These two conditions, i.e. wet and dry, characterise the seasons on the island.

3.2.2.6. Special Considerations

The sky conditions are cloudy throughout the year on the mainland. The sky is bright and glaring even with thin cloud cover, and the radiation is high. With thick clouds, the radiation is low. Over the islands the sky is often clear with limited cloud presence. This means that the daylight radiation on the mainland is often diffuse but high with thin cloud cover, and more direct on the island.

The sky can be considered as a surface with a certain temperature (sky temperature) determining this long wave radiation. During clear nights and days the sky temperature can be 20 - 30° C lower than the air temperature, but during very cloudy days only a few degrees lower. Shading is an important method of cooling. Shading the air cools it and shading surfaces cools them, that is if the material used for shading does not itself collect heat and radiate it, such as vegetation. Two factors are all important; the sun and the wind. The intensity of light from the sky translated into building terms affects the size of the openings required.

To face the house so that the long sides get the minimum of east - west sunlight and maximum natural ventilation are the most important factors.

Vegetation in the landscape is also important, to filter and provide comfort for the house from the solar heat and wind. Good used of passive air cooling to reduce energy use in ventilating and air conditioning is essential.

It has been found by Raeissi and Taheri (1996) that by using a shaded-pond, pond and shaded roofs for the house respectively, cooling load demand reductions of 80%, 60%, and 40% may be obtained.

Warm exhaust gases from transport create problems for thermal comfort in urban areas.

3.3. OVERHEATING CONSIDERATION

In Bali, Indonesia, the sun intensity is too hot and bright. It heats all the exposed surfaces of a dwelling, the roof, walls, windows, terraces and surrounding ground.

The surfaces reflect light and therefore heat, into the house; they transmit it by conduction through roofs and walls into the interior, at an interval depending upon the nature of the building material.

The roof of a house has the greatest exposure to the sun. With heat generated during the day, the problem is one of reducing the penetration of heat to the interior as well as dispersing any calorific accumulation to mitigate further heating at night.

East- and West-facing side walls of the house have highest exposure to the sun, and transmit heat into the interior. With well-orientated walls, the house can be kept relatively free from direct sun.

Glass transmits heat and having trapped it inside is loath to part with it again, so unguarded glass windows offer a significant heat gain to the interior.

A veranda can protect from direct sunlight, but can transmit heat and glare of the sun through into the house.

The average ground temperatures around the house remain at the upper levels of air temperature. Heat and glare are then reflected into the interior of the dwelling.

The more grass, vegetation and water, the more shade, the less hot its pavement, the lower is the glare from ground surfaces and less heat radiation into the house.

Overheating and cooling patterns throughout the year in Bali, Indonesia is shown in Figure 3.4.

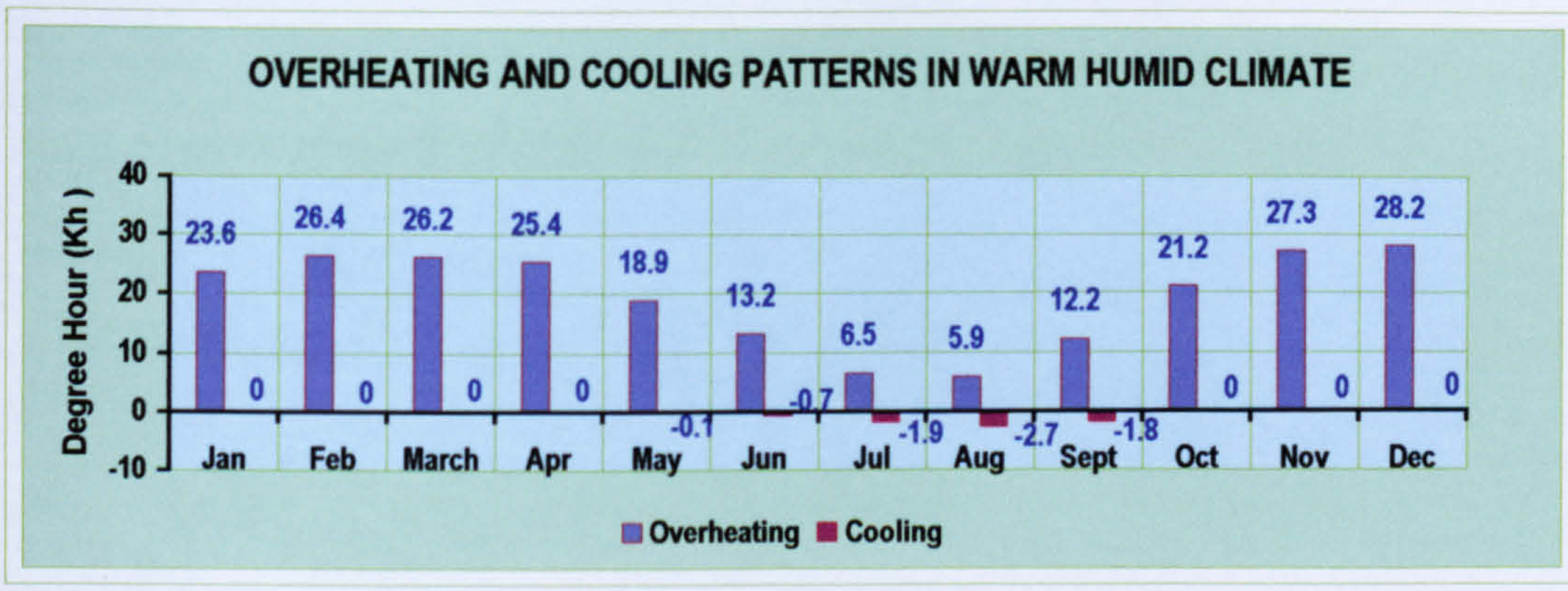

Figure 3.4. Overheating and Cooling Patterns

According to Antaryama (2000), similar levels of overheating were experienced in the months of January, February, March, April, November and December, with cooling degree-hours falling between 23.6 to 28.2 Kh in every case. In these months, the temperature can reach as much as 31.4 to 31.8° C. December was the hottest month. June, July, August, and September, on the other hand, were relatively cool, August being the coolest month. In these months, the cooling degree-hours do not exceed 7 Kh and there was little cooling, less than 3 Kh.

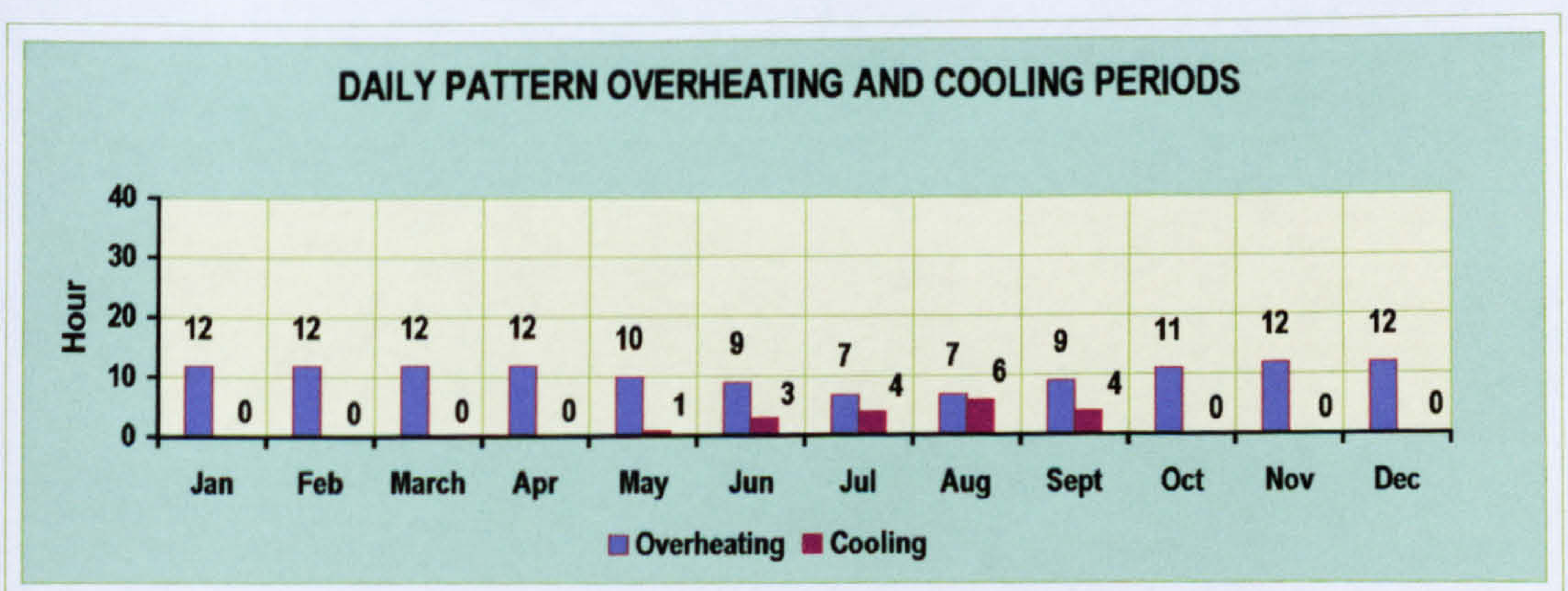

Figure 3.5. Daily Pattern Overheating and Cooling Periods

During the hot season, overheating generally occurs for a 12-hour period, between 10.00 and 21.00 h. during the night, and early morning conditions are comfortable. Figure 3.5. shows the daily pattern of overheating and cooling periods.

During the cool season, the period of overheating is reduced to 9 hours in June and September, and to 7 hours in July and August. The hot period extends from midday to early evening, with the highest temperature (about 30°C) at around 14.00-h. Under-heating is only experienced during the early morning.

Over the year, the overheating degree-hours amount to 3,850 Kh, while the under-heating degree-hours total only around 550 Kh. Over a year, the periods of overheating make up 7,200 hours, while under-heating occurs for only 300 hours in all (Figure 3.6) (Antaryama, 2000).

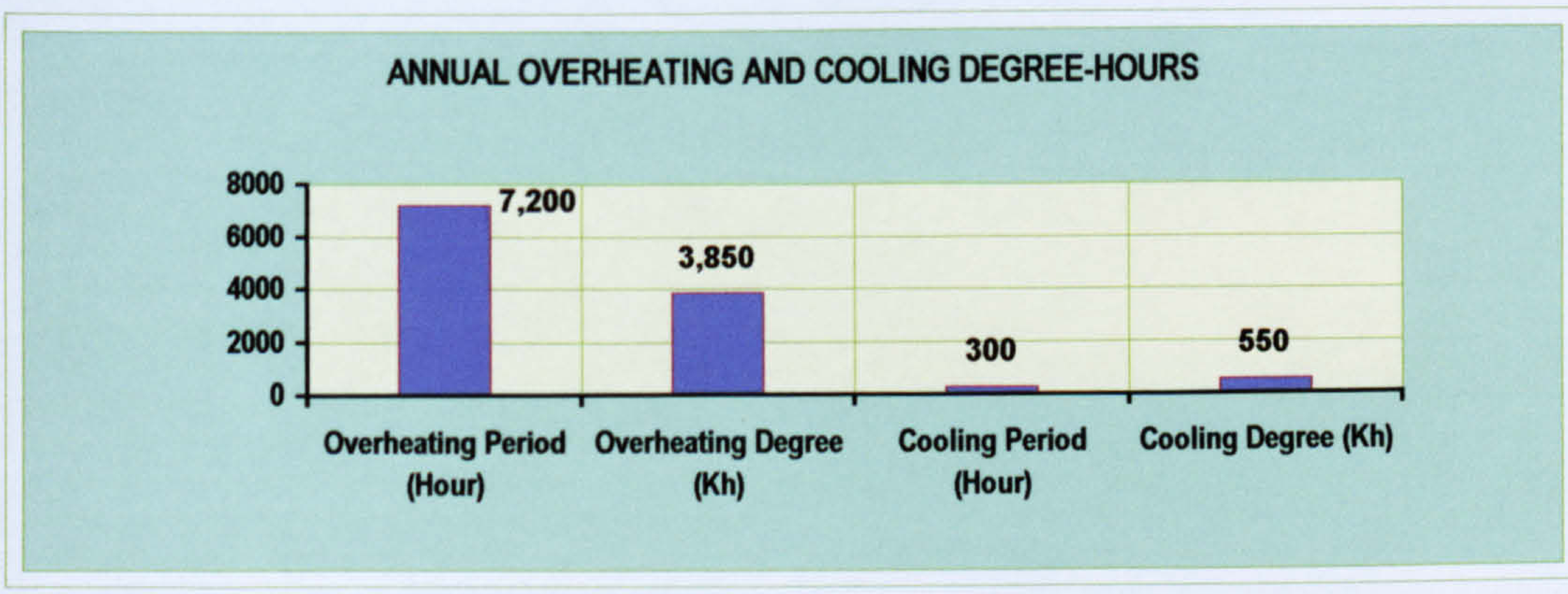

Figure 3.6. **Annual Overheating and Cooling Degree-Hours**

It is clear then that overheating can be a major problem for buildings in the warm humid climate, particularly during the time when most activities are carried out.

Thermal comfort is only experienced between midnight and the early morning, when most people are normally asleep, in conditions where the wind and breeze movements are not calm. Otherwise, the dwelling still provides uncomfortable conditions.

As described previously, where comfort performance is concerned, overheating is crucial in these circumstances. Ignorance of these particular problems will often lead to an increase in thermal discomfort.

3.4. THERMAL COMFORT AND BIOCLIMATIC ANALYSIS

Physical comfort in a passive cooling house comes from the cooling contact on skin, and light clothes allowing free air movement. These parameters affect the heat lost from the body. In this respect, Fanger (1973) described comfort related:

> *"The operative temperature determines a person's heat sensation, the feeling of heat and can be used to define comfort."*
>
> Fanger, 1973.

It is influenced by the indoor climate and also influenced by that outdoors. The indoor thermal climate is not only influenced by the air temperature, but is also equally affected by the surface temperature of surrounding indoor surfaces.

The temperature of indoor surfaces of dwelling elements facing out-doors is influenced by the ambient air temperature, and also to a high degree by the absorbed solar radiation on the outside; and to a lesser extent by long wave radiation to the sky during clear days.

3.4.1. Human Requirements for Thermal Comfort

The ancients taught that humans had seven senses (animation, feeling, hearing, seeing, smelling, speaking and tasting).

However, it is no more than coincidence that the principal influences which affect human comfort are also seven in number (Martin and Oughton, 1995):

- Temperature
- Conduction, convection and radiation
- Air volume and movement
- Activity and clothing
- Air purity
- Humidity
- Ionisation

The body due to metabolism, or the processes of food conversion and tissue building, continuously produces heat. Additional heat is produced by muscular activity, which varies from 70 watts while sleeping to 1,100 watts from maximum heavy manual work. Of all the heat produced 20% is utilised, while 80% must be dissipated, in order to maintain a deep body temperature of 37°C. Any heat gained from the environment and from solar radiation must also be dissipated.

The body can lose heat by convection, radiation and evaporation, and to a lesser extent by conduction.

Convection is produced when heat is transferred from the body to the air adjacent to the skin or clothing, which rises and is replaced by cooler air. Radiant heat loss depends on the temperature of the body surface and the temperature of opposing surfaces.

Evaporative heat loss depends on the rate of evaporation, which depends on the humidity of the air. Evaporation takes place in the lungs, and on the skin as perspiration.

Vasomotor adjustments continually balance temperature by varying the flow of blood to the skin surface. If normal adjustments are insufficient, sweating will occur in hot climates and shivering (which causes a rapid increase in metabolic heat production) in cold ones. Some acclimatisation occurs with movement between climates (Clark, 1992).

Human physical comfort in the passively cooled house not only comes from the cooling of the air. Its occupants' well being, degree of acclimatisation and suitability of clothing are contributory factors.

There comes a point, varying from one person to another and from those whom in active motion to those who remain still, where heat and air restricts the body's normal loss of heat by radiation, convection, and evaporation.

Loss of heat by radiation and convection only occurs when the air temperature and the surroundings are less than body temperature.

Loss of heat by evaporation presupposes an air dry enough to absorb further moisture.

In warm humid conditions, the body requires less energising nourishment and cover.

The pressures of climate enforce a rhythm of movement and relapse of energy given out, and can be restored by sleep.

3.4.2. Thermal Comfort Indices

According to Antaryama (2000), the human body continuously produces heat. The process of heat generation, and superfluous heat disposal result in a continuous heat exchange between the body and its surroundings, which may take place by convection, radiation, evaporation and conduction. In order to ensure that the body temperature is maintained at the normal and steady level, thermal equilibrium must exist between the body and its environment.

Under certain environmental conditions, i.e. cold or hot, the body will respond physiologically by means of its thermoregulatory mechanism (Figure 3.7). Through these mechanisms, thermal equilibrium can be maintained within relatively wide limits of the environmental variables.

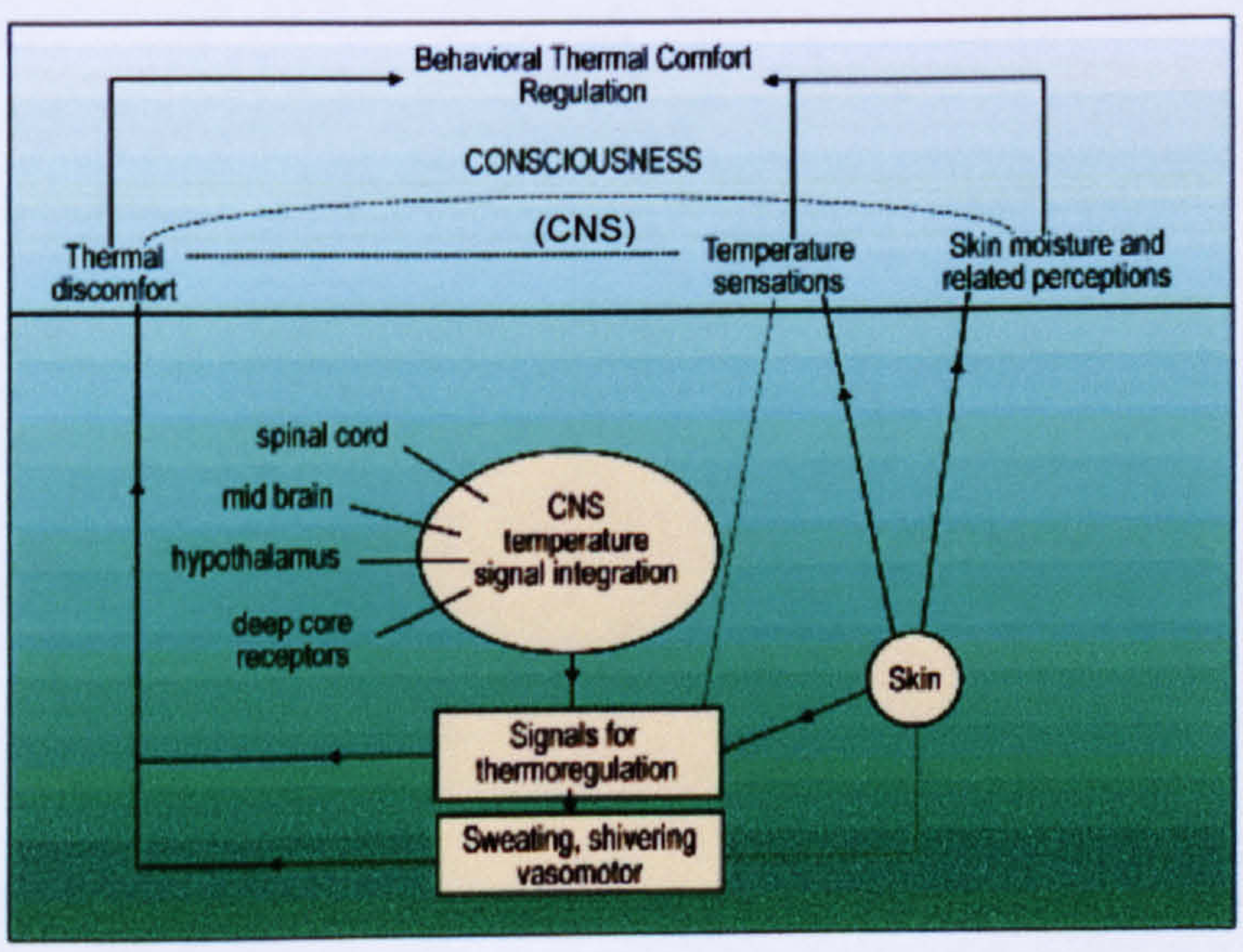

Figure 3.7. A Representation of Comfort and Related Sensations (Berglund, 1998)

However, in order to feel thermally comfortable, the deep body temperature, and thus thermal equilibrium must be maintained within a narrow interval (Fanger, 1983; Evans, 1980; Macpherson, 1965). In such a condition the thermoregulatory mechanism of the body are in a state of minimal activity (Givoni, 1969; Macfarlane, 1958).

It is important to distinguish here between thermal equilibrium and thermal comfort.

Thermal equilibrium refers to a physiological response to thermal exchange between the human body and the environment, whereas thermal comfort is associated with the expression of a response to hot or cold conditions. Gagge et.al. (1973) described the other aspect of thermal comfort:

"A good correlation to thermal comfort is thermal sensation."

Gagge et.al. 1973.

The words and numerical scale commonly used to categorise or label thermal sensation are shown in Figure 3.8. Thermal comfort is generally associated with a neutral or near neutral, the whole body thermal sensation.

Thermal sensation depends on body temperature, which in turn depends on thermal balance and the effects of environmental factors (temperature, radiation, air motion and humidity), as well as personal factors (metabolism and clothing) (Gagge et.al. 1973; Fanger, 1972).

Thermal Sensation	Numerical Code	Thermal Comfort	Numerical Code
very hot	+4		
hot	+3	intolerable	4
warm	+2	very uncomfortable	3
slightly warm	+1	uncomfortable	2
neutral	0	slightly uncomfortable	1
slightly cool	–1	comfortable	0
cool	–2		
cold	–3		
very cold	–4		

Figure 3.8. Thermal Comfort and Thermal Sensation (Berglund, 1998).

Antaryama (2000) furthermore noted, the natural process through which heat is exchanged between the body and its environment depends primarily on four climatic elements; i.e. air temperature, radiation, humidity and air movement, which are therefore determinants of thermal comfort. All of these elements produce simultaneously a thermal effect on the body.

In warm humid environments, air temperature will cause body heating as well as determine the process of conductive and convective heat dissipation from the body to its environment. Water vapour pressure, which is one expression of humidity, affects the rate of evaporation from the human body. Air movement influences body cooling. It induces heat loss by convection, and accelerates evaporation from the human body causing a cooling sensation.

Finally, solar radiation, like air temperature, affects human comfort by causing body heating. This impact is experienced either directly on the body, or through re-radiation from internal enclosing surfaces.

The latter, which is termed mean radiant temperature (MRT), is particularly significant in hot environments since it has the greatest effect on thermal sensation, next to air temperature.

Besides these environmental factors, as mentioned previously, human thermal comfort is also dependent on factors which are peculiar to the individual. These factors such as state of health or physical condition, age and sex, acclimatisation, activities, social pressure, cultural variation and clothing will determine the thermal preference of individuals.

In order to express the combined effect of some of the four environmental variables above, many thermal comfort indices have been produced over a period of more than 70 years. These include effective temperature (ET); operative temperature (OT), equatorial comfort index (ECI) and heat stress index (HIS).

The most recent index, which is regarded as the most general and important particularly under conditions of high humidity and temperature, is the Standard Effective Temperature (SET) (Szokolay, 1991; McIntyre, 1980; Gagge et.al. 1973).

An example of Standard Effective Temperature diagram is presented in Figure 3.9. (Ye et.al. 2003).

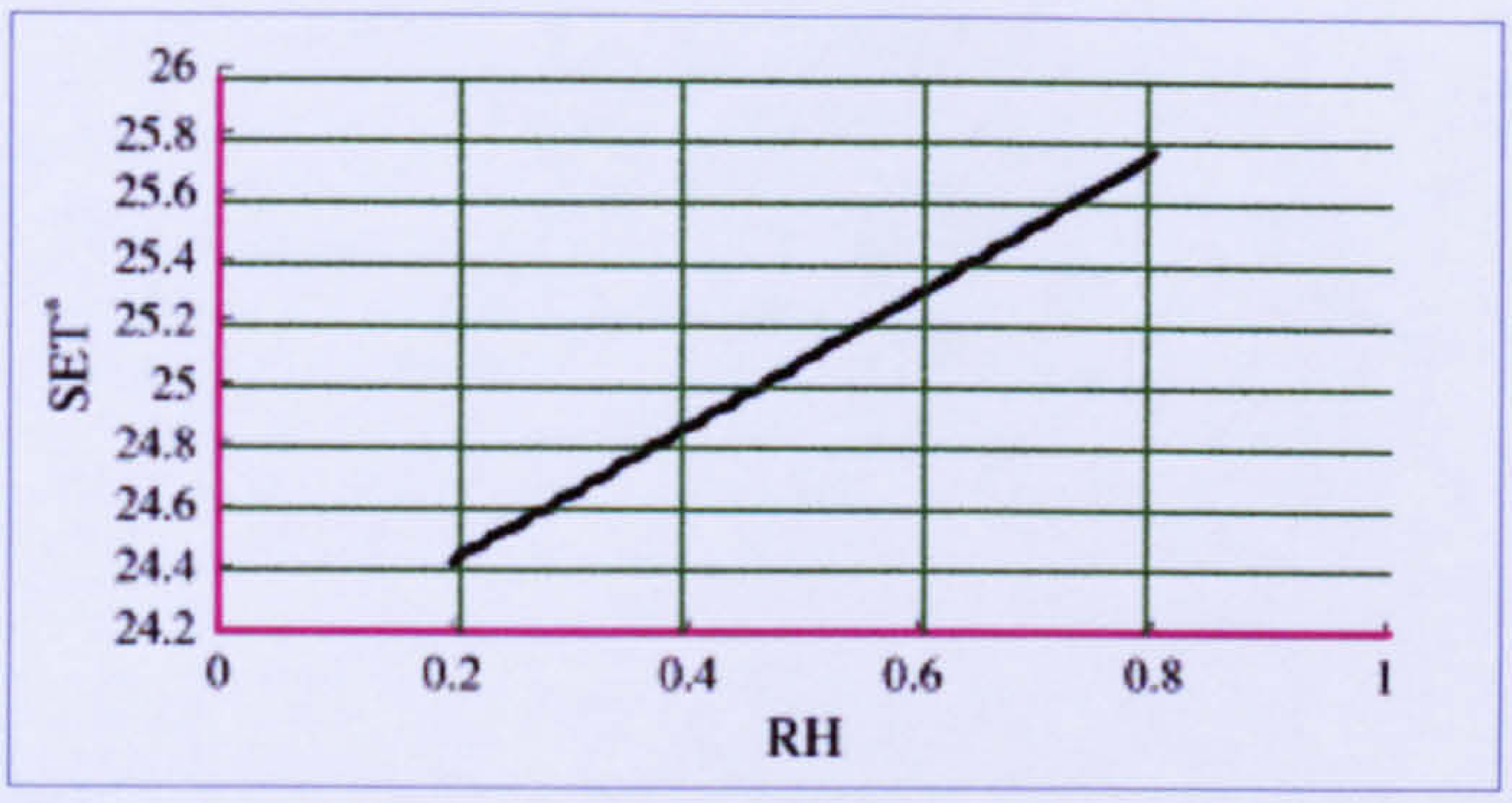

Figure 3.9. The variation of SET values as a function of the relative humidity (RH) when the equivalent temperature is equal to 25°, (activity M = 1 met, Cloth I_{cl} = 0.67 clo)

As Antaryama (2000) also described, this index combines the effect of air temperature and humidity when mean radiant temperature (i.e. the average temperature of all internal enclosing surfaces) is equal to air temperature, and the air is still. Apart from these physical variables of the environment, SET is also a function of activity and clothing (Markus and Morris, 1980).

Yet for architectural design purposes, *"there is no point in integrating several of these environmental variables into a single index, as different means within a building can be used to control each variable"* (Szokolay, 1991).

Evans (1980) defined the thermal comfort indices:

> *"Thermal comfort studies are intended to determine the range of thermal conditions in which neutrality (i.e. the feeling of being neither cold nor hot) is expressed; a range termed the comfort zone. The conditions considered as lying within this zone are those when 50 to 70% of the population would feel comfortable."*
>
> Evans, 1980.

Several research workers through both laboratory and field studies, have defined this range of conditions in many different climates. For a given location however, estimation can be made to determine the width of the comfort zone.

Studies have conclusively shown that thermal neutrality is influenced by the climate to which individuals are accustomed, and related to mean outdoor temperature (Anliciems, 1983; Humphreys, 1975).

In this regard, mathematical models have been produced to define the neutral temperature in relation to mean outdoor temperature.

For people in a hot environment, the equation given by Auliciem is more appropriate (Coldicut et.al. 1991; Szokolay, 1987; Humphreys, 1975).

This equation which is valid for neutral temperature within the range 18 to 32° C and unconditioned buildings, is as follows:

$T_n = 17.6 + 0.31\ T_{av}$, where T_{av} is mean outdoor temperature.

Human beings can tolerate a fairly wide range of climatic conditions, but comfort in the climatic sense involves more than just avoiding the extremes of freezing to death and dying of heat exhaustion.

Comfort depends on more than temperature; air temperature, humidity, radiation and air movement all produce thermal effects. Most climatic comfort indicators are objective, i.e. they can be measured, and acceptable ranges established quantitatively.

In air-conditioned buildings, the indoor climate is aimed at being within the comfort limits.

Fanger's (1972) comfort equation and index predicted mean vote is often used to describe comfort. The comfort range is that in which 80% of people are supposed to be satisfied. Adamson and Aberg (1993) pointed out the thermal comfort indices:

> *"There have been a number of indices developed summarising the indoors climatic parameter to a one index."*
>
> Adamson and Aberg, 1993.

3.4.2.1. Relative Influence of Mean Radiant Temperature

Indoor surfaces temperature of a dwelling facing outdoors is influenced by ambient air temperature, and also to a high degree by the absorbed solar radiation on the outside; and to a lesser extent, by long wave radiation to the sky during clear days. Providing material for the external walls that does not itself collect heat, or radiate it at the wrong time of day, is recommended.

3.4.2.2. Relative Influence of Air Humidity

In the warm humid climate, heavy rain driven by strong winds may penetrate buildings as well as leading to an increase in the level of humidity. In a passive system, this can build up in the dwelling without any natural cross ventilation and solar gain through the windows.

3.4.2.3. Relative Influence of Air Velocity and Thermal Comfort Conditions in Bali Indonesia

Relative influence of air velocity and thermal comfort requirements and the climatic conditions of Bali were plotted by (Antaryama, 2000) on the psychometric chart (Figure 3.10) (see also Appendix - II).

The method itself follows that of Szokolay (1987). This will illustrate the extent of problems posed by the climate. In this case, utilisation of air movement is chosen as a design strategy for restoring comfort (i.e. physiological cooling), since it represents the most recommended strategy for naturally conditioned building in warm humid climate.

For the analysis, the thermal comfort zone of Bali is established by using standard effective temperature (SET) as an index, which combines the effect of dry bulb temperature (DBT) and humidity when the mean radiant temperature (MRT) is the same as DBT, and there is no significant air movement.

It is clear that general overheating is the major problem for this climate. This is indicated by climate conditions in Bali (area EABGF) which are far above the comfort zone (area ABCD). The source of problems is not only the high temperatures, but also the combination of high temperatures and high humidity. As has been suggested by many studies, air movement can be used to ameliorate such problems.

It can be seen from the figure that by the introduction of air speed of 1 m/s, the comfort zone apparently can expand to the extent where almost all of the twelve months, the outdoor temperature conditions fall within the area (area EADKJI).

Overall less than 10% of the 24-hour period of the outdoor temperature is beyond the potential control zone (i.e. those low in temperature and high in relative humidity). Consequently, a further increase in air speed up to 1.5 m/s is unnecessary (area EADNML).

On the other hand, an introduction of wind speed of less than 1 m/s (i.e. 0.5 m/s) is considered as inadequate, since it is not sufficient to counter the existing climatic problems (area EADHGF).

Thus given such climate conditions, comfort in Bali can be restored only if an air speed of 1 m/s is available. Yet the question arising from this is whether such a speed can be induced into the building, bearing in mind that air speeds in Bali, as in many other warm humid regions, are relatively low.

It has been shown that the annual mean wind speed at 10 m above the ground is 2.7 m/s, and about 1.3 m/s at 3 m height. This will be considerably reduced when it enters the building, unless the building is fully open and in case of a series or cluster of buildings, the spacing between them is sufficient to maintain the original speed of the incoming wind. This limited option then is restricted still further by the fact that throughout the year, winds of low speeds occur frequently during the hot months (i.e. November to April). Added to these considerable overheating problems is solar radiation, both direct and diffuse, which is generally high throughout the year.

To summarise, heat is the main obstacle to achieving comfort in Bali. This is aggravated by the fact that humidity is high on the island. Air movement, which is the only means of restoring comfort in this location, is unfortunately available only at relatively low speeds at the times when it is most required.

Despite these limitations however, the existing climate conditions can still offer a reasonable benefit if any wind resistance on, or around the building can be kept to a minimum.

Yet this effort has to be maintained constantly. Failure to do so may result in overheating.

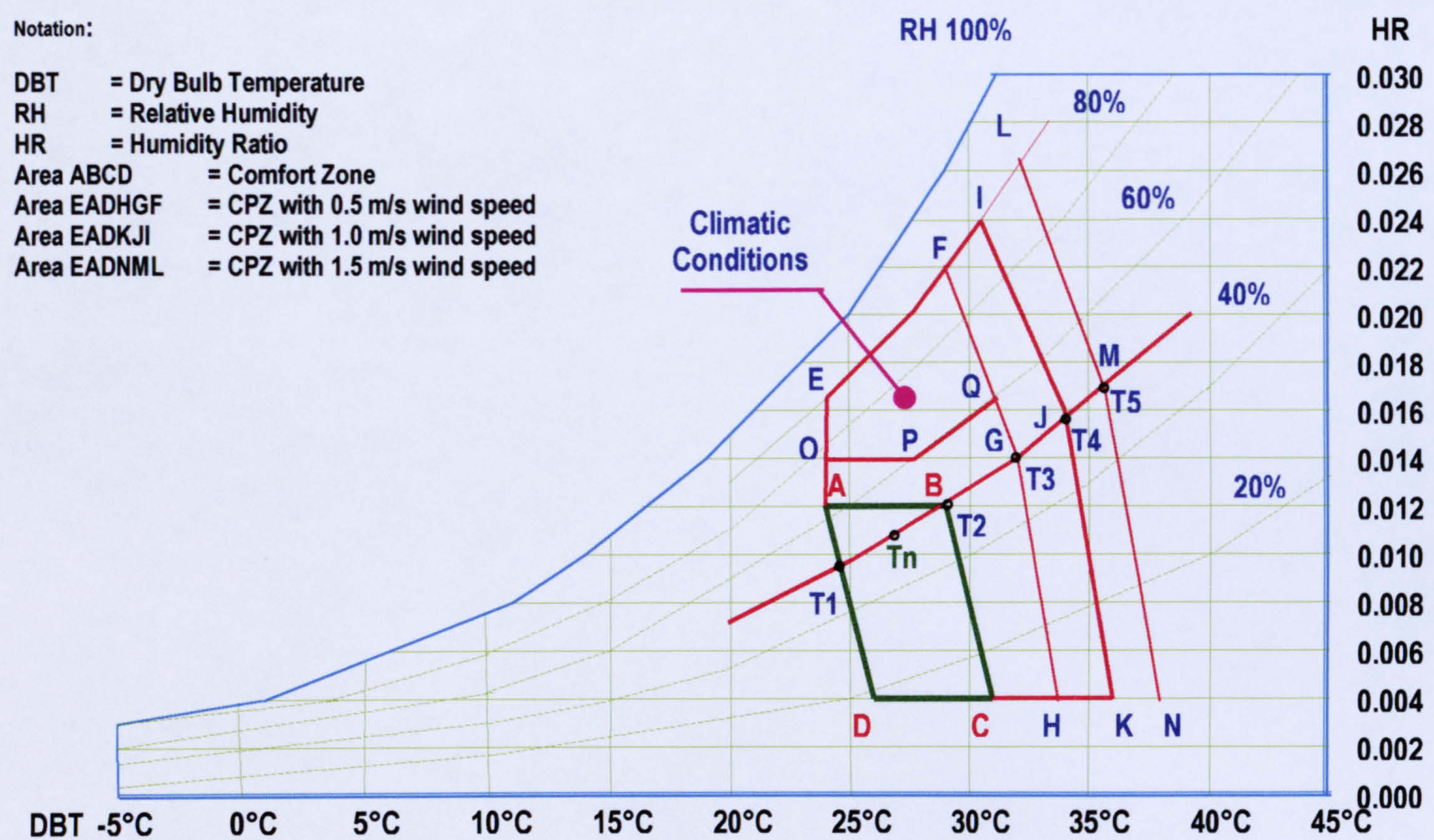

Figure 3.11. Bali - Comfort Zone, Climate Plot and Control Potential Zone (CPZ) (Antaryama, 2000)

3.4.3. Thermal Comfort In A Warm Humid Climate

A previous study of thermal comfort in the warm-humid climate of Indonesia, where Bali is located, has been carried out by Karyono (2000).

From the point of view of male and female thermal comfort, the male subjects had a mean vote of +0.29 while the female's subjects had +0.03. This gives an indication that males felt warmer than the females.

The study shows that the preferred neutral temperature for female subjects was about 0.1°C lower than for the males.

Reviewing some previous studies in which male and female subjects were compared in terms of their thermal preference, the results showed no significant difference in the preferred thermal environment between males and females (de Dear et.al. 1991; Busch, 1990; ASHRAE, 1989; Olesen, 1982; Ballantyne et.al. 1979; Humphreys, 1976; Fanger and Langkide, 1975; Fanger 1970; Black and Milroy, 1966; Nevins et.al. 1966; Olgyay, 1963; Hickish, 1955; Ellis, 1953).

Regarding the thermal comfort of occupants under and over 40 years, most experiments showed identical preferred temperatures between elderly and college-aged persons (ASHRAE, 1989; Wong, 1987; Olesen, 1982; Collins and Hoinville, 1980; Langkilde, 1979; Fanger and Langkilde, 1975; Rohles, 1972; Fanger, 1970; Olgyay, 1963).

This study shows that the subjects over 40 years of age had a neutral temperature lower than subjects under 40 years of age.

Regarding thermal comfort of occupants with various degrees of fatness, there are five classifications for people's level of fatness (Metropolitan Insurance, 1983); they are malnutrition, underweight, normal, overweight and obesity. The common idea is that fatter persons tend to be more resistant to cooler environments than slimmer (thinner) ones, because the fat layer functions as thermal insulation.

The study found that the fat group had a neutral temperature of about 0.26°C lower than the thin group. Amongst the elderly the result was otherwise, where the fat group had a neutral temperature 0.17°C higher than the thin group.

However, the results of Fanger's investigation showed that there was no significant influence of body-build on thermal comfort conditions for sedentary people (Fanger, 1970).

This study shows that the group of fat subjects had a neutral temperature lower than the normal group, and lower than the thin group of subjects.

Concerning thermal comfort for subjects from various ethnic backgrounds, many studies failed to show a statistically significant difference in their sensation of thermal comfort (de Dear et.al. 1991; Tanabe and Kimura, 1987; Fanger, 1970, 1982; Ballantyne et.al. 1967; Nevins et.al. 1966).

The above discussions indicates that in the warm humid climate of Bali, Indonesia, the ethnic, gender and age differences in neutral temperatures were not statistically significant for individuals, at the 5% level.

3.4.3.1. Comfort Votes in the Warm Humid Climate

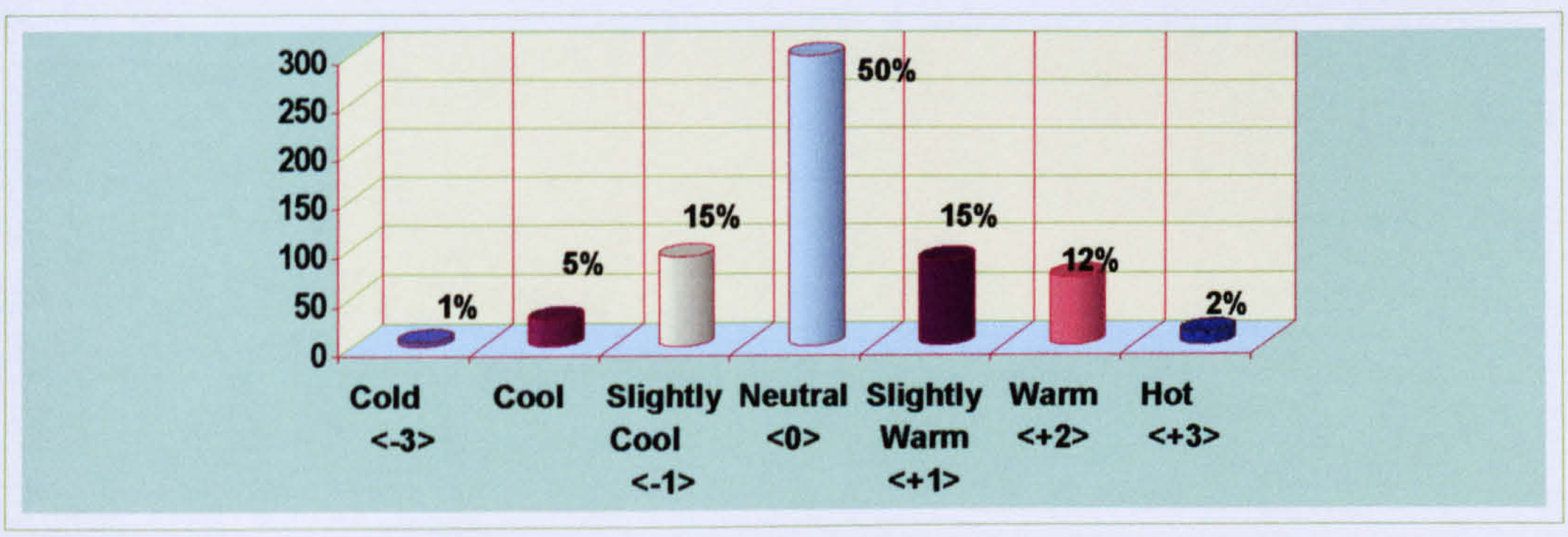

Figure 3.11. Occupants Comfort Votes

A study in the warm humid climate shows that about 50% of the subjects gave votes of `0' or `neutral', while 21% subjects voted below neutral and another 29% subjects voted above neutral.

This figure indicated that, on average, there were more subjects on the warm side rather than those on the cool side (Figure 3.11).

3.4.3.2. Neutral Temperature and Comfort Range

A linear regression of actual individual vote (*AIV*) against temperatures (T_a, T_o, T_{eq}) is applied to determine the subjects' neutral temperature and comfort range.

The figures are presented in Figure 3.12, Figure 3.13, and Figure 3.14.

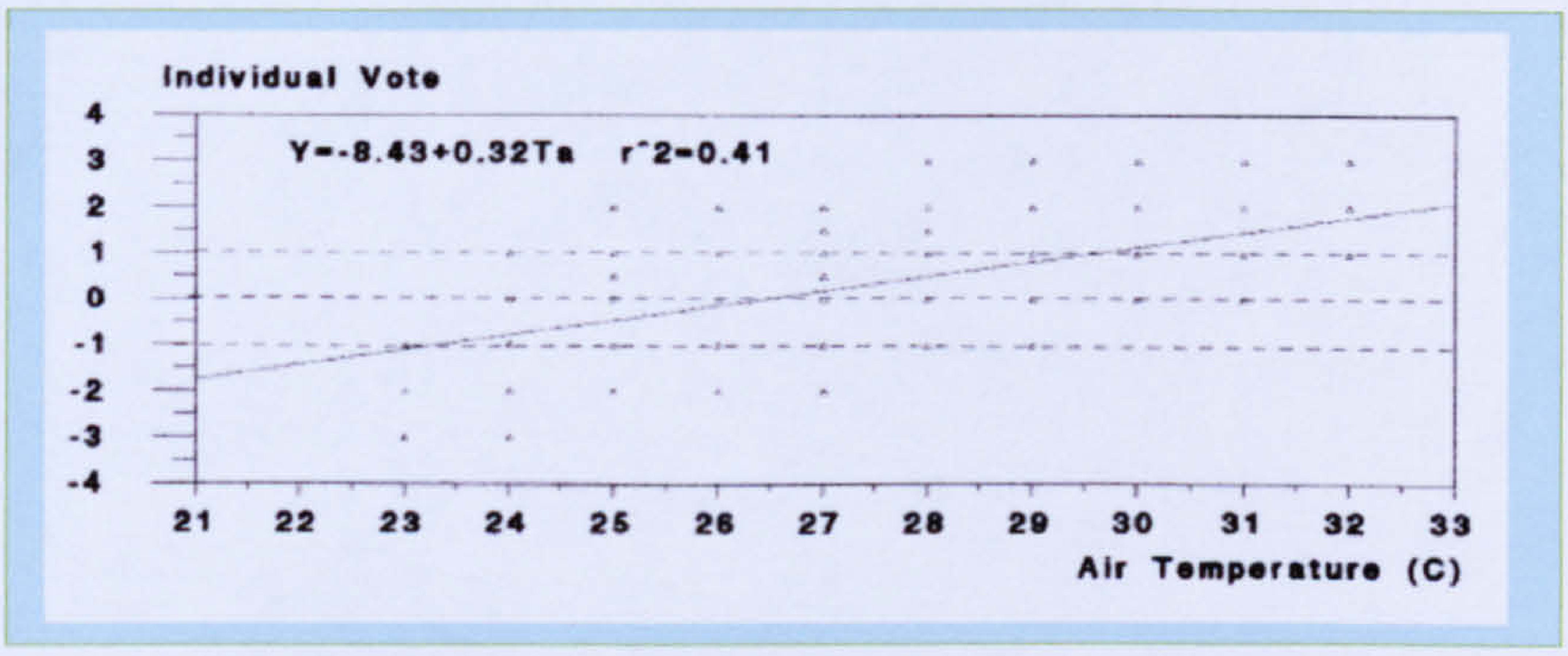

Figure 3.12. Linear regression of actual individual vote (AIV) against air temperature

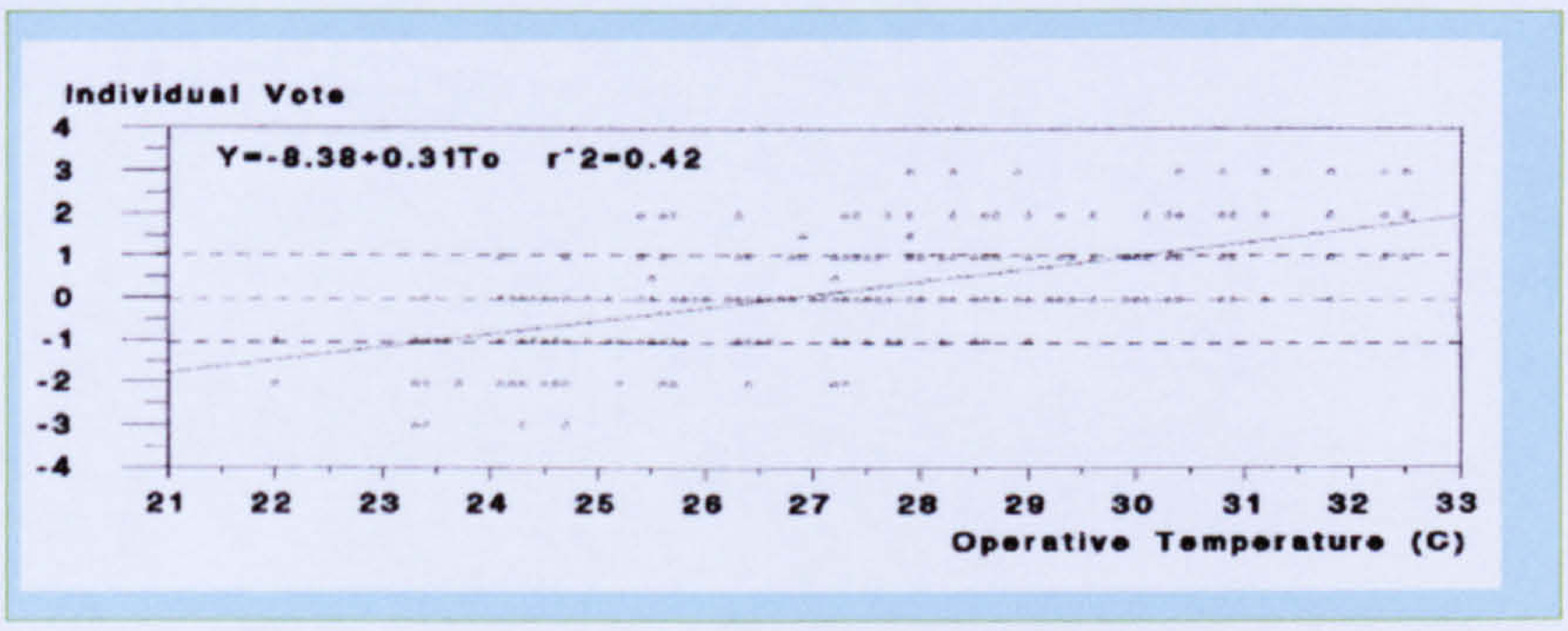

Figure 3.13. Linear regression of AIV against operative temperature

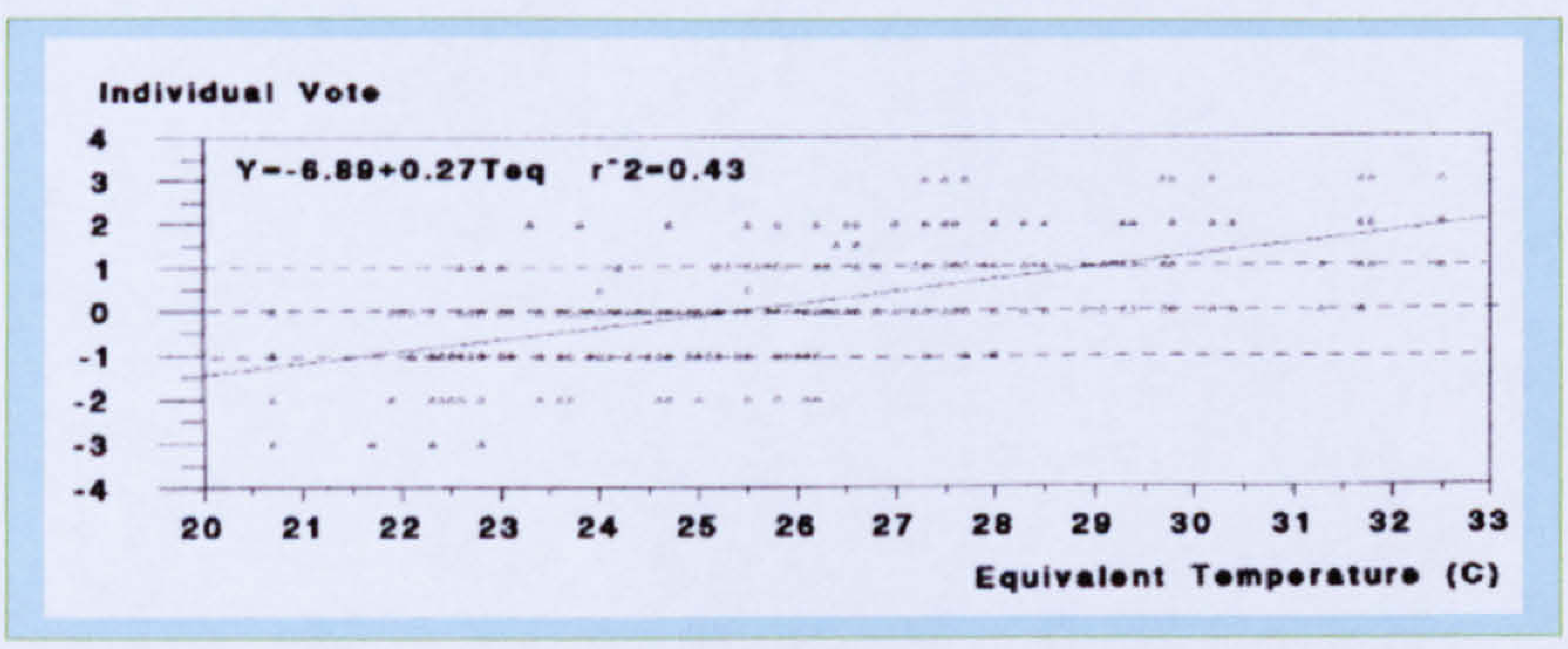

Figure 3.14. Linear regression of AIV against equivalent temperature

Source of Figures: Karyono (2000)

The above figures indicate how temperatures were measured in three different forms: air, operative, and equivalent temperatures. Occupants' neutral temperature (T_n) and comfort range (T_{cr}) were expressed accordingly.

The calculations of neutral temperatures and comfort ranges were derived from linear regressions of actual individual votes against temperature.

Based on these regressions, T_n and T_{cr} for all the occupants in all buildings (e.g. naturally ventilated, hybrid, and air-conditioned buildings) were defined. The neutral temperature T_n and thermal comfort range T_{cr} is defined in Table 3.2.

	T_a (°C)		T_o (°C)		T_{eq} (°C)	
T_n	26	96.5%	27	95.3%	26	94.6%
T_{cr}	23-30	83%	24-30	86%	22-29	87%

Table 3.2. Percentage of Subjects Comfortable at the Neutral Temperatures (T_n) and at the Comfort Range Temperatures (T_{cr}) (Karyono, 2000)

The results above show that between individuals' comfort votes of -1 and +1 (the range of comfort temperature), more than 80% of subjects still felt comfortable, which is slightly higher than those predicted by the PMV/PPD model in ISO-7730 (1994), i.e. 75% of subjects are expected to be comfortable.

3.4.3.3. Daily Thermal Comfort Rhythm

The internal body temperature has a daily rhythm which is at a maximum in late afternoon, some time before the sleeping period, and a minimum in the early morning, some time before the body wakes up, with an amplitude of oscillation of 0.3°-0.5°C (Olesen, 1982).

This phenomenon, therefore, may lead to a different neutral temperature for people between morning and afternoon hours (Fanger, 1970; Nevins, et.al. 1966).

Results from this study shows that neutral temperatures of subjects from all selected buildings were higher in the afternoon hours (between 15:00 and 16:00 h) than in the morning hours (between 09:00 and 10:00 h).

The neutral temperature of subjects in the afternoon was 4°C higher, in terms of air temperature (T_a), than in the morning, or 3.1°C higher in terms of operative temperature (T_o) and 3.8°C higher in terms of equivalent temperatures (T_{eq}).

The difference between subjects' neutral temperature between 09:00 and 10:00 h and between 15:00 and 16:00 h was statistically significant at 5% level.

This outcome is useful to develop thermally comfortable dwelling in the warm humid climate of Bali.

3.5. CONCLUSION

Over the beautiful island of Bali there are wet and dry season environments, with high temperatures, high humidity, a small range of daily temperature and indoor temperatures higher than outdoor temperatures, all the year.

The direct solar radiation is high, both daylight and long-wave infrared. The intensity of radiation coming from the sky is high and is reflected as well as diffused from a cloudy sky. Devices such as sunscreens designed to shade the sun are therefore only partially effective when the sky is cloudy.

The climatic analysis confirmed that overheating is the greater problem in the warm humid climate of Bali. The combination of high temperature and high humidity, coupled with high solar radiation, traditionally leaves high rates of ventilation and air movement as the only practical way of restoring comfort.

The study thermal comfort and bioclimatic analysis reveals that in the warm humid climate, there were not significant differences in thermal comfort, between ethnic, gender and age of individuals.

However, the difference thermal comfort sensation between individuals in the morning and in the afternoon was statistically significant.

The general study on neutral temperature and comfort range of individuals' in all kind of buildings (e.g. the naturally ventilated, combined natural ventilation and air conditioning, and fully air-conditioned buildings) show that the comfort votes of subjects still in the range of comfort (e.g. between -1 and +1).

However, the study also reveals that on average, they were more on the warm side rather than those on the cool side.

It was found that the indoor temperature is much influenced by the building design.

A dwelling which is oriented North - South has good natural ventilation and having maximum protection from the sun, can enjoy quite low indoor temperatures.

On the other hand, the dwelling that is oriented East - West has little natural ventilation, and having no protection from the sun on these sides can suffer higher average indoor air temperatures.

Looking at these figures, by means of correct design there is a great opportunity for dwellings with North - South orientation to be naturally cooled to temperatures lower than buildings with East - West orientation.

To achieve thermal comfort in warm humid regions, to reduce external heat gains, reduce internal heat gains and provide effective ventilation are all important.

Other considerations that should also be taken into account in the dwelling design are the exclusion of glare and admission of daylight and protection from, and disposal of, rain which can be done by shading devices, a veranda, overhang, a pitched roof and landscape.

These overall outcomes are important points to be taken into account for a further development of thermally comfortable dwelling in the warm humid climate of Bali.

Chapter Four

BASIC DWELLING DESIGN FOR MODERN HOUSING DEVELOPMENTS IN BALI INDONESIA

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Chapter Four

BASIC DWELLING DESIGN FOR MODERN HOUSING DEVELOPMENTS IN BALI INDONESIA

4.1. HOUSING DEVELOPMENT IN WARM HUMID CLIMATES

4.1.1. Indigenous Considerations

Bali is situated in the warm humid zone of the world, and is a part of the developing Indonesia. The background of the research cannot be separated from the housing development in Indonesia.

The United Nations has defined shelter as an enclosed environment in which man finds protection against the elements, is safe and secure from hostile forces and can function with greater vigour, more efficiency; be assured of privacy, and achieve increased comfort and satisfaction.

Studying housing development in warm humid climates needs to take into consideration the design of technological innovations, environmental aspects, energy and economic management. Another important point related to the housing development in Bali, Farokh et.al. (1978) noted:

> *"That such efforts would greatly ease the housing problem, as well as resulting in many more houses being built appropriate to local conditions."*
>
> Farokh et.al. (1978)

Furthermore he recognised, an effective strategy for meeting housing needs requires a comprehensive, integrated and green effort, which is environmentally friendly. This has to be done through research, experimentation and development of local building resources, coupled with an understanding of those natural resources. This is the endogenous approach to development.

However, this approach should also respect current technological innovations.

Comfort is in itself a desirable objective if situations have to be long endured. Poor design of housing can aggravate the natural climatic discomforts, and it would seem only reasonable to avoid such effects wherever, whenever possible.

From the forgoing discussion can be recognised that dwellings design in Bali to be in touch with the environment, aimed to mitigate discomfort, to adapt to the climatic conditions and developed indigenous natural resources in the best way possible to meet the needs. Healthy housing development in this region must first attempt to exclude solar radiation and other harmful elements of the environment, while encouraging natural ventilation wherever possible as well as resulting in many more houses being built appropriate to local conditions.

4.1.2. Healthy Housing Development

Designing housing development in Bali, Indonesia has to draw upon studies from the developed countries, selecting and absorbing the applicable achievements as well as learning from the mistakes made.

In this respect, there are five essentials for healthy housing;

- ***Occupant Health***

  "High efficiency room and ventilation system designs to ensure superior indoor air quality, the use of hardwood and tile floors which are easier to clean, building materials that do not emit formaldehyde and other vapours, for better occupant health."

- ***Energy Efficiency***

  "High efficiency air conditioning to reduce energy consumption, increased insulation levels in walls and attic, high efficiency windows and doors, energy efficient appliances, energy efficient lighting, generous windows to reduce lighting costs."

- ***Resource Efficiency***

  "Efficient use of building materials to reduce construction waste. Extensive use of recycled building materials, use of rapid-growing woods, locally produced materials to support local economy."

- ***Environmental Responsibility***

  "Recycling of old building materials, better use of site by increasing occupant density, use of building products that require lower energy to manufacture."

- ***Affordability***

  "Use of products that are readily available at reasonable cost, flexible design that will reduce future renovation costs, low maintenance, long lasting materials and finishes and lower health care costs and energy efficiency means lower cooling and electricity costs."

Canada Mortgage & Housing Corporation (C.M.H.C), (2000).

4.1.3. Environmentally Sustainable Development

In a wider context of housing development in Bali, it is important to address the milestones in the development of the sustainable paradigm that were stated:

- *"1972 Publication of the **Limits to Growth.** The report highlighted the problems of resource depletion and environmental pollution."*
- *1987 Publication of **Our Common Future.** This report described in an authoritative way the need for a profound revision of the concept of development, and stresses the need for a global approach.*
- *1992 UNCED in Rio de Janeiro of the **Earth Summit,** the world's nations' representatives agreed on several action plans towards a sustainable planet."*

Malliet, 1998.

In terms of energy sustainable development that is related to the study, there are other important points from the Johannesburg Summit 2002, which delegates committed to:

> *"Renewable energy and improved access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy service and resources, and sufficient to achieve the Millennium Development Goals."*
>
> The United Nations, 2002.

Malliet (1998) further noted, the defining principles of sustainable development can be described as below.

Sustainable development was defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. A sustainable economy is the product of sustainable development, maintains its natural resources, continuing to develop by adapting and through improvements in knowledge, organisation, technical efficiency, and wisdom.

A sustainable society lives by these principles; respect and care for the community of life, to improve the quality of human life, conserve the Earth and its diversity, to minimise the depletion of non-renewable resources, keep within the Earth's carrying capacity, to change personal attitudes and practices, enable communities to care for their own environments, to provide a national framework for integrating development and conservation, and create global alliance.

In an architectural perspective Kremers (1990) pointed out; the aim of architecture is to improve the quality of life and environment. The popular interpretation of the word sustainable describes an approach to architectural design that minimises sustenance or resource consumption, to prolong the availability of natural resources. Sustainable architecture simply expresses the fact that those resources should maintain the environment and receives what they need from the universe. Sustainable architecture, then, is a response to awareness and not a prescriptive formula for survival

Sustainability is a term that represents the social and cultural shift in the world order, patterns and styles of living. It is another step in the process from a nomadic, to an agricultural, thence to an industrial system and is currently moving to becoming an information-based order. In addition, it represents mere survival at the expense of improved quality of life. Sustainability represents a transition from a period of deterioration of the natural environment to a more humane and natural environment. Sustainability can create environments that consume less than they produce (Koester, 1998).

With reference to the information above, it is clear that in order a housing development in Bali to be culturally and environmentally sustainable, to draw the energy conservation upon sustainability architectural design is important.

4.2. PROBLEMS ASSOCIATED WITH HOUSING AND HOUSING DEVELOPMENT IN BALI INDONESIA

4.2.1. Housing Problem

The United Nations (UN) Centre for Human Settlements, 1986, report suggest that in the developing world which includes Indonesia where Bali is located, while not all informal settlements provide unsatisfactory living conditions, they are usually inadequately served with essential infrastructure. Extremely high population densities and room occupancy rates, while not proof of unsatisfactory housing conditions, usually indicate an inadequate supply of housing.

In Indonesia where Bali is located, *"housing is one of the most difficult problems confronting the governments and people of the developing world"* (Aga Khan Award, 1979). It encompasses so many different considerations, requirements, and unknown variables that perhaps one of the principal results has been to bring this immense complexity out into the research.

As also already happening in Bali, Landaeta and Larson (1987) state related to the warm humid climate in such countries that *"the shelter situation is constantly aggravating, and the deficit of housing is one of their most urgent and difficult problems to solve."*

In addition, pressures on the informal housing development sector are increasing. The pressures are clear, and include a growing number of marginal settlements, overcrowding and more unserviced urban settlements. Furthermore, commercialisation has tended to increase in the informal housing sector. This is resulting in a burden of affordability for those with low incomes. Some examination of housing development in Denpasar explains the process by which urban growth and housing sector causes more sprawl, and a scattered pattern of urban growth. The informal housing sector causes intensification and fragmentation of existing villages (World Bank, 1995).

This problem is rapidly increasing due to population growth, the continual rural to urban migration, urban density and the destruction of housing caused by recurrent natural catastrophes and decay.

According to the United Nations, between 1970 and 1985 Indonesia's urban population including Bali, increased by more than threefold. From 20.5 millions to 42.2 millions, with the greatest absolute increase of 21.7 millions or on average 106 % and by the year 2000 this is projected to increase by 33.8 millions, with the total urban population about 76.0 millions (The United Nations, 1989).

In Bali, increasing land use competition due to absence of an adequate land use control system has brought about a situation in which land development decisions are left entirely to market processes. Given that land is an essential factor in housing development, access to affordable land is an important determinant of the failures and successes of housing development.

In Denpasar, the capital city of Bali for example, the failure of formal housing development for low and middle income people was caused in particular by the uncertainty of land supply, while the strength of informal housing development was based on flexible, informal access to land.

Whilst the city has long had development master plans on paper, the means with which to implement these plans seem to have been lacking. Consequently, informal housing develops wherever land is available, without regard to the climate, environmental conditions or long-term consequences.

Even housing constructed by public sector agencies and by real estate developers, with high on-site specifications, is often located in areas with totally inadequate vehicular access and without connections to main public services. Much strategically located land is held back from development by influential landowners, resulting in a sporadic and inefficient pattern of development.

In Bali, assuming that annual urban population growth of 7% will continue, it is possible that the urban population will be around 3 million in the next five years (Bali Statistic Bureau, 2001).

This means that on average, about 3,000 housing units should be built per year to meet the housing need of new urban households, or units built to relieve overcrowding and to replace non-upgradeable units. It is clear that some form of public intervention is needed to accommodate this large amount of housing demand (Department of Public Housing of Indonesia, 1996).

In this respect, the government and private sectors around the country of Indonesia do undertake programmes in housing development, but the scope of these projects is rather small in comparison with the needs, standards and cost for the people as a whole. The projects are often to benefit the middle income group of people, who represent the majority in the country (see Chapter One, point 1.1.3.2.).

In this regards, when designing housing in Bali, it is recommended to consider how to build more number houses that can be made affordable for the most people, and especially for people with lower incomes by providing assistance such as loans with long period and soft instalments.

4.2.2. Real Estate Development

4.2.2.1. Introduction

Real Estate Indonesia (REI) is an association composed of real estate companies; it was formed in 1972 at the time when the Government of Indonesia started a series of five-year development programmes.

The newly established National Co-ordination Board identified the need for the co-ordination of housing-related institutions that could participate actively in the provision of housing. Besides the establishment of the State Ministry of Housing, the National Urban Development Corporation, and a State Savings Bank, it was recommended that an association of private realtors be established.

The membership of REI has increased steadily, reaching 500 in 1985. By 1996, over 2,000 real estate developers, appraisals, and property management and brokerage companies had become members of REI, spread over 27 regional chapters throughout Indonesia, Bali included.

REI plays an important role in urban housing development and play a significant role in supporting the development of the industrial, tourism and trade sectors by actively developing industrial estates, tourist resorts, offices, hotels and other commercial properties. REI has steadily grown to become an important part of the national development scene.

REI is thus active in the national development efforts and is constantly in consultation with the Government and society in general to further advance its mission. The role of REI in the next 25 years will have to be enhanced, with participation in large-scale urban development and renewal projects as well as increasingly concerned with urban infrastructure provision.

4.2.2.2. Urban Development

a. Housing Development

The biggest housing demand in Indonesia including Bali, is in the urban areas and the formal sector's contribution to supply is estimated to cover only 20 percent of the demand.

The Sixth National Five-Year Plan (1994 - 1999) places a target of 100,000 to 120,000 dwelling units per annum, over 50% of which are to be provided by REI. In April 1994 to November 1995, the actual number of dwellings built exceeded the target, with REI building about 170,000 dwelling units. The majority of REI members are active in developing housing estates that provide for the low, middle and luxury housing markets, ranging from small subdivisions to large-scale new towns all over the nation.

To encourage the development of low-income housing, the government has also introduced a formula of 1:3:6, which obliges developers to build in the ratio 1-luxury unit, 3-middle, and 6-low-income housing units.

b. Apartments and Condominiums

The increasing pace of urban development in recent years has seen an increasing number of apartment and condominium projects being developed by REI. With the advent of strata-titles, condominiums have become an important point of the property market in the last three years. In 1992, there were only 33 apartment complexes with 2,304 units. In the year 1997/1998, there were 139 strata-title apartment projects with a capacity of 35,079 units. These projects represent a fantastic jump in supply.

c. Commercial Development

By the end of 1995, the total supply of prime office space in Jakarta amounted to 2,233,000 square metre. In comparison with the cumulative supply in 1990, this constitutes about 110% increase. Strong demand is experienced for office buildings located in super blocks.

d. Shopping Centres

The fast development of centres between 1992 and 1995 has resulted in increasing the number of available retail space from 250, 000 to 829, 270 square metres.
By 1998, the anticipated total supply was likely to range between 1.6 and 1.8 million metres square. The rising middle class is causing an increasing demand for better quality retail facilities combining recreation and shopping malls, all under one roof, and air conditioned comfort is becoming a prerequisite.

e. Recreation & Leisure

The spectacular growth of tourism has meant that there have been many new hotels and recreational projects undertaken in the larger cities, as well as new tourist destinations such as Bali and Batam. The establishment of agro-tourism and tourist resorts is also on the increase.

f. Industrial Estates

As part of the drive to increase non-oil exports, the government has recently passed a bill which will allow full participation of the national and international private sector in establishing industrial estates. Some 20,000 hectares of industrial estates in the greater area will come on-stream in the next few years.

4.2.3. Review

Housing demand is a problem in Bali and in the rest of Indonesia. The National Housing Policy and Strategy emphasises the importance of enabling principles for improving the performance of the dwellings (as has also been particularly discussed in Chapter One, points 1.1.2.1 to 1.1.2.8). Most of the dwellings currently being erected could be described as compact houses, with little or no design consideration for culture and thermal comfort. The gap between housing needs and supply has remained alarmingly large, due to serious resource constraints and the poor performance of the dwellings sector.

Given its magnitude, any serious effort to address the dwelling problem requires a major change in the policies governing dwelling design. A critical need in this respect is the recognition of the potential of the traditional dwelling comfort pattern, and an enabling policy environment to help low-energy dwellings to realise the housing needs.

In addition as Carter (1995) stated, *"in the past 25 years, Indonesia's demands for energy electricity have risen very fast, increasing about 8% annually. The growth in overall primary energy consumption is in the range of 9.5% per year."*

In summary, it is suggested to provide more number of houses in a good quality of comfort and be designed more affordable for all class-incomes people of Bali as well as for all people in other parts of Indonesia.

In addition, human comfort in this warm humid climate is the main point of dwelling design development in Bali, Indonesia, but it must take into account both energy consumption and conservation.

4.3. ENERGY REQUIREMENTS

4.3.1. Introduction

The 17th Congress of the World Energy Council has analysed that the demand for energy will increase by between 50 and 70% by 2020 (Leonard, 1998).

United Nations figures suggest that today's population of nearly six billion is forecast to increase to over 10 billion by 2050. Eighty percent of that population increase will be in developing countries, where 50% of the population does not have electricity supply connection. Renewable energy sources, solar, wind and biomass will inevitably take over the role of fossil fuels. By 2050, renewable sources will provide 22% of the global energy supply. The increase in the renewable contribution goes on unabated, rising by 33% by 2100 (The United Nations, 1989).

With the international drive toward sustainable development, the role of renewable energy is crucial in any scenario. Yeang, (1995) noted about the energy sustainability; *"looking at the global economy today, one has to be increasingly aware of energy as a scarce resource; the need for architects to design for a sustainable future becomes a self-evident imperative.*

He further recognised the ecologically design with climate;

> *"A further justification is ecological. Designing with climate would result in a reduction of the overall energy consumption of the building by the use of passive structural devices. Savings in operational costs derive from less use of electrical energy, which is usually derived from the burning of non-renewable fossil fuels. The lowering of energy consumption would further reduce overall emission of waste heat, thereby cutting the overall heat-island effect on the locality."*
>
> Yeang, 1995.

4.3.1.1. Bali's Energy Load

Bali has experienced tremendous growth in tourism. The economic sector and energy use have had an important role in this. Electricity is recognised as a fundamental feature of modern societies, essential to Bali's drive toward development.

However, a developing electricity supply system should be concerned with expense, efficiency, adequacy, and environmental impacts.

In terms of the Balinese energy loads, Suarnatha (1995) noted:

> *"Bali has shown dramatic changes in production and consumption of energy. Especially the use electricity for developing of tourism. Eighty percent of Bali's electricity comes from oil-powered generators."*
>
> Suarnatha, 1995.

In addition, self-sufficient communities, the private sector, and government have undertaken the development of micro hydroelectric sources, and diesel power, on a small scale. Alternative energy resources that have the potential to be developed are geothermal, hydro, micro hydropower, charcoal and solar energy.

4.3.1.2. Bali's Energy Stations & Distribution

The electricity system in Bali is provided by the state electricity company and is connected to the Java's electric grid through an interconnecting system of 150 KV underwater transmission lines. Sub-stations and gas turbine power stations are located in the capital city, Denpasar. The capacity, peak load and power station are presented in Table 4.1. (The Central Statistic Bureau of Indonesia, 1992)

No	Month	Capacity		Peak Load	Supply from Java	Machine
		Installed (MW)	Firm (MW)	(MW)	(MW)	(unit)
1.	Jan	104.7	69.7	113.0	69.0	11
2.	Feb	104.7	65.0	113.5	76.0	
3.	Mar	104.7	65.0	118.9	66.0	
4.	Apr	104.7	72.0	121.9	66.0	
5.	May	104.7	75.6	121.5	72.0	
6.	Jun	104.7	75.2	121.1	72.0	
7.	Jul	104.7	63.0	120.3	73.0	

Table 4.1. Power Stations and Peak Load 1992
Source: PLN (The State Owner Energy of Indonesia), 1992, PLN Region XI-Bali.

The supply from Java ranged from 66 to 76 MW, although the submarine cable transmitting electricity across to Bali has a capacity of 200 MW. At present most of the power stations use oil and coal oil energy. Thus production costs are very high, and increase the energy load.

4.3.1.3. Bali's Energy Production and Consumption

Figure 4.1. shows the increase in electricity production from 121 million KWh in 1981 to 525 million KWh in 1991 (16.1% average annual increase). The consumption increased from 104 million KWh in 1981 to 359 million KWh in 1991 (13.5% average annual increase) (The Statistics Year Book of Bali, 1991).

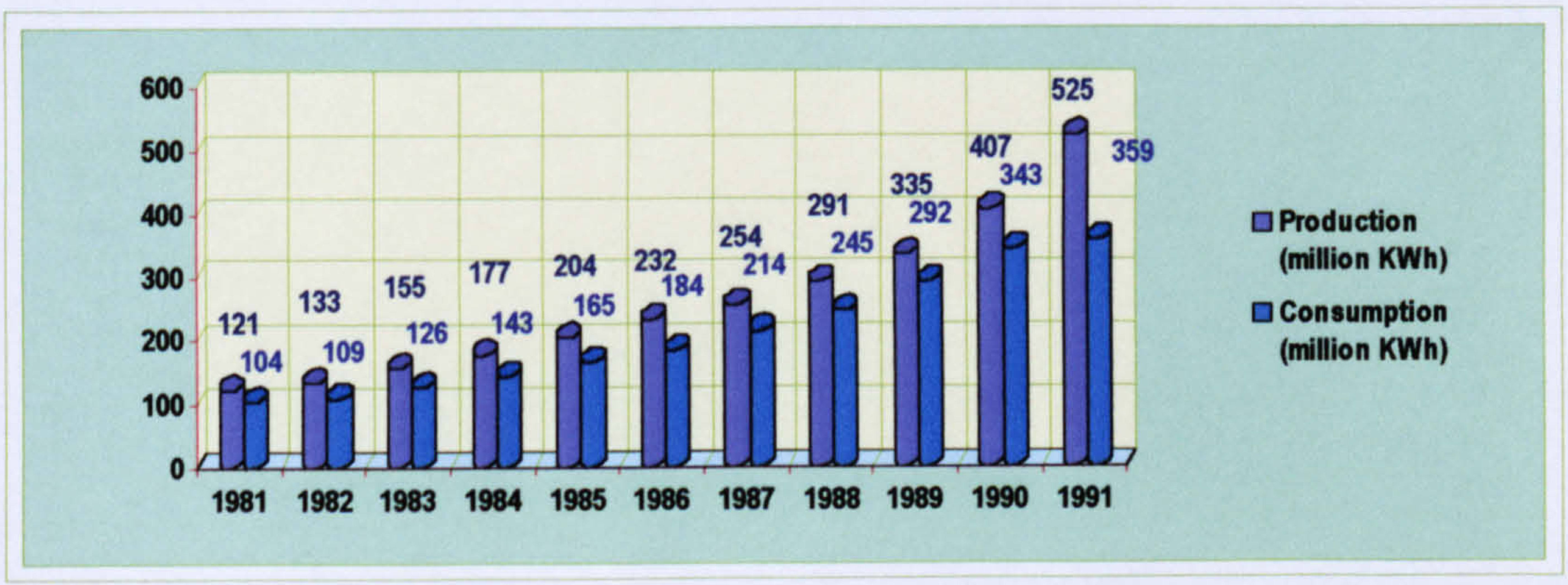

Figure 4.1. Bali's Energy Production and Consumption of Electricity 1981-1991

In 1991, for instance, the overall electricity consumption consisted of 38% household use, 9.7% economic activities, and 46.3% hotel and industry use. The remaining 6% were public uses such as street lighting and government buildings, as shown in Figure 4.2. Furthermore, in 1992 the capacity of the electricity system was 136 MW, while the peak load was 120.3 MW (88% of capacity). (Suarnatha, 1995).

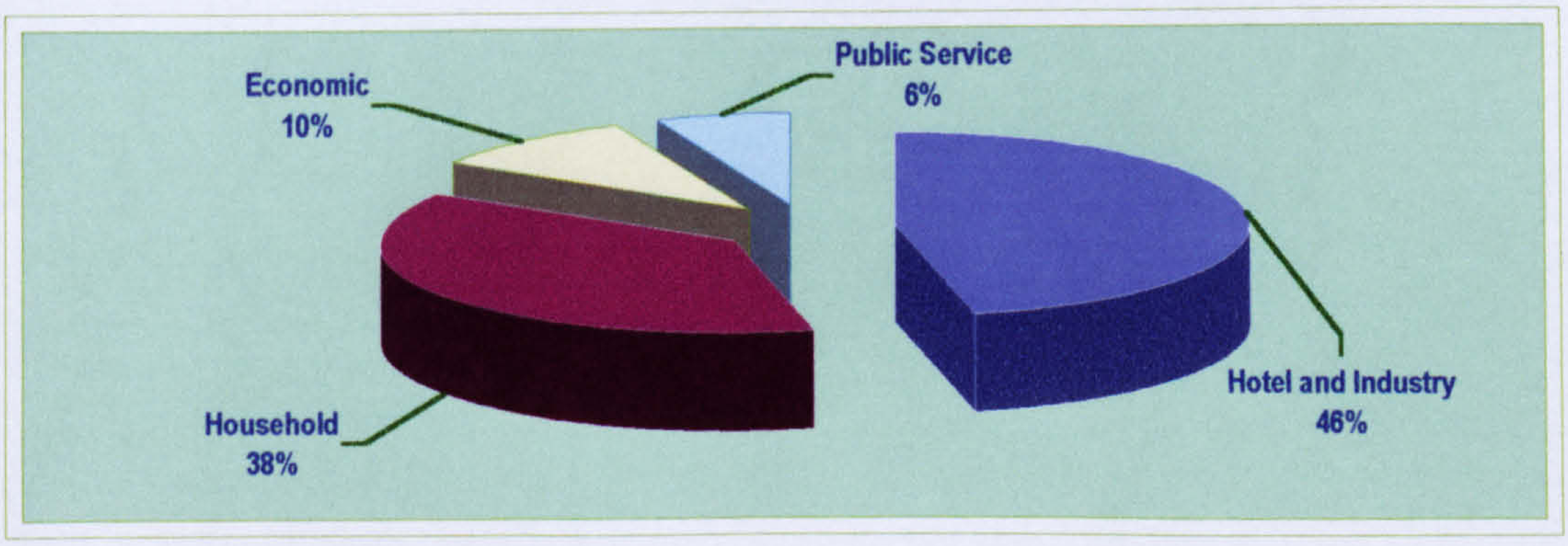

Figure 4.2. Energy Consumption Pattern of Bali 1991
Source : The Statistics Year Book of Bali, 1991.

A previous study (The State Owner Energy of Indonesia, 1991) had assumed an increase in demand electricity of 14% per annum, leading to the unexpected shortfall in energy.

With an estimated 17% annual increase in demand, peak load were surpassing existing capacities, leading to power shortages and brown-outs.

4.3.1.4. Bali's Energy Demand

The study for the proposed Ayung River hydro-electric power development project (JICA, 1998) has calculated that the growth in demand for both electrical power and electricity energy in Bali would increase at a rate similar to that of the last 5 years, or approximately 14% per year, as shown in Figure 4.3.

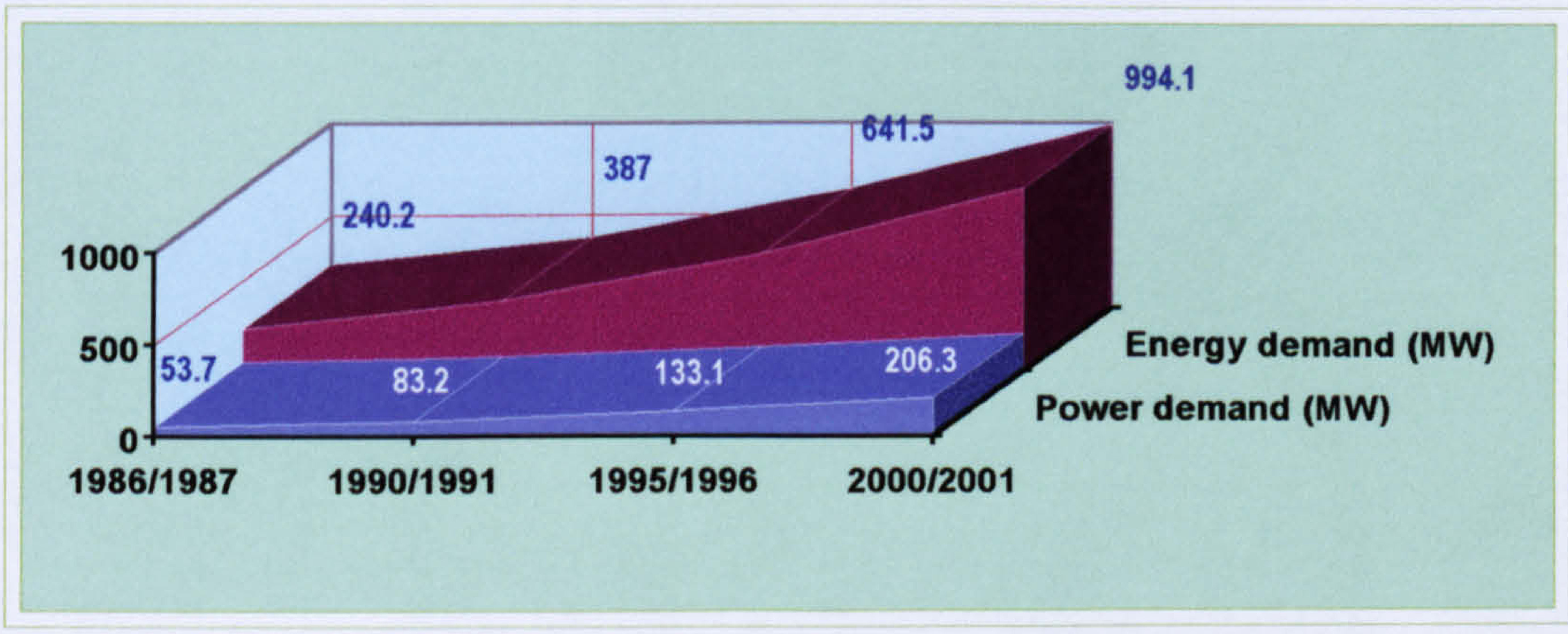

Figure 4.3. Projected Electricity Demand in Bali
Source: Japanese International Cooperative Agency (JICA), 1988, Ayung River Hydro Electric Power Development Project (AHEPS)

As shown in Figure 4.3, electricity power and electricity energy demands were calculated to reach 206.3 MW and 944.1 MW in 2000/2001 respectively, given existing rates of growth.

On the basis of these projections, the Japanese International Cooperative Agency (JICA) concluded that a new plant would be needed to cope with the increasing demands and recommended that the Ayung Hydro Electric Power Station (AHEPS) project be considered to meet this demand for electricity.

Between 1988 and 1990, three independent reports were produced concerning possibilities for the expansion of electricity supply through additional power stations and methods:

- The Ayung Hydro Electric Power Station (AHEPS), 43.9 MW (JICA, 1988).
- The Bali Power Development Plant (Merz and McLellan, 1990).
- The Geothermal Power Development Plan, Bedugul, 200 MW (The State Owner Energy of Indonesia, 1991).

4.3.1.5. Bali's Energy Production Stresses

The economic growth rate has been 7% rather than the 5% estimate used in electricity supply planning, a 40% shortfall if one assumes that electricity demand grows at rates at least equal to economic growth (Suarnatha, 1995).

Thus, in the absence of programmes to increase the efficiency of electricity use there is a greater need for electrical production to support economic development.

In addition, there have also been losses of electricity within the distribution network, this being mainly due to the length of cables used to transmit electricity from Java to Bali, and because of losses from electricity used only for illumination.

Hotel development has not been well co-ordinated with the state electricity owner; too often they have been built without considering the electricity supply capacity, and the rapid building of them has increased unpredictable demands on the electricity network (The State Owner Energy of Indonesia, 1991).

4.3.1.6. Bali's Energy Production Capabilities

Households as a total were the largest group of electricity consumers, while their ratio of electricity used per consumer was the smallest.

Conversely, industry had the smallest number of users while their ratio of electricity used per consumer was the largest. Although households consume the largest percentage of electricity, rates of increasing demand by industry, particularly the tourism industry, have been higher than rates of increasing demand by households. Electricity used in economic activities can increase efficiency, support education and stimulate work productivity as well as increase the homebase community income (The State Owner Energy of Indonesia, 1991).

4.3.1.7. Bali's Energy Strategies

The State energy owner should decide to set a limit on electricity production and responsible for integrated development planning by eco-development as a balance between economic and environmental development. Electricity supply for households should not be sacrificed to development of the tourism industry. Suarnatha (1995) suggested the energy strategies of Bali:

> *"Large tourism industry should have its own power generators as long as an environmental impact assessment is conducted first. Avoid fossil fuel power plant that can impact upon human health by promoting energy conservation and communities' awareness in terms of using energy wisely."*
>
> Suarnatha, 1995.

4.3.2. Energy Resources

4.3.2.1. Coal Energy

Indonesia is now the fourth largest exporter of thermal coal in the world. From 1994 (11 million Mt) to 1999 (21 million Mt) of coal were exported. Current estimate is more than 36 billion Mt. With mine expansions, the country is on track to mine an estimated 70-plus million Mt by the end of this century.

Figure 4.4. indicates the balance between export, domestic demand and total planned coal production by the national private, contractor and state-owned industry sectors.

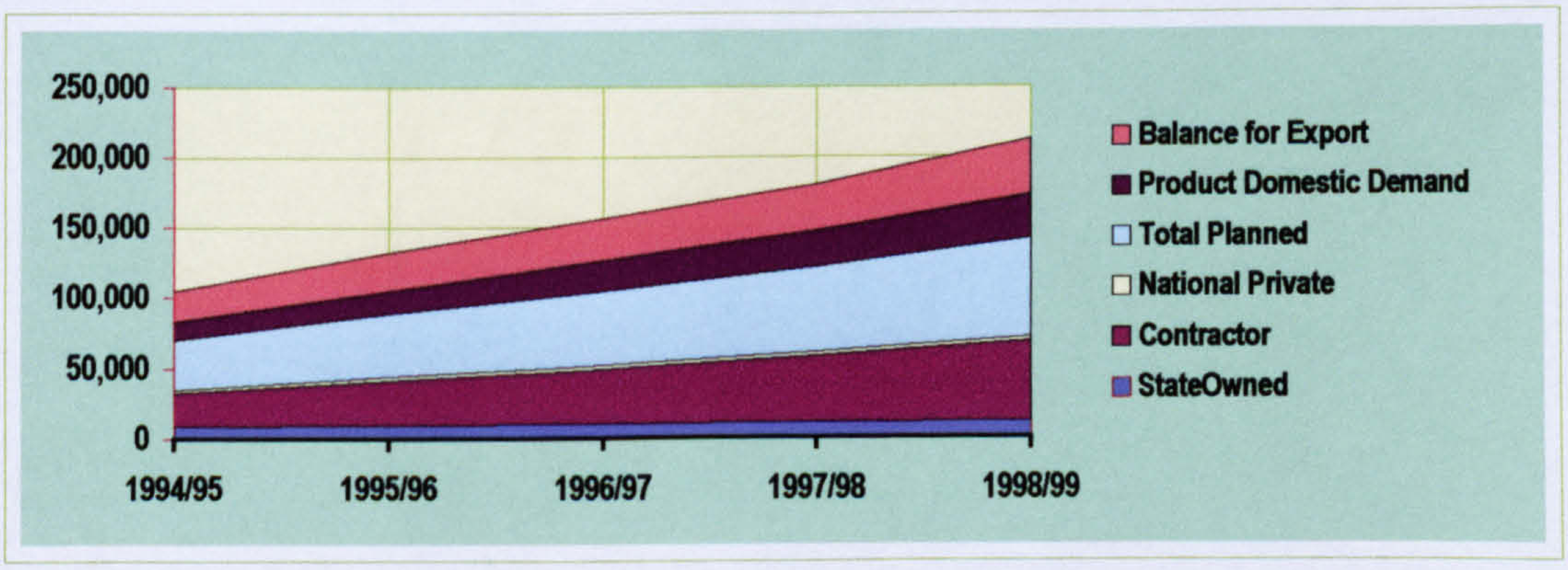

Figure 4.4. Planned Coal Production by Industry Sector, 1994-1999 (P.T.B.A. 2000).

Its series of five-year plans extending through the year 2004 envisage coal replacing petroleum's current 46% share of generating capacity, and petroleum consumption for that purpose dropping to about 8% of total capacity.

It estimates that the country's reserves are sufficient to meet domestic demand for about 140 years at a predicted consumption rate of 35 million Mt per year after the year 2000, compared with its oil and gas reserves that have reserve-to-production ratios of 20 and 40 years, respectively.

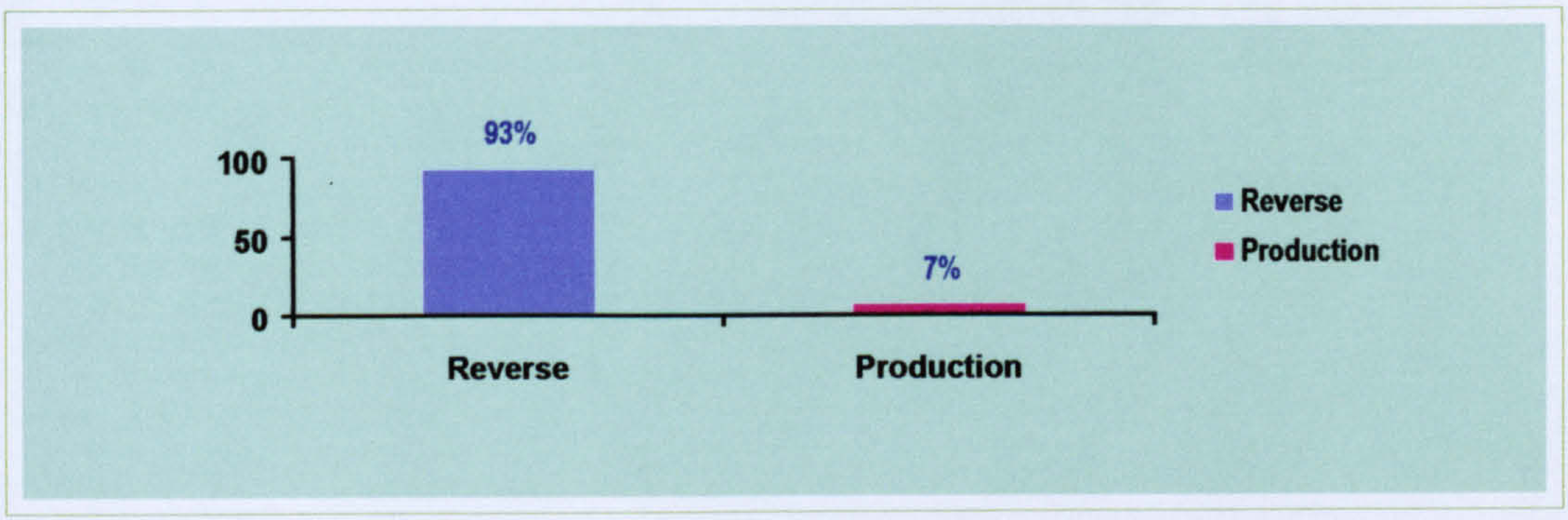

Figure 4.5. Coal Reserve and Production, 1994/1995 (P.T.B.A. 2000).

Indonesia's coal reserve and production are shown in Figure 4.5, primary energy supply and consumption are shown in Figure 4.6 and 4.7.

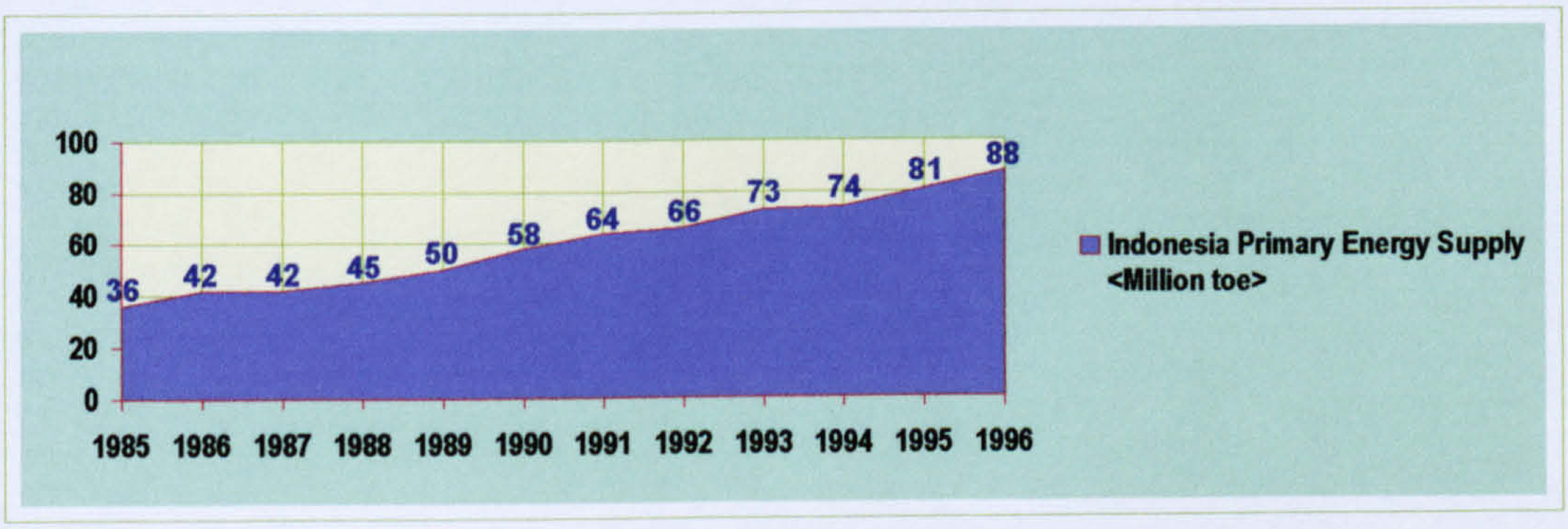

Figure 4.6. Indonesia's Primary Energy Supply (I.E.A. 1998)

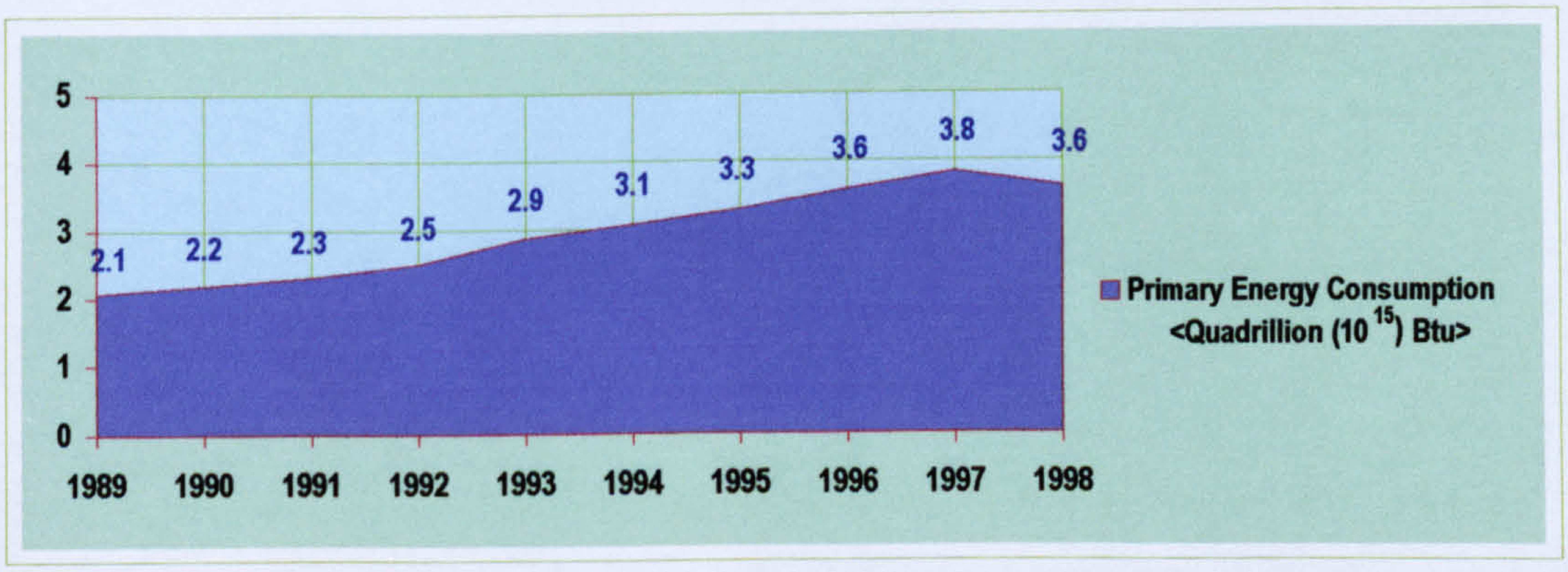

Figure 4.7. Indonesia's Primary Energy Consumption (I.E.A. 1998)

To achieve the additional 25,000 MW to 30,000 MW of generating capacity visualised in the government's economic plan which extends to the year 2010, industry observers estimate that US$ 45 to US$ 60 billion in investment will be required, much of which will have to come from private sources.

The deal will allow the first of a series of mega-projects, the 1,230 MW power plant, to get under way. In terms of investment opportunity, Indonesia is wide open. Indonesia's primary energy coal production and consumption are shown in Figure 4.8.

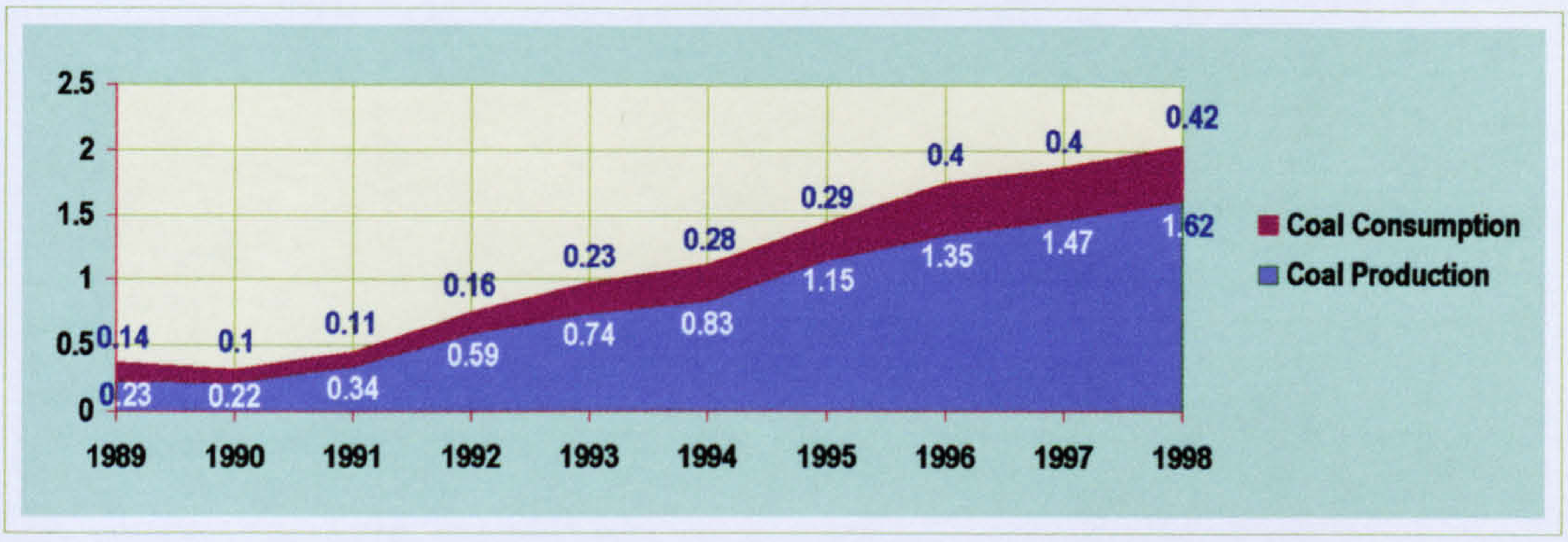

Figure 4.8. Indonesia's Primary Energy Coal Production and Consumption (I.E.A. 1998)

4.3.2.2. Geothermal Energy

Geothermal power is also a viable alternative; however, development of this resource has been slow and plagued by technical and operational problems.

4.3.2.3. Solar Energy

In any efforts to increase the share of electricity, Indonesia's geography will not allow this goal to be reached solely by extension of existing electrical grids. Only Java and Bali, the two most populous of Indonesia's islands have extensive electrical grids and even they do not extend to all parts of the island. Figure 4.9. shows the biomass, geothermal, solar and wind electric power in Indonesia.

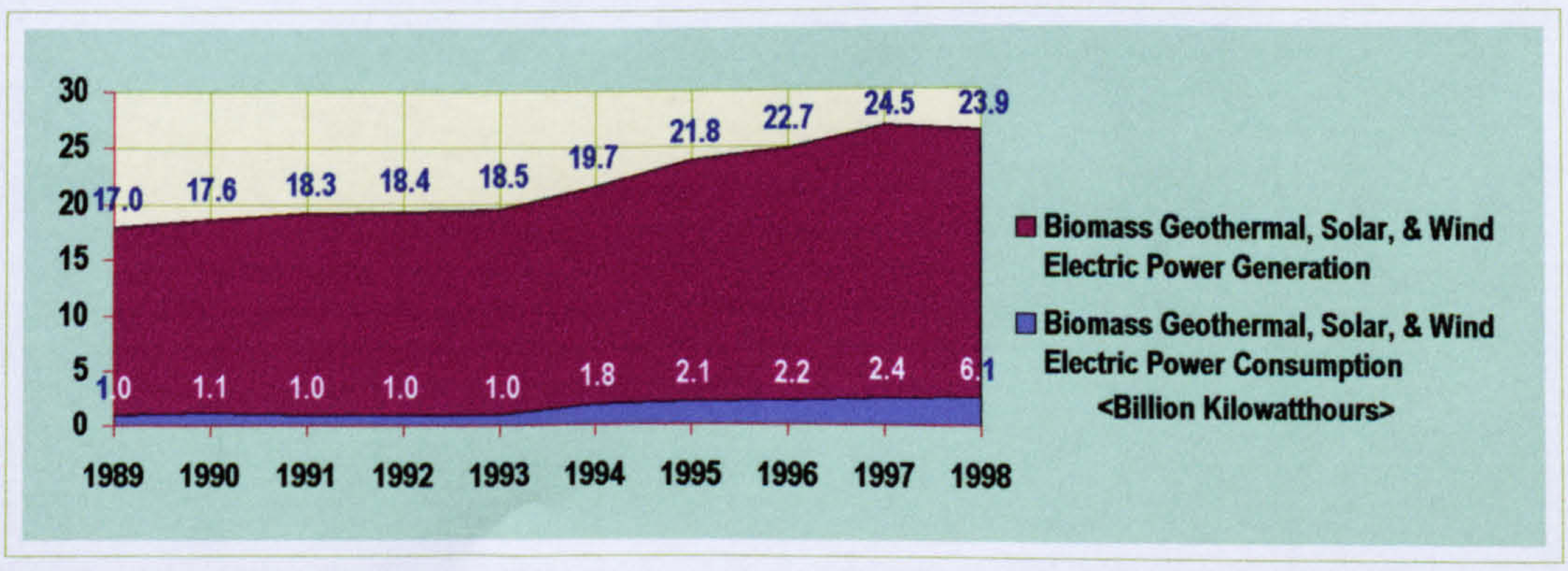

Figure 4.9. Biomass, Geothermal, Solar & Wind Electric Power (I.E.A. 1998)

A recent US $44 million World Bank loan to Indonesia is the first to solely target 200,000 solar home system projects. The Bank's financing includes a US $25 million grant that does not need to be repaid, from the Global Environment Facility (GEF) 1997/1998 which can be tapped for projects that mitigate global warming. Solar technology clearly represents a turning point for the adoption of an important renewable energy technology, and ecological leadership.

However, most of the money that has come their way so far has been directed into massive coal and hydroelectric projects. With loans over US$ 10 billion for power projects each year, both private banks and international aid agencies seem more interested in financing energy projects that increase dependence on fossil fuels and damage the environment. One reason is the relative ease with which private capital is attracted to large projects.

4.3.2.4. Hydropower Energy

Hydropower is plentiful, but sources are scattered throughout the islands and on Java, the most populous island, 75% of the hydropower resources are already developed. The hydroelectric power generation is shown in Figure 4.10.

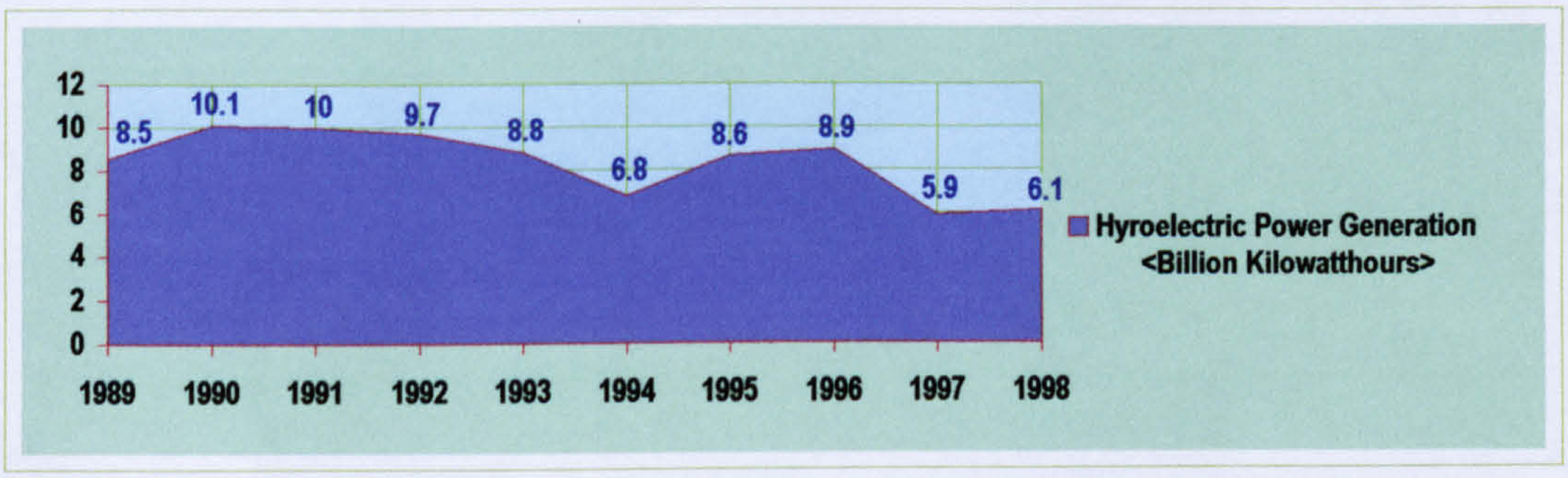

Figure 4.10. Hydroelectric Power Generation (I.E.A. 1998)

4.3.2.5. Nuclear Power

Nuclear power is another option, and the National Atomic Agency (BATAN) announced plans to build a US$ 1.2-billion nuclear plant, that was due to start in May 1995. The announcement generated public controversy and opposition from some members of Parliament, because of perceived dangers from the proposed plant's location near a population centre that is also in an earthquake prone area. The project, if approved, is expected to come on-line in 2004 (Carter, 1993).

4.3.2.6. Oil and Gas

The following are recent developments by Indonesia State Owned Oil, in the oil and gas sector (Figure 4.11). The government announced that at a US$ 6.00 per barrel domestic price versus the US$ 2.00 per barrel world price of oil, there is a real incentive to smuggle kerosene to neighbouring countries. The Arun Liquid Natural Gas (LNG) plant is currently producing 31,000 cubic feet per day of LNG. Production will increase to 44,000 cubic feet per day (Energy News, 2000).

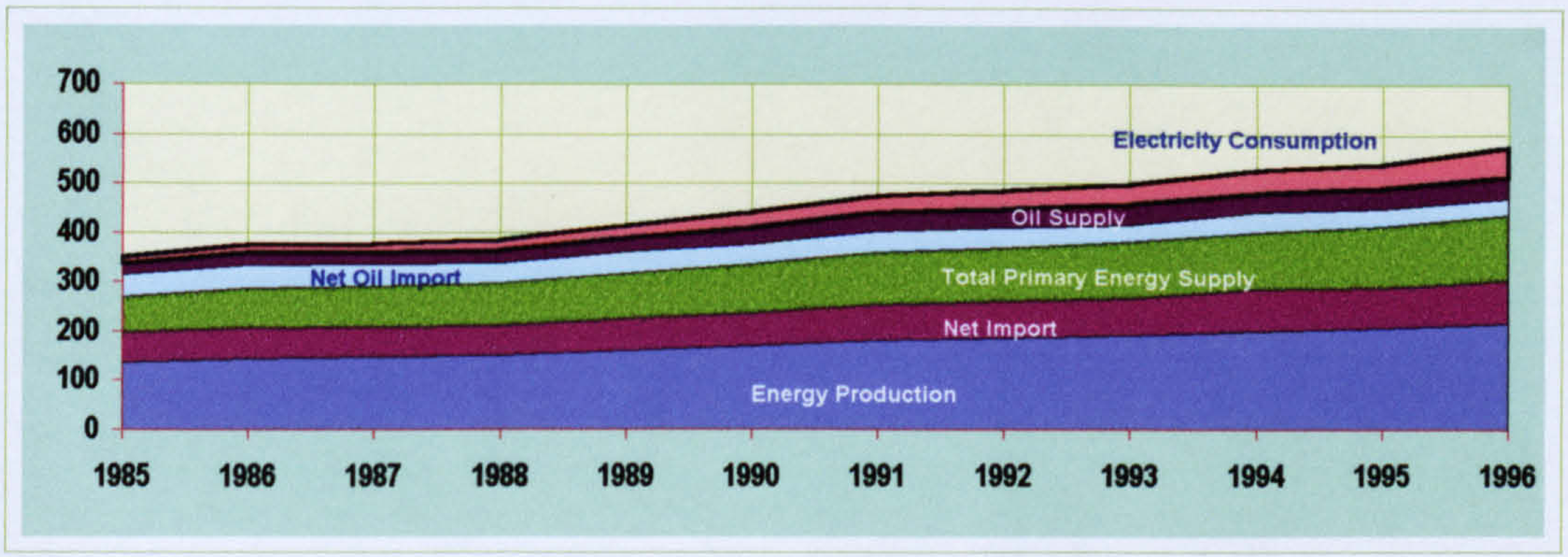

Figure 4.11. Indonesia Energy Indicators 1985 to 1996 (I.E.A. 1998).

4.3.3. Electrical Energy Generation

PLN, Indonesia's state-owned power company, at present can only provide part of the nation's industrial electricity demand from its hydroelectric, coal-fired, or combined-cycle generating plants and other sources. Total generating capacity is approximately 13,000 MW. Less than 20% of this capacity comes from coal-fired steam plants (Wilson Select Database, 1995). The remaining power is supplied by the captive generating system. Typically these are owned by private users, and consist mainly of oil/gas plants or generating sets powered by diesel or other petroleum-based fuels. They account for almost 9,000 MW of generating capacity.

However, the use of cheap, state-subsidised petroleum products to power these systems is a matter of concern to a government that urgently needs the export revenues its petroleum reserves could garner in the world market.

The total net electricity consumption is shown in Figure 4.12.

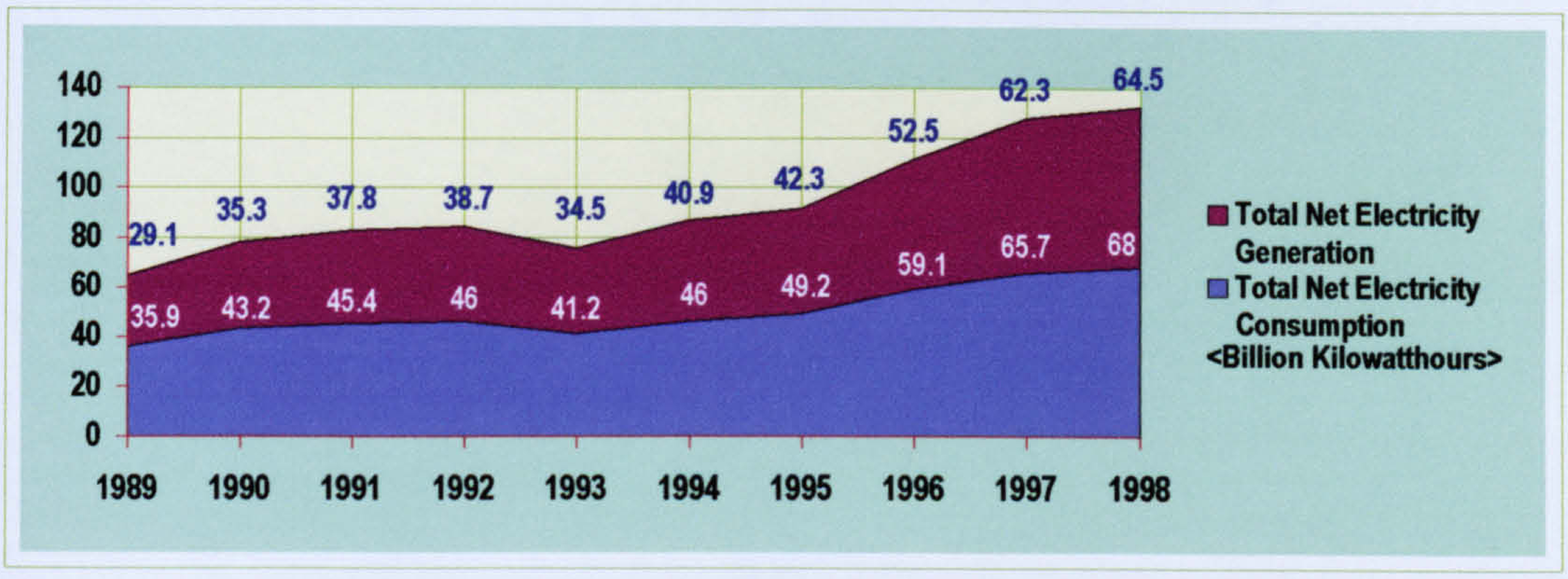

Figure 4.12. **Total Net Electricity Consumption (I.E.A. 1998).**

4.3.4. Review

In Bali, Indonesia, the following factors should be considered in managing electricity consumption and production; the rate of population increase, tourism development plans, rural electricity programs, privately owned power plants, the waiting list of large consumers, national economic development programmes, and the marketing of power. All of them are important for energy conservation of the country. As Merz and McLellan (1990) described about the power of energy for a such country:

> *"Energy is the engine that drives a country's economy, and energy efficiency is essential to keep country competitive in international markets and ensure future supply."*
>
> Merz and McLellan, 1990.

On the other hand, energy production and consumption have a strong impact on the environment which should be carefully weighed to ensure sustainable growth and development.

The current electrical consumption exceeds the generating capacity of Bali, with its excess requirement imported from Java.

However, by encouraging an energy efficiency programme, Bali could became self sufficient and have extra capacity to supply local industries.

Energy efficiency and conservation also contribute to environmental protection. These strategies can be done starting from the small to large scales of households.

In this respect for the people of Bali, Pamela and Jill (1999) advised:

> *"It is important that individuals can do much to save energy and for energy conservation in the house."*
>
> Pamela and Jill, 1999.

Regarding the energy cooling for a dwelling design in Bali, they furthermore recommended:

> *"It is recommended to tap the natural energy sources as much as possible, by providing maximum natural ventilation, to reduce energy consumption by using less power for less time by turning down the thermostat without reducing the comfort standard, to have more energy efficient air conditioning, insulate the house against heat gain, run during off-peak hours and use less power whenever possible."*

It is necessary to set up a National Building Code for energy efficiency in private residences. Within the dwelling design, it is also very important to teach people to become familiar with energy conservation. The government also needs a teaching campaign in housing, where it can reach more with its message of renewable energy and conservation.

In summary, there are two ways for more energy efficiency in the future; by lobbying for more responsible government policy on energy efficient dwellings, and to set an example by people's own good energy habits.

4.4. ARCHITECTURAL FEATURES OR STRATEGIES DEVELOPED TO MODIFY ENERGY USE

4.4.1. Design Thermal Comfort

4.4.1.1. Thermal Stress in Warm Humid Environments

From a study by Antaryama (2000), the paramount problems for thermal comfort in warm humid regions according to Evans (1980) are the high temperature and humidity, causing internal conditions that may be too warm.

Thermal discomfort arises when temperatures are continually very near to that of the skin (31-34 °C), owing to excessive solar radiation over the building structure and internal heat gains.

Under the high temperature conditions in the dwelling, *"bodily heat dissipation to the air by conduction, radiation, and convection, which very much relies on temperature difference, is therefore negligible"* (Koenigsberger et.al. 1974).

Lippsmeier, (1969) described the high humidity as another thermal stress in the warm humid region which is difficult to handle:

> *"In addition, under high humidity making these conditions difficult to tolerate, the cooling effect of evaporation is impeded from the skin, because the air itself cannot absorb enough moisture."*
>
> Lippsmeier, 1969.

As the night sky is too cloudy to allow dissipation of the outgoing radiation from the earth and surroundings, there is only a slight drop in temperature; a similar level of discomfort will almost inevitably be experienced at night as during the day. Since indoor temperature often exceeds that outdoors, natural ventilation can be used to some extent to lower the temperature by replacing warm with cool air.

The scope is limited, however, as it is not possible to cool the building below the outdoor temperature (Szokolay, 1993; Van Strasten, 1967; Atkinson, 1960).

In this respect, *"air movement is the only way to achieve natural cooling in these regions"* (Koenigsberger et.al. 1974; Ballantyne and Spencer, 1972; Smith and Tamakloe, 1970; Lippsmeier, 1969; Fry and Drew, 1956).

Air movement is used to assist and accelerate evaporation of sweat, thus creating physiological cooling.

This however, can only be utilised when the air temperature is lower than the skin temperature; otherwise, the body is heated. *"Another condition which makes this method ineffective, is when the relative humidity is above 85%, since in order to have some effect a velocity greater than 1.5 to 2 m/s is required"* (Antaryama, 2000).

Where these conditions apply, mechanical control is the only option. However, this is not always a direct solution, particularly if the building is to be air-conditioned.

The reason is that a building which was originally designed for passive cooling would be totally unsuitable for air conditioning, *"as the large ratio of surface area to volume will increase the heat gains"* (Muncey, 1964; Danby, 1963), thus making a mechanical cooling system inefficient and expensive to operate.

4.4.1.2. Basic Principles

According to Antaryama (2000), a warm humid climate is the most difficult to handle. The options open to the designer seem to be extremely limited, because the conditions do not permit a number of the passive cooling methods that have been employed in other hot regions. Even active systems still present difficulties. As far as passive design is concerned, however, there are two important points to observe with respect to thermal stress, heat avoidance and the provision of air movement.

To incorporate these into the design, the heat exchange processes in the building should be considered first. As discussed elsewhere (Koenigsberger et.al. 1974; Szokolay 1980, 1987) heat exchange in a building primarily constitutes heat transferred through the building envelope, either inward or outwards, by means of conduction (Qc); heat received by the building envelope from solar radiation (Qs); heat exchange in either direction by means of ventilation (Qv); internal gains (Qi); and heat evaporated from the surface of a building (Qe). Thermal balance in buildings is obtained when Qc + Qs + Qv + Qi + Qe = 0.

For hot climates this should be less than zero, in order to cool down the building as well as to avoid increase in indoor air temperature.

Having considered all of these aspects, the general principles (these will be widely discussed at the next sections) that should be applied to achieve thermal comfort in the warm humid regions are:

- *"To reduce heat gains through the building envelope by means of solar control and appropriate building materials and construction,*
- *To reduce internal heat gains by controlling heat production,*
- *To provide effective ventilation to remove excess heat and promote evaporation loss."*

Antaryama, 2000.

4.4.1.3. Reduction of Heat Gains Through the Building Envelope

The primary sources of radiation that affect buildings can be direct and diffuse, originating from the sun and the sky. Diffuse radiation is as important in warm humid climates as direct radiation, since it is non-directional. Added to these is radiant heat from the surroundings. All of these elements will contribute to the heat gained by the building envelope, and thus the increase in internal temperature. To minimise the heat load from all surfaces, solar radiation that reaches the building should be controlled, and building materials should be able to exclude heat.

Solar control means the reduction of heat by solar isolation. To lower the heat gains, the surface area exposed to solar radiation has to be minimised.

This can be achieved either by manipulating the form and orientation of a building, or by providing shade over the structure. Shading is also required to protect occupants from direct radiation, particularly through transparent surfaces, to alleviate the negative impact of heat indoors (i.e. temperature elevation of internal air and surfaces). Building materials should be specified according to their ability to prevent heat from being transferred from outdoors to indoors.

A distinction is usually drawn between radiation through opaque and transparent surfaces.

In the case of opaque surfaces, the effect is indirect, i.e. by heating the surfaces. This is usually manifested in the form of the 'sol-air' temperature concept: the combined thermal effect of solar radiation incident on the building and ambient air temperature. On transparent surfaces, on the other hand, the effect is direct, i.e. by penetration. The impact on solar radiation, particularly direct solar radiation is dependent on orientation. Solar air temperature, by contrast affects all surfaces of a building in the same way.

4.4.1.4. Reduction of Internal Heat Gains

Apart from heat produced by the metabolic processes of the body, internal heat gains arise from appliances and light fittings.

Whilst heat dissipated from the body varies according to body size and activity level, that from appliances mainly depends on their kind and function, and that from lighting is determined by the required level, type and system of the lighting adopted.

There is scope to reduce these internal heat gains, but is dependent on Government policy. Energy coding of appliances has enabled consumers to select the most energy efficient appliances.

Good design has also promoted use of compact fluorescent fittings which use but a quarter of the equivalent incandescent fittings. For appliances and lighting, the use of more efficient types appears to be the most practical way to achieve a significant reduction in the overall heat gain in buildings.

4.4.1.5. Provision of Effective Ventilation

Natural ventilation is required in a building for three main reasons: firstly for health, i.e. replacing the used internal air with fresh external air; secondly for thermal comfort, i.e. removing excess heat and promoting evaporation from the skin; and finally for structural cooling by convection.

As noted above, despite its limitations ventilation can be used to lower the indoor air temperature.

If copious and continuous ventilation is induced into the building, it is even possible to reduce air temperature to outdoor levels (Givoni, 1991; Petherbridge, 1974).

Such a condition might however be rather difficult, or perhaps impractical, since it will require a very large area of openings. The certainty that the indoor temperature is not much warmer than that outdoors and does not exceed the skin temperature is particularly important, if air movement is to be used to assist evaporation of sweat.

However, since lowering the temperature alone in this situation cannot provide cooling, air velocity is the critical factor for restoring comfort rather than the volume flow rate.

As well as assisting in thermal comfort, ventilation is mandatory for health, and can have a significant impact on structural cooling where there is a wide temperature variation between day and night.

In principle, natural ventilation in buildings depends upon the existence of a pressure difference between the inside and the outside. This can be created by means of either thermal force or wind force.

The former, which is often referred to as 'stack effect', relies chiefly on temperature difference across different parts of the building, while the latter is mainly governed by the dynamic effect of winds.

As the climatic conditions of warm-humid zones generally give rise to only a slight temperature difference, thermal force ventilation cannot be very great. Since it results in relatively low air speed, it is insufficient to give thermal comfort. Thus, wind force ventilation seems to be the only one that can be relied on.

Effective air movement can be generated in a building only by cross ventilation. To obtain this, openings should be positioned so that the inlet and outlet face a high and low-pressure respectively.

Physiological cooling can be ensured when the incoming air is at body height (normally termed the 'living zone'), and at floor height. For this purpose, openings should be positioned so that the airflow passes through the living zone, and even distribution of air velocity is achieved.

The rate of airflow through the openings is determined by the magnitude of the pressure difference across the building and the flow resistance of the apertures (openings), whilst the speed and pattern of internal airflow are chiefly governed by the size, shape and location of openings.

In principle, more initial wind speed can be secured when the wind flows follow a straight path, and reduction may occur when there is a change in direction.

4.4.2. Building as A Climate Modifier

Apart from Antaryama (2000) study, it was noted that since the performance of buildings in relation to the ambient environment is governed by considerations such as form, plan layout, structural elements, orientation and the effects of external features, it is vital to take advantage of those elements in building design.

4.4.2.1. Shape and Form

> *"The shape of a house is one of the building properties, which can be manipulated in order to modify the climate for internal thermal comfort."*
>
> Antaryama, 2000.

He further indicated, the most basic concept related to this is surface-to-volume ratio. It should be noted that for a given volume, the rate of heat flow inward and outward is proportional to the surface area.

Geometrically, a sphere or hemisphere if compared to other forms without taking account of their bases has the least surface area per unit volume of any form (Blackweel, 1984; Snyder and Catanese, 1979; Markus et.al. 1972; Chalkley and Cater, 1968). Other things being equal, these forms are the ideal ones.

However, since a circular or curved geometry is not always appropriate for construction and space use, the most efficient form in practice is the cube (Szokolay, 1987, 1993; Markus & Morris, 1990; Chalkley & Cater, 1968).

A number of theoretical studies have examined the relationship between form and internal comfort in different types of climate.

Hawkes (1981), in his study of building shape and energy use arrived at the conclusions. Among the three forms (a square plan, a rectangle with a plan aspect ratio of 4:1, and a triangle) of the same floor area, the triangle was found to be the form with the least fabric heat loss, followed by the rectangle and the square. For the square plan, 15% of the walls were glazed, while for the rectangle and triangle their major facades, which faced south, were highly glazed and the remaining walls had 30% glazing.

From a computer analysis of a theoretical 10-storey building, Wilson (1976) reported that in temperate climates a building with a square plan shape has a smaller maximum summer cooling load than a rectangular building, irrespective of its orientation. Yet building with a plan aspect ratio between 2 and 3, and an east-west axis, produced the lowest maximum cooling load among rectangular buildings. It also emerged from Wilson's study that due to self-shading, an L-shaped building of basic plan ratio 5:1 has a lower maximum cooling load for many different orientations than a simple rectangular building of the same total floor area.

However, a rectangular building may still perform better when oriented on east-west axis. Among the L-shaped buildings, the introduction of an appropriate north-south wing on to the east-west block can lead to a small reduction in cooling load.

Unlike the three previous studies, which are concerned with individual buildings, Gupta (1984), has looked at thermal performance of groups of buildings in hot climates, and suggested that multiple court and street forms are preferable to pavilions.

Olgyay (1963) suggested that providing there is a certain percentage of glazing on all faces of the building, the most desirable form of the house for all climatic conditions is one that is elongated east-west. A square building, as opposed to an elongated one, gives the best thermal performance only where there are small window openings.

For warm humid conditions, it seems that the ideal house form is narrow and elongated (Evans, 1980; Koenigsberger et.al. 1974; Atkinson, 1953, 1960).

However, this form only works well when the dwelling faces north and south, for the purpose of ventilation, otherwise, the large surface area expose to the sun will cause bigger heat build-up.

Considering *"a square form also gives the best thermal performance"* (Olgyay, 1963), therefore for that reasons, narrow and square forms proportionally combined, is possibly a perfect model for a dwelling in the warm humid climate.

The narrow form is also well known in the traditional Malay house (e.g. the Bumbung Panjang) (Yuan, 1987).

In Bali, the dwelling shape had been experienced and long-time tested in the traditional compound dwellings, in which each building stands alone individually. This had never been adopted for current contemporary dwellings, where normally each has a group of square-shape rooms under one roof.

On the contrary, both the traditional Malay house and traditional Bali dwelling have building hierarchies and building orientation differences. The Malay house is oriented to enable Muslims to turn to toward Ka'ba in Makkah when praying, which is to the North-West, while the Balinese is oriented to the North-East.

These come from the different religions, the former being Islamic and the latter Hindu.

Providing 'orientation' and 'shading' are properly taken into account, these forms have been shown the most effective with respect to 'ventilation' and 'solar radiation'.

Shading of external surfaces is of importance due to the fact that in this region any surface will also receive diffuse radiation.

Apart from solar radiation, building form can be exploited to induce ventilation and air movement.

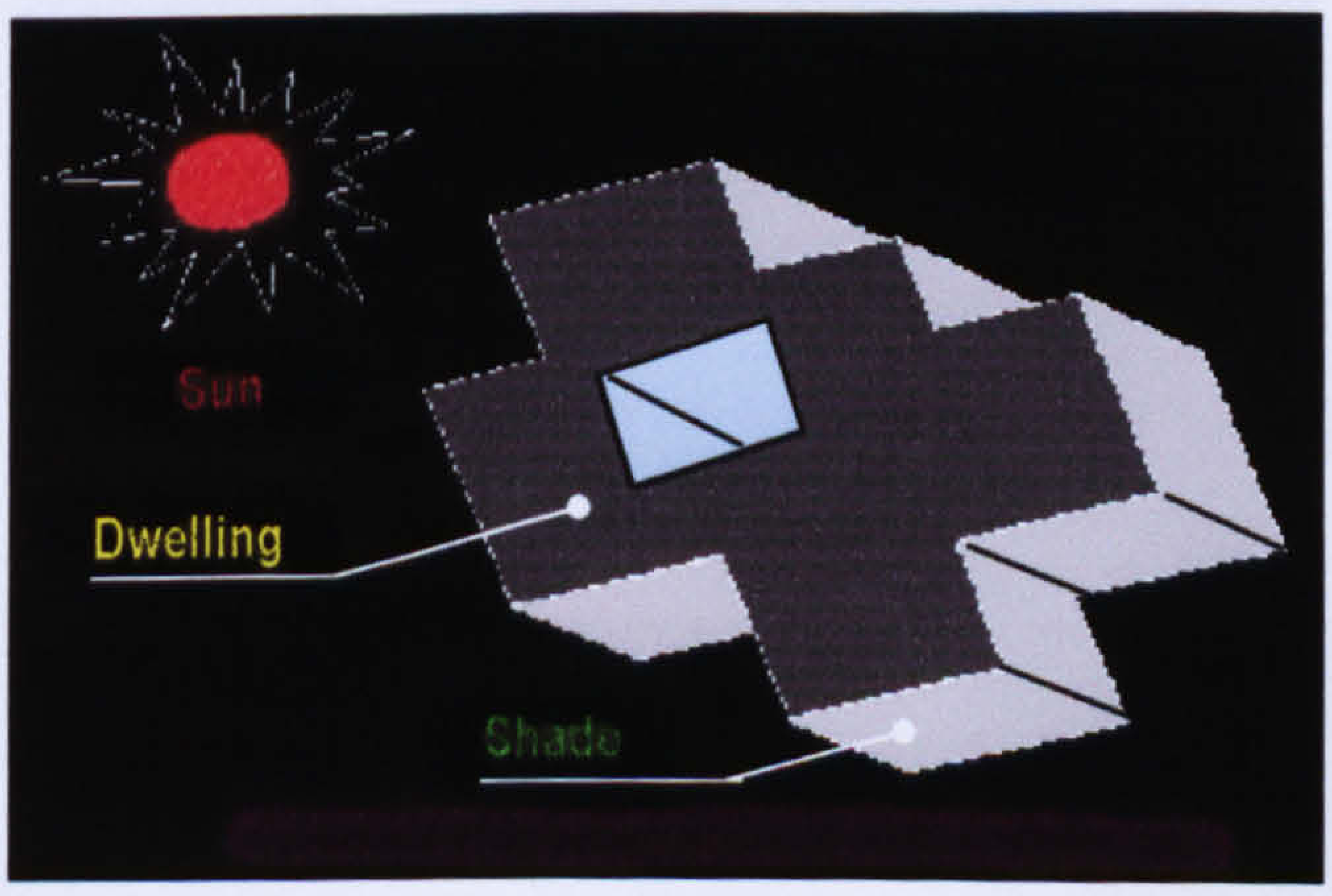

Figure 4.13. An Example of Shape and Form of Dwelling

It is clear from the forgoing discussion, a combination of square small forms for ventilation and corners formed by walls for shading from the sun is the best configuration dwelling for the warm humid climate conditions (e.g. Figure 4.13).

Furthermore, many studies (Aynsley, 1972, 1991; Givoni, 1969; Olgyay, 1963) have concluded that the shape of buildings determines the pattern and pressure of air that flows around them.

Features included in the shape of the building are projections from the building surface (e.g. eaves, columns, and beams) and attached elements such as sunscreens, as well as the overall geometry.

Equally important are the openings into the building. In this respect, the resulting airflow patterns are independent of air velocity. Provided that openings are available on all facades, such forms will tend to have better cross-ventilation than compact shaped ones, as in the latter rooms are likely to be arranged in more than single file, thus offering greater resistance to the wind.

Evans (1980) noted that the pattern and length of wind shadow are determined not only by the geometry of a building, but also by the roof form and the direction of the prevailing wind on the windward side. The width of the building, according to Konya (1980) has little effect on the extent of wind shadow.

As far as rain is concerned, the most appropriate roof form in regions where frequent and intensive rain is dominant is the pitched type with a steep slope.

Having such a roof type may result in a larger surface shading area around the dwelling, hence excluding heat gain, and modification of construction and materials may lead to internal temperature reduction.

4.4.2.2. Building Elements

Dominant roofs and open plan designs are marked in the buildings of warm humid regions. The roof plays a particularly important role from the point of climatic protection, owing to the high levels of solar radiation and precipitation. The open plans are more a manifestation of requirements for ventilation (Antaryama, 2000).

Olgyay (1963) reported that in these regions ventilation is needed for 85% of the year. Air movement, as has been noted, is critical for physical comfort.

Volume flow rate, on the other hand, can only help to lower the internal air temperature, and cannot be relied upon for physiological cooling.

Extensive discussions on air flow through and around buildings are available in the studies by Karamchandani and Amin (1983); Aynsley (1972, 1977); Van Straaten (1967); Givoni (1965, 1969), while a descriptive summary of the subject can be found in Bowen (1983). Some of the most important points were outlined by Antaryama (2000) below.

Air movement in a building can be generated when wind resistance in the building is minimal.

This can be achieved by making the plan of a building as open as possible, ideally no more than single file depth. In climatic terms, walls have less positive value than in any other region, though of course they may still be required for the purposes of privacy, security and protection from undesirable external conditions such as rain.

Maximum air velocity can be achieved by manipulating the relative sizes of the inlets and outlets. Givoni (1965, 1969) noted that an increase in average indoor air velocity is obtained by increasing the size of both inlet and outlet simultaneously.

Yet to create higher wind speeds through the interior, especially near the inlets, the inlets should always be smaller than the outlet (Lippsmeier, 1969; Aynsley, 1972).

The pattern of airflow through the interior, on the other hand, is specifically determined by the position of the inlet; the outlet position has no effect (Olgyay, 1963). Thus, the arrangement and type of inlets will play a major role in this mechanism.

In a situation where openings can only be positioned on a single exterior wall, according to Givoni (1969) cross-ventilation may still be induced in a building. This is achieved with the help of a vertical projection, providing that the house is oriented at an oblique angle, up to 60°, relative to the wind.

In many cases, either vertical or horizontal projections can be employed to direct airflow into an internal space.

However since projections also generate pressure patterns, they should be positioned so as not to alter the air flow pattern required (Koenigsberger et.al. 1974; Aynsley, 1972; Lippsmeier, 1969).

To increase the natural ventilation flow rate, openings need to be made as large as possible. However, it should be remembered that the rate of velocity falls off as openings get larger.

In order to obtain higher ventilation rates, the presence of any intervening obstructions must be minimised. Similarly, to retain most of the desirable wind speed in a building, the use of windows with fixed glass panes should be avoided.

Opening types, such as sashes, canopies, and louvers have a significant influence on the indoor air flow pattern, while fly screens or mosquito nets can substantially reduce air velocity (Koenigsberger et.al. 1959, 1974).

Internal partitions, obstructions and non-rectangular planning of rooms can modify the air velocity inside the building, both by changing the direction of the airstreams and by drastically reducing its speed (Lippsmeier, 1969). Thus when partition walls are needed in the design for any reason, they should be completely perforated, or have openings. This even applies where all internal doors are kept permanently open.

Finally, two things should be noted with respect to the provision of ventilation and air movement. Firstly, the incoming air should be cooled before entering the building, otherwise it will only increase the heat gain, thus affecting thermal comfort. To achieve such conditions, air approaching the building should be directed to pass under shaded surfaces, without passing over or through the heated ones. Vegetation can play a major role here. Secondly, in order to achieve effective air movement, openings should be free from external obstruction.

In respect of solar radiation, the part of building that is most affected is clearly the building envelope. As far as heat exchange is concerned, it is the area and material of the external surfaces that are most important, particularly those of the roofs and windows (i.e. transparent or glazed surfaces).

The roof constitutes the only part of the building that is unprotected against radiant heat from the sun and overcast sky. Windows are the greatest single source of internal heat gain (Konya, 1980; Brown, 1985).

Koenigsberger and Lynn (1965) pointed out that in order to minimise heat gain, the roof must absorb as little as radiant heat as possible, and offer almost complete resistance to heat flow from the outside to inside.

For warm humid climates, they recommended a double construction, such as that formed by a pitched roof and horizontal ceiling, with roof space ventilators.

Peterbridge (1974) stated that with adequate ventilation, air temperature of an attic space in such a roof can approach the outdoor temperature, thus offering great resistance to heat flow. Its effectiveness, therefore, is largely dependent on the wind and the orientation of ventilators.

Santoso (1993, 1988), however, argued that in this type of climate the use of roof ventilation is ineffective, due to the small daily and monthly temperature variations and the frequently calm conditions. He further stated that in such a roof the construction acts as a heating element during the day and even during the night, when the outdoor temperature is low.

Window size, position and orientation largely determine climate modification through window design, like openings. All of these factors affect the amount of solar radiation that will be received by the building. Since windows also perform functions other than climatic control, such as allowing a view out and excluding dust, the size and arrangement will inevitably reflect the interplay of such factors. Solar gain can be minimised through the selection of suitable materials and, most importantly, by providing shading over the windows.

The thermal performance of a building may also be improved by protecting the structure from solar radiation, e.g. by shading devices.

The most effective are overhangs, awnings and fixed horizontal and vertical devices which provide external shading (Cofaigh et.al. 1996; Santosa, 1993; Szokolay, 1987, 1993; Danby, 1963; Olgyay and Olgyay, 1957).

This is because the heat absorbed by such screens is freely lost in the ambient air, thus avoiding additional heat transfer into the building.

Lippsmeier (1969) pointed out that screening all windows, openings and in some circumstances complete facades, may be imperative as radiation from the sky can be both direct and diffuse. With adequate shading, the indoor temperature can be kept at about the same level as that outdoors (Lippsmeier, 1969; Koenigsberger and Lynn, 1965).

In this respect, the local position of the sun is an important design consideration. Internal shading devices such as blinds and curtains can also be used, but these have comparatively little effect on solar heat input.

While reducing direct radiation, they also absorb much of the solar heat, and eventually become a source of heat themselves (Szokolay, 1987; Koenigsberger et.al. 1974). Finally, vegetation, such as deciduous trees, can also be used to provide shading, especially for low-rise buildings.

4.4.3. Building Orientation and Density

According to Antaryama (2000), the position and alignment of a building will determine the influence of solar radiation and wind.

A design aspect, which is often used to indicate the proportion of the façade exposed to both sun and wind, is the plan aspect ratio (i.e. ratio of the longer to shorter plan dimension). This can be optimised as a function of solar irradiation and wind direction on the various surfaces, at times when these elements are wanted or unwanted.

As for solar radiation, the angle of incidence of the sun to a given surface is important, because it affects the radiant heat load on that surface.

As the angle of incidence relative to the surface in question approaches 90°, heat load increases. It follows that for buildings in equatorial areas, the north and south facades take up less heat than east and west facades.

Antaryama (2000) further described, the highest levels of radiation on north and south facades occur when the sun is low in the far north (i.e. in June) and the far south latitudes (i.e. in December). Above all, the horizontal surface of the building (i.e. the roof) will receive the most radiant heat. Because of the high cloud cover, all facades and parts of a building will be equally subject to the resulting diffuse radiation from an overcast sky.

Taking account of all the aspects above, to avoid a high intensity of solar radiation thus reducing heat gain, buildings should be elongated in an east-west direction (Koenigsberger et.al. 1974; Lippsmeier, 1969; Olgyay, 1963; Atkinson, 1953, 1960; Fry and Drew, 1956).

If open facades or windows are to be incorporated into the design, they should face north or south so that direct radiation from a low sun can be avoided. The impact of radiation over all facades can then be further reduced by the use of external shading devices.

As found by de Wall (1993), Givoni (1991) and Givoni and Hoffman (1966), if natural ventilation even at a low rate is incorporated in the design, the provision of effective shading can materially diminish the effect of different window orientations on the indoor air temperatures.

From the point of view of cross ventilation, buildings whose larger facades face north and south can be beneficial, especially when the wind blows from northern or southerly directions. Much of the equatorial area does in fact fall under the influence of Northeast and Southeast winds (the trade winds) for part of the year, although, as noted earlier, calm conditions tend to prevail.

If rooms are arranged in a single file and sufficient openings are available on those facades, wind entering a building of this orientation will reach almost all parts of it. Eastern openings, if adequately shaded, are also very desirable in the zone for the same purpose.

The orientation of openings relative to the prevailing wind direction determines the velocity and distribution of air within the building.

In general, a full sweep of velocity is received in the windward side when buildings are perpendicular to the wind direction (Olgyay, 1963).

With this orientation, greatest pressure on the windward side can be generated, thus producing greatest indoor air velocity.

Koenigsberger et.al. (1974) reported that a 50% pressure reduction will occur when wind incidence is at 45°. This phenomenon may be due to the fact that air acts on a greater width of the building, with such orientation.

Yet in asymmetrical buildings, the long direction should still be arranged to face the wind, as this makes cross ventilation easier (Karamchandani and Amin, 1983).

Since orientation to the prevailing wind is frequently different from that required by solar radiation, the best compromise must be reached in each case. However, it should be borne in mind that it is quite possible to control airflow within a building and partly outside it, whilst solar geometry cannot be changed. Therefore, orientation to the prevailing wind need not be considered as unalterable, while solar radiation has to be regarded as constant.

It is still advisable however, to face the prevailing wind when the building concerned is single-storey or low rise, since radiation is low, especially if the walls are adequately shaded (Koenigsberger et.al. 1974).

In warm humid climates, the correct arrangement of a group of buildings will ensure that air movement can reach all the buildings.

Koenigsberger et.al. (1974) reported that a satisfactory housing layout with respect to air movement can be achieved when a group of buildings is arranged in a staggered (checkerboard) pattern. In this arrangement most of the flow-field is uniform, and stagnant air zones can almost be eliminated.

When single storey buildings are to be placed in a normal pattern (grid-iron), the spacing required to allow the wind to return to the ground after being deflected upward by buildings (i.e. a complete dynamic process of wind) is about five to seven times their respective heights (Evans, 1980; Koenigsberger et.al. 1974; Olgyay, 1963).

In relation to both spacing and building density, Lee et.al. (1980) from their cuboid model tests found that to develop the above process the spacing must be over 2.4 times the building height, in both a normal and a staggered pattern. These values correspond to building densities of around 8.5% and 17 % respectively for the normal and staggered pattern.

With regard to the effect of the distance between the side walls, Santosa (1995) suggested that in a grid pattern when a spacing equal to the building height is allowed between the side walls, the complete successive front and rear sides of the houses is 3 times that of the building height. To achieve this, a building coverage ratio (density) no greater than 34.5% is needed.

It should be stressed that in a group of buildings, aside from the influence of surface roughness and the properties of the natural wind, the distribution of the wind is not merely affected by the geometry of the building but also by the whole grouping of the buildings themselves.

If follows that when the density of a group of buildings increases, e.g. in suburban and urban areas, the geometry of each building becomes less important than the group in influencing the distribution of the wind speed and turbulence experienced by each building. This is because the geometry of each building becomes a detail in the group as a whole. The implication of this in design is that when the arrangement of buildings becomes dense, surface roughness of the environment increases, and the use of the natural environment as a means of passive cooling hence becomes restricted.

Similarly, with respect to the orientation of a building or a group of buildings, when the shape of the site permits only one orientation it is unlikely that advantage can be taken of climate to improve the indoor conditions.

4.4.4. Building Materials

It has been pointed out that materials of the building elements can play a vital part in the thermal performance of a building.

Their selection therefore will determine the level of thermal stress in the building, and hence the occupants' thermal comfort.

Effects of material on the thermal performance of a building depend primarily on the nature and thermal characteristics of the material. Antaryama (2000) confirmed that despite these characteristics:

> *"They include surface qualities (i.e. absorbtance or reflectance), thermal inertia or capacity (commonly termed capacitive insulation) and thermal insulation."*
>
> Antaryama, 2000.

As he recognised, solar heat gain in a building is strongly influenced by surface qualities (i.e. absorbance or reflectance) of the structural elements.

In hot humid climates where heat prevention is stressed, a more reflective material should be used. For wall and roofs which are directly exposed to solar radiation, more heat will be reflected if their surfaces are painted white. For the same purpose, heat-reflecting glass can be used for windows, but should be considered only as a last resort. Other methods of solar control, such as the use of sunscreens, the correct window size and orientation, are more recommended in this respect. Since heat transfer through a building is mostly transient as a result of the ever-changing outdoor climate, the control exercised by the structure on indoor temperature conditions is determined not simply by the thermal resistance characteristics of the different elements, but rather by a combination of thermal resistance with the thermal capacity of the elements.

The latter will determine the amount of heat that will be absorbed by the elements, which in turn results in damping or accelerating effects on the interior temperature changes. Two parameters used to indicate these characteristics are 'time lag' and 'decrement factor', which both refer to the differences between certain characteristics of the heat flow profile of a given construction and that of zero thermal mass. Time lag refers to the delay of the peak flow, and decrement factor to the ratio of peak heat output deviation from the mean heat flow. The thermal capacity of materials provides a very powerful tool for the timing of heat inputs.

Antaryama (2000) further reported, the role of thermal capacity is clearly observed in the difference between the thermal performance of heavyweight and lightweight structures.

Since the amount of heat stored in an element is largely dependent on the weight of material, the heavier the material, the more heat it can store and the less heat will be transferred to the internal space during the day. At night, the stored heat will be lost both to the inside and the outside.

Conversely, with a lighter material, the structural element is warmed and cooled down rapidly, resulting in a close correspondence of internal and external air temperature.

Many studies (Salmon, 1999; Koenigsberger et.al. 1974; Lippsmeier, 1969; Van Straaten, 1967; Atkinson, 1960, 1953) have agreed that in warm humid climates where daily temperature variations are small but solar radiation intensities are high, massive construction tends to be detrimental.

It would be efficient only during the day when it offers a cooling effect, though only a tiny one, while at night it would be disadvantageous because the slight drop in air temperature does not permit heat emissions, and the stored energy is transferred inwards. Here lightweight structures can be more desirable thermally.

For roofs, thin and light materials with a reflective upper surface are needed (Lippsmeier, 1969; Evans, 1980). This will reduce solar heat gain during the day and avoid the storage of heat, which would increase discomfort at night.

As mentioned, apart from thermal capacity, the thermal resistance of a structural element is the determinant that controls heat flow through elements of the building envelope. It acts as an insulation whereby the transfer of heat, whether by conduction, convection or radiation, is effectively retarded so that the undesirable direction of energy flow can be prevented.

In the case of hot environments, the direction under consideration is that which goes inward. Large resistance values therefore will indicate a good insulating material. There are three kinds of thermal insulation that can be incorporated in the design of a structural element, namely reflective, resistive, and capacitive.

Reflective insulation is effective in a condition where heat transfer is primarily radiant, such as across a cavity or through an attic space, and has no effect when in contact with another material. A good reflective insulator is that with a low emittance and a low absorbance. An example of this kind is aluminium foil (Antaryama, 2000).

In warm humid climates this sort of insulator has a significant effect if it is incorporated in roof design, particularly that with an attic space, as it reduces the impact of radiant heat (Koenigsberger and Lynn, 1965).

This works well in a roof when it is combined with roofing materials such as sheets of aluminium, corrugated iron or asbestos cement.

Szokolay (1987), however, suggested that due to deterioration by dust deposits, the foil would be better placed under the roof structure, face down rather than on top of the ceiling.

In contrast to reflective insulation materials whose thermal insulation properties depend entirely on their surface characteristics, resistive insulators rely entirely on their thermal conductivity characteristics to retard heat transfer.

Of all materials, still air is the best. Thus, materials which contain or enclose air will have low thermal conductivity, hence producing a good resistive insulation. This kind of insulator is of importance for heated and air conditioned buildings, in very cold climates and hot climates, respectively.

Furthermore, it should be noted that reflective and resistive insulation materials respond to temperature change instantaneously and are most effective under steady-state conditions.

4.4.5. Passive House

The following passive parameters influence the indoor climate in a passive house, for instance ventilation rate (with possibilities for cross ventilation), window size and location in the wall, solar shading, colour of outer walls as well as thermal insulation and colour of the roof.

4.4.5.1. Ventilation Rate

In the passive house, natural ventilation is the only way to remove the heat in the building. Studies (Adamson, 1993, 1991) have shown that the ventilation rate affects heat removal from the interior while all other passive house parameters influence heat gain to the interior of the house.

In the passive house ventilation has to be produced by natural means, for example by wind and stack effects. Indoor and outdoor temperatures are similar, and the stack effects are insignificant and will not greatly affect the cross ventilation.

Therefore, the ventilation rate is dominated by the wind.

Accordingly, the passive house has to be oriented with respect to the prevailing winds; and designed to allow good cross ventilation and enough openings between the rooms so designed to arrive at a good airflow pattern within the house.

It can be assumed that wind through a carefully oriented and well-designed house will generate 20 air changes per hour, or more. Most essential for good ventilation is the size of openings between rooms and the outer walls. Indoor walls need large openings for cross ventilation.

4.4.5.2. Windows

Solar radiation through unshaded windows increases the cooling requirement, mostly on east and west facing windows. The isolation depends on both the size of the glazed sections, and the possible solar shading. Architectural window size is often decided solely from this point of view. Louvered windows are useful for the passive house, where they can regulate the ventilation and guide the airflow.

However, if the windows are unshaded, the glass area must be limited to 15% of the facade area. An increase of the glass area to 30% will increase the room heat, with east and west facades most affected.

From the energy standpoint reflective glazing, which has low heat transmittance, could be an advantage. However, low heat transmission also means low light levels, leading to the use of electric lighting and further increase in internal gain. Unshaded glass absorbs direct and diffuse solar radiation, and the glass mean radiant temperature is increased by 10°C or more.

That absorbed heat will be transmitted into the room which will considerably increase the operative temperature in the house.

In this warm climate, an energy efficient window can lock out heat and save energy cooling. These are smart windows, based on a technology which allows the window to change its transmittance to solar radiation as needed. On cloudy days, the glass window can be made about as transparent as a traditional window, while on those clear days with strong sunshine, the window can be darkened and overheating reduced (Roos, 1998) (see Appendix - III).

4.4.5.3. Solar Shading

Facades oriented toward permanent shade are less affected by solar radiation. Solar shading of glazed areas is a way to reduce the solar heat gain through the glazed areas. Blinds and shutters should be placed on the outside and be light coloured, in order to avoid absorbing too much of the incident radiation. Dark blinds and shutters on the inside windows are disastrous, because they absorb practically all the solar radiation and transfer most of the heat to the rooms. Horizontal fins above the windows, projecting from the facade are often used.

4.4.5.4. Roof

For a house in the sun, absorbing solar radiation increases the outer surface temperature of the roof by 30 - 40 °C above air temperature, and a considerable heat gain through the roof can occur, resulting in a high ceiling temperature and increased operative temperature.

On the other hand, the long wave radiation emanating to the sky during a clear night will decrease the outer surface temperature 5 - 10 °C.

Thermal insulation of roofs is an important measure to reduce the ceiling temperature during a sunny day, and improve the indoor thermal climate; and by ventilation of the roof, the heat gain from absorbed solar radiation is removed.

The overhanging pitched roof is preferable, as this permits easier diversion of rainwater and is easier to ventilate and insulate thermally as well as sun shading parts of the house.

The roof should have a thermal insulation corresponding to U-value = 0.5 W/m2K, with vapour barrier on the outside of the roof with outside of the wall, thermal insulation that should be well connected and air tight to the roof vapour barrier. Good ventilation through the attic, by large openings in eaves and gables is desirable. A pitched terrace and bright colour for the roof are other ways to protect a house from direct solar radiation.

4.4.5.5. Outer Walls

Brightly coloured outside walls are recommended to reduce solar radiation heat through the house, and thermally insulated outer walls facing west and east are the best way to avoid high operative temperature. Insides of external walls can be thermally insulated, to reduce solar radiation but this insulating material must be vapour permeable, to avoid water accumulating on the outside of the insulating material.

The vapour pressure of the outer wall is higher on the outside than on the inside, and the vapour barrier needs to be placed on the outside of the wall itself.

If a light wall construction is chosen, the U-value should not exceed U= 1,0 W/m^2K. Therefore, it is essential to design the facade so that the wall remains dry, and the roof overhang can do best in this respect.

4.4.6. Active House

4.4.6.1. Cooling the House

In an air-conditioned house, the indoor climate aims at being within acceptable comfort limits. Cooling is required to remove the heat produced indoors, absorbed through the building envelope, the heat gain from ventilation and possibly, some stored heat.

The way to decrease the cooling load requirement within the active house is to minimise the internal heat production by the occupants, equipment, solar transmission through the windows and the building envelope.

Cooling is supplied by electrically driven air conditioning. The cooling machine delivers approximately three times more energy than the electrical energy supplied to the compressor.

When a house is air-conditioned to a certain set point, the indoor temperature is more or less constant at that set point. This is true for all the cooling season, providing the plant has sufficient capacity to cope with the load.

Air conditioning systems within the house normally use air as the cooling medium.

Air has low thermal capacity, and therefore a lot of air is needed for cooling. In order to limit the cooling of fresh air, part of the air supply can be re-circulated. This should be done in such a way as to keep odours, smoke, and micro-organisms from spreading around that room or to other rooms of the house.

Airtightness of the house is essential for the purposes of restricting leakage of cool air, controlling the ventilation rate and the positive air balance, avoiding mixture of cooled air and leakage of outdoor air. In the house, there is obviously a need for good airtightness of the building envelope, and the windows in particular should be of good quality and well sealed between casement and frame, as well as between frame and wall.

4.4.6.2. Air-Conditioned House

In a warm humid climate, there is a small difference between the outdoor temperature and the desired indoor temperature of the house during part of the year. At the same time, the outdoor vapour content is high.

In this situation, a heating coil can be needed for humidity control, especially if the internal heat load is small. In this case, the air is cooled beyond the desired temperature and then heated afterwards.

The air conditioning system can be designed in three ways, as below.

- A Room Unit; this is the simplest air conditioning system, the air conditioning is placed in a hole through the outer wall and serves the individual room.

- A Split Unit; the split unit consists of one compressor and refrigerator unit placed outdoors, and a pipe system distributing the cooling media to several room-cooling coil units.
- A Central Unit; the central unit is combined with a central ventilation system, and the cooling coil is placed in the ventilation system.

A central air conditioning system can be combined with split air conditioning units, for individual regulation of temperature. Comfort can be done actively by air conditioning equipment; however, the air conditioning system needs servicing and may occasionally break down.

4.4.6.3. House Insulation

In an air-conditioned house, the external walls have higher temperatures on the outside than the inside, and absorbed solar radiation raises the mean radiant temperature above air temperature.

It needs high energy to cool the inner surface to the room air when the air conditioning is switched on. Thermal insulation can be installed to reduce cooling energy. This insulation has to be constructed to avoid heat radiation on the outside of the insulation material, and airtightness is essential in air-conditioned houses.

Airtightness of windows is important, because undesired ventilation increases the need for cooling. Special requirements have to be set for the airtightness at a given pressure difference of 1.7 m^3/h per m^2 window area at 50 Pa pressure difference, and this requires rigid insulation windows of the house.

It has been argued that the air-conditioned house needs double-glazed windows in order to reduce the cooling load.

Adamson (1991) has shown that this does not seem to be justified due to the high cost. In addition, it uses sealed glass units that are expensive and difficult to replace when broken.

Therefore, to design a perfect window that can accommodate all of these problems is challenging. A reduction of the direct and diffuse radiation by 50% of a glazed area equal to 30% of the facade area by insulation, will reduce the maximum room cooling loads by 25-40% and the annual room cooling requirement by about 20-30% compared with unshaded glass area of the house.

With low emission coatings, windows can be made to have U values less than 1 W/m^2K (Roos, 1998). Conversely, in hotter climates they can keep out heat and save energy for cooling.

In terms of comfort, the main purpose of the roof is to protect against solar radiation, and again insulation is the most important element to protect against roof deterioration by heat and solar radiation.

The roof should be insulated so that solar heat gain through the roof is kept at a reasonable low level, and ceiling temperature close to the air temperature in the house, to keep the operative temperature low. This can be done by a combination of removing the solar heat gain by ventilation, and thermal insulation of the roof. Unventilated spaces in pitched roofs should be avoided in an air-conditioned house.

A positive pressure difference of air movement (also air insulation) should be maintained between air inlet and outlet openings, and has to be oriented to the longitude of the prevailing wind direction.

Thermal insulation material should be placed below the air attic space on the ceiling and not exceed U-value = 0.5 W/m^2K or less. A vapour barrier can be placed on the upper side of the insulation.

Another consideration that should be highlighted, with potential influence on solar protection and energy used within the building is an integrated overhang pitched roof design. Free circulation of ambient air on the underside of the roof results in a relatively low operating temperature and high efficiency of cooling operation (Goethe and Kwasny, 1993).

4.4.7. Passive and Active Dwelling Characteristics

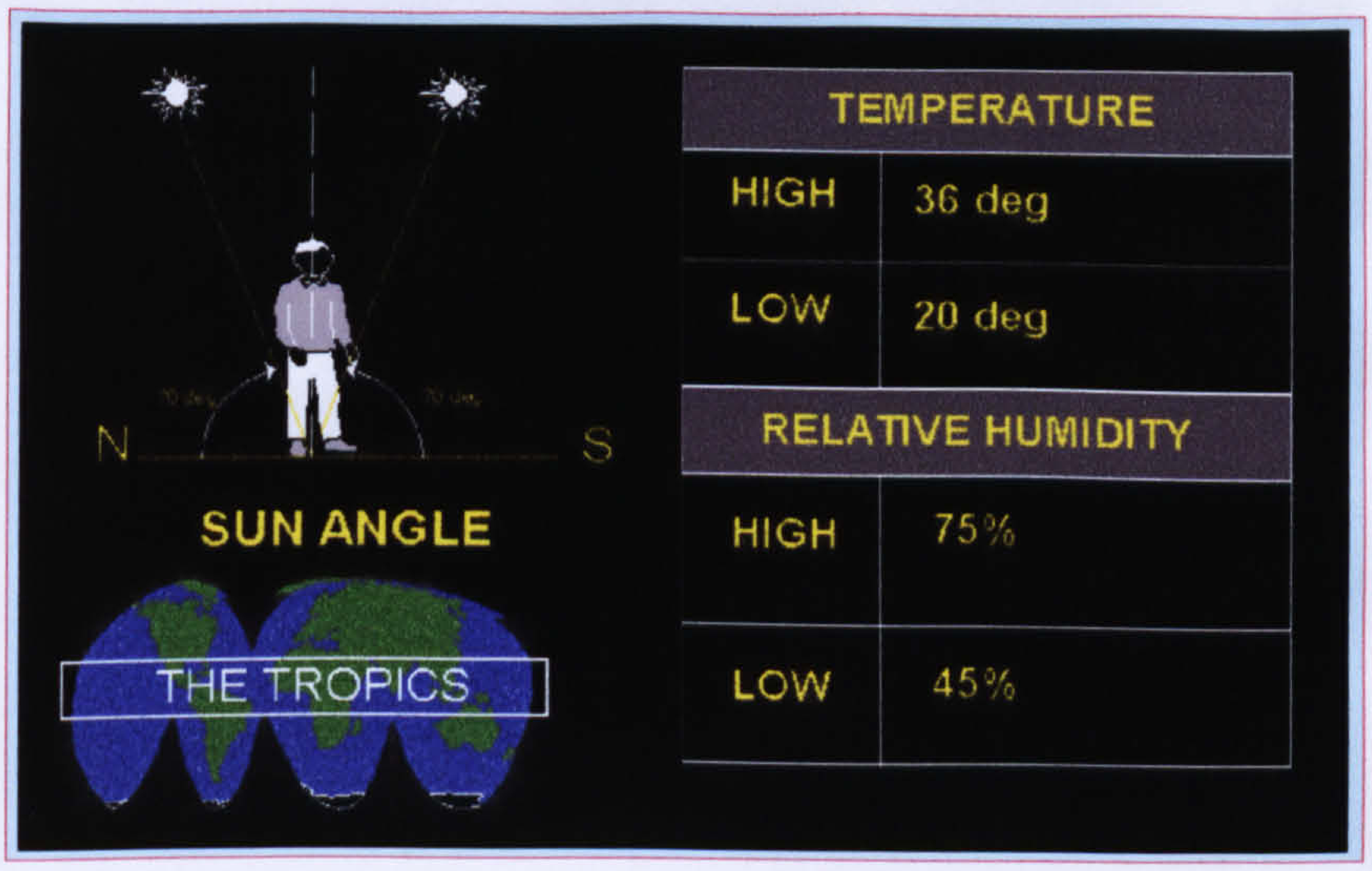

Figure 4.14. Warm Humid Climate Characteristics

▪ Passive Cooling	▪ Active Cooling
▪ provide shade against the sun	▪ provide shade against the sun
▪ **accelerate evaporation** *	▪ **cooling evaporation** *
▪ shading devices	▪ shading devices
▪ **cross ventilation** *	▪ **active cooling air circulation** *
▪ **passive cooling** *	▪ **active cooling** *
▪ orientation manipulation	▪ orientation manipulation
▪ building design manipulation	▪ building design manipulation
▪ building envelopes manipulation	▪ building envelopes manipulation
▪ fenestration manipulation	▪ fenestration manipulation
▪ building material manipulation	▪ building material manipulation
▪ landscape manipulation	▪ landscape manipulation
▪ roof and ceiling insulation	▪ roof and ceiling insulation
▪ roof overhang for shading	▪ roof overhang for shading
▪ less windows on east and west sides	▪ less windows on east and west sides
▪ central courtyard for cooling pressure	▪ central courtyard for cooling pressure
▪ wind scoop or baffle	▪ airtight of building envelopes
▪ surrounding greenery	▪ surrounding greenery
▪ attic ventilation	▪ attic ventilation
▪ low heat conductivity of building material	▪ low heat conductivity of building material
▪ reflective insulation	▪ reflective insulation

Table 4.2. Passive and Active Dwelling Characteristics

The important characteristic of the warm humid climate is shown in Figure 4.14. may be manipulated to achieve a comfortable dwelling by either passive, passive and active, or active cooling based on the following considerations (Table 4.2). These items indicates that most of their characteristics are the same, particularly those related to architectural features; the differences between them are in their cooling techniques, which are natural ventilation and air conditioning (*).

4.4.8. Passive and Active Building Energy Consumptions

A previous study by Karyono (2000) described the cooling type of buildings and the monthly energy consumption of a natural ventilation (NV), a combination natural ventilation and air conditioning (Hybrid), and an air conditioning (AC) alone in the warm humid climate of Indonesia, where Bali is located (Table 4.3).

Building	**NV**	**HYBRID**	**AC**
Indoor Air			
Conditioning Building	NV	NV+AC	AC
Energy Building			
Energy Consumption (Kh/m^2)	2	5	20

Table 4.3. **Energy Buildings Consumption** (Karyono, 2000)

Regarding energy consumption, the naturally-ventilated building consumes very little energy at 2 kWh/m^2 compared, for example, with that of the air-conditioned building. Unfortunately, this building possesses relatively high indoor temperatures, which will cause a high proportion of the occupants to be thermally uncomfortable. By changing the orientation, any naturally ventilated building similar to this should be able to provide lower indoor temperatures, thus allowing a higher proportion of occupants to be thermally comfortable.

The hybrid building, which is naturally ventilated with some rooms being air conditioned, consumes a relatively low amount of energy, 4 kWh/m^2 per month, or about one fifth of the air-conditioned building's consumption. At the same time it allows a greater proportion of the occupants to feel thermally comfortable.

After all, this is the highest proportion of subjects being thermally comfortable (voted from `slightly cool' to `slightly warm'). Again, this is further evidence that thermal comfort conditions can be provided by a building with small energy consumption, if that building is correctly designed for the climate.

On the other hand, the air-conditioned building will consume a large amount of energy, around 20 kWh/m^2/month. This could be due to the design; creating a massive `green house' effect in the building, which increases the indoor temperatures. To provide a lower indoor temperature in this building, an even greater amount of energy has to be consumed.

4.5. CONCLUSION

Due to the environment, land availability, and cost, the state-owned and most other property industries aim to meet popular requirements by producing compact dwellings. The established practice of using high ventilation rates to achieve comfort in the traditional dwelling is not applicable to the compact dwelling. This needs emphasis upon other aspects of dwelling design to achieve comparable comfort.

In Indonesia (including Bali) overall primary energy consumption and particularly electricity, has risen annually. Energy consumption and production should be managed by the country, based upon the population, tourism, and national economic development of marketing power.

However, all these together represent a developing process from deteriorating natural resources to a more humane and natural environment with sustainability that can create living space in a comfortable environment while consuming less energy.

The important conditions in warm humid climate that making for an uncomfortable dwelling are the continually high temperature, very near body temperature, and high humidity. The cooling effect of evaporation is inadequate, because the air cannot absorb enough moisture, prevent the body cooling by evaporation.

At night, there is only a slight drop in temperature; a similar level of discomfort will almost inevitably be experienced.

In these respects, air movement is a reasonable way to achieve natural ventilation cooling. This however, can only be achieved while the indoor air temperature is lower than the body temperature; otherwise, the occupants are heated.

The scope for natural ventilation is limited. It can only be used to a certain extent to lower the temperature by replacing warm with cool air, however, it always impossible to cool the dwelling when temperatures indoors are higher than outdoors. When a high air temperature coupled with high humidity is experienced, mechanical control is the best option.

However, this is not always a direct solution, specifically when air conditioning is to be applied in a non-integrated dwelling design.

A building which was originally designed to be naturally-ventilated would be inadequate as an air-conditioned dwelling.

The heat gains make an air conditioning system inefficient, while the orientation of unprotected glazed windows and the thickness of buildings seem to contribute to the higher energy consumption in air-conditioned buildings.

A critical need in this respect is the recognition of the potential of the traditional comfort pattern, and an enabling policy to help low-energy house groups to meet the housing needs.

In particular, the individual can do much to save energy in the dwelling and it is important to realise that energy conservation is a pivotal environmental issue. In the dwelling, occupants should adopt the habit of energy conservation without reducing their comfort standards by using as much natural ventilation as possible, more energy-efficient use of air conditioners, insulating the dwelling, and generally using less power whenever possible.

A compound pattern with a combination of small forms for better ventilation, square shapes to reduce heat radiation on the surface area and corners for shading, is the ideal dwelling to facilitate both cross natural ventilation while being able to reduce energy consumption for air conditioning.

Since the evening has the highest air temperatures, it is possible to set the air conditioning to respond when it is needed most.

The achievement of indoor temperatures in the comfort range for both air-conditioned and naturally ventilated buildings can be assisted by building design.

For both naturally-ventilated and air-conditioned dwellings, however, the building has to be orientated North - South to avoid the direct heat of solar radiation. If otherwise due to the building site conditions, efforts can be made to isolate the east-west sides of the dwelling from the sun's disturbance. This can be done by insulation, verandas and installing shading devices.

Using all of these above approaches in an appropriate dwelling design, energy consumption can be minimised while comfort within the dwelling can still be maintained.

When considering all the previous aspects discussed in this chapter, in order to develop dwelling designs in Bali, Indonesia, these points need to be taken into consideration.

Firstly, concerning the warm humid climate, it is recommended that a better dwelling design within a sustainable environment means a combination of the indigenous approach with technology.

Secondly, when considering dwelling developments that meet the growing demand, a suitable dwelling standard which is affordable for the majority of people (e.g. a middle class dwelling) needs to be considered.

Thirdly, to achieve the goal of energy conservation, a combination of passive and active dwelling designs is recommended.

The brief preliminary theoretical conclusions can be drawn as follows.

Thermal comfort in a dwelling design in the warm humid climate of Bali, Indonesia; can be achieved by taking the advantageous elements from the indigenous pattern, and the technological approach, coupling it with passive and active cooling designs.

In another perspective, an effective strategy for meeting housing needs in Bali requires a comprehensive approach in satisfying many various design requirements into the one comfortable dwelling design as well as resulting in many more number of houses can be built, respect to the past cultural and appropriate to current conditions.

In the next chapters, these hypothetical outcomes will be used to build up the others methodology research employed to achieve objectives of the research.

Chapter Five

THE SURVEY RESEARCH

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Chapter Five

THE SURVEY RESEARCH

5.1. INTRODUCTION

The survey aimed to consider the interrelations between people who have experienced living in a warm humid climate, and their dwellings.

The aim of the survey was to build up an image of energy use and thermal features characterising dwelling and comfort performance.

Participants were expected to respond to the questions based on the conditions and expectations of their home and thermal environments.

The survey was aimed at discovering what type of cooling system was used within their current home, and what their ideas about a comfortable dwelling are. In particular, the main survey also focused on the energy consumption of the dwelling in terms of cost related to income.

Conclusions of the survey-research analysis will be comparatively analysed in conjunction with the results of a study computer simulation, previous studies undertaken, and literature reviews to develop a thermally comfortable dwelling design for housing development in Bali.

5.2. THE SURVEY RESEARCH METHOD ADOPTED

As one of the research methods in this study, the research method survey was designed in order to achieve objectives of the research by taking into account the following considerations:

5.2.1. Electronic Survey Technique

> *"Mail is very commonly used in a survey research."*
>
> Dillman, 1978.

However, this survey research was conducted by electronic mail. Respondents replied quickly to the latter technique and proved less responsive to the former. This email survey technique is quite efficient, less time consuming, and people were eager to help and keen to reply.

This electronic survey technique is supported by interesting statement in the previous research undertaken by Coomber, (1997). He described as follow;

> *"The Internet and electronic mail increasingly offer the research community opportunities that it did not previously have, which present enormous possibilities to the research, currently in its infancy, to reach individual research subjects."*
>
> Coomber, 1997.

He further suggested the advantages of using this technique:

> *"In particular, there may be significant research benefits to be gleaned where the group being researched is normally difficult to reach and/or the issues being researched are of a particularly sensitive nature. The target groups, illicit, for some reason are difficult to access and contact under normal conditions, which concludes that the Internet can be a valuable source of indicative as opposed to easily generalise-able data."*
>
> Coomber, 1997.

On the other hand, mail survey techniques and door-to-door surveys are the opposite; they are inefficient, time consuming and people are less willing to respond.

Many experiences show that the postal survey was one of the most difficult techniques, and only 30% response to this survey system was very common.

To achieve that percentage, a £50 prize draw was used for both a survey of student health and a survey of postgraduate students' expenditure as an additional technique to encourage the mail survey (Humphrey, 1998).

However, *"in order to obtain an adequate response, the work becomes impossibly inefficient"* (Rapoport, 1973).

Door-to-door survey techniques are inefficient, in terms of time and unpredictable response. The privacy of the respondent is the main obstacle in this investigation technique.

Therefore, a conclusion can be drawn that an electronic technique is one of the best options, and has significantly achieved the goals of the survey research method.

In general, this conclusion has also been supported by previous researchers (Hyde and Docherty 1997; Hanna and Simson, 1996; Maitreya, 1991; Santosa, 1988; Turner and Szokolay, 1982), and particularly a similar conclusion from the previous study in Bali by Antaryama, (2000) which will extensively be discussing in Chapter Six, together with the other previous studies in Indonesia (e.g. Karyono, 2000; Funo and Silas, 2000), as previously described in the research methodology (Chapter One section 1.4).

Time-usage for the electronic survey was very efficient and was not comparable to other survey techniques.

However, this e-mail survey also has limitation which will also be discussing as part of the limitations of the research (see Chapter Ten section 10.4).

Therefore, the outcomes of the survey as the main goals, which have been supported by this technique, are more important than the technical methodology itself (e.g. electronic-mail survey).

5.2.2. Quantitative Approach

The quantitative approach is a strategy of establishing relationships out of different variables to make a certain definition, and is mainly applied when the research has to deal with a large numbers of cases under limited and controlled data variables.

In this approach, the survey research has broadly identified the particular aspects of non-thermal comfort related studies. In order to reach firm conclusions; this term is connected to quantities and numbers (e.g. occupant's number, occupant's age, energy spent, and income).

Standardisation in measurements to overcome the diversity of response in variables that may exist when dealing with the subjects is also required.

However, this research is conducted to provide the range of options rather than the exact number of answers.

5.2.3. Qualitative Approach

In this approach, various indoor environmental aspects of climate related studies were used to highlight the survey research. This is a strategy to collect data through electronic-direct investigation, to achieve an adequate freedom of answers in the responses.

In this respect, to find out ideas of an ideal dwelling type, the sensation of thermal comfort, and the current cooling system of the occupants' house are parts of the survey research. *"This focus on comfortable dwelling perspective as an aid to better understanding of the interaction between occupant and indoor environment"* (Moore and Golledge, 1976).

5.3. SURVEY AIMS AND OBJECTIVES

The survey aims were to establish the comfortable living conditions in a tropical environment, taking into account the relationship between people and their accommodation, as well as the ideal house in Indonesia.

The objectives of the survey were to capture the necessary respondents' information concerning the feeling and idea of comfort in their home. It will be reviewed and resumed, to be comprehensively cross-analysed to the results of study simulation, works undertaken and literature reviews, to find out a thermally comfortable dwelling design finding.

To achieve this objective, questions were asked on the topics listed below.

- The cost of energy consumption is important and establishing how much people spend dependent on their accommodation needs to be established. This also needs to be compared with annual income. Both of these pieces of information will be used to analyse the relationship between energy consumption and income.
- The number of occupants may also be related to the use of energy.
- The occupation of the residents can be essential to determine the occupancy of the house.
- Establishing the most convenient cooling system for the house, whether it be air conditioning or a ventilation strategy, is also necessary.

- Whether a typical modern or traditional house is being considered.
- Dwelling location and educational background of the residents has a relationship to the attitude and awareness of energy conservation.
- Comfort, air conditioning, natural ventilation, health and energy conservation in dwellings are all vital aspects of the thermal building design.

5.4. SURVEY DESIGN AND FRAMEWORK

The survey form was simply designed and offered a choice of answers. The electronic mail was used to send the questionnaires to respondents in Indonesia.

As already discussed, this technique was chosen based on the considerations that as one of the research methods, outcome of this survey together with other research methods chosen are very useful to compare to the result of computer simulation study, thus, the conclusion of the study is widely researched.

In technical terms, the survey is divided into two parts; the first nine questions concern personal data of the respondents; location and ownership of their house. The subsequent seven questions relate to their dwelling circumstances and opinions about the ideal of a comfortable house.

In terms of the research, as based on the survey research methodology above, and in order to achieve the research aims, the framework contains two approaches; they are a non-climatic related study approach, and a thermal- comfort related study approach.

The survey design is focused on gathering adequate data collections that can be used to satisfy the research aims and objectives for studying thermal comfort characteristics and energy conservation in the dwelling.

The information needed to accomplish this study to examine the standard type of dwelling is to be represented as a model for large scale housing, particularly in a warm humid region of Bali and Indonesia. In order to obtain significant responses from the respondents, the framework of the survey research is designed as simply as possible.

5.4.1. Scope of Survey

The scope of the survey is focused on data collection related to a comfortable dwelling, from middle income people considering the common house types recommended by the government and built by national housing authority in Indonesia. The people with middle incomes chosen, since they represent the majority of people who live in the national standard dwellings.

The main points related to thermal comfort highlighted in this survey are;

- What was experienced of living in their current dwelling?
- What is an ideal comfortable dwelling in their idea?

Included this survey was energy consumption of the dwelling related to respondent income. The information to be collected from the respondents was mainly concerned with the original cooling technique, whether naturally ventilated or air-conditioned, used in their dwelling. As well as collecting information on desired comfort conditions, the occupant's experience of the sensation of thermal comfort was also included.

5.4.2. Sampling Procedure

> *"Sampling is the process of selecting the subjects to be approached. Ideally it would be preferable to collect information about everyone in the group under investigation, but when the group is too large the process will be prohibitively impractical, time consuming and inefficient."*
>
> Monawar, 2000.

In order for the procedure to be more convenient, efficient, and to have the flexibility to control and define the sample, the alternative is to select a sample from the major group in such a way that their responses and characteristics reflect those of the groups from which they are drawn.

A representative sample is one which accurately reflects and constitutes a suitable representative part of a group, and mainly depends on the nature of the research problem. A large sample size will be more representative; however, collecting large data samples can be time consuming.

In practice, an essential determinant of sample size is the need to look separately at different groups, and make sure that the sample is sufficiently large and contains sufficient numbers for the purpose of comparison. *"The rule of thumb in this position is to ensure that the smallest samples have at least 50 to 100 cases of the group"* (de Vaus, 1996).

Sample size should ensure sufficient numbers for meaningful analysis. However, it was not easy to apply certain techniques to determine sample size; yet a degree of precision being needed, it also required many respondents to answer to the survey question.

The survey sample in this research was strongly affected by the time, resources and cost availability therefore a relatively small sample, 250 respondents, was chosen, represent of Bali's urban population of around 1,000,000 people.

5.5. QUESTIONNAIRE

> *"A questionnaire is one of the most important and widely used instruments of researchers. A question's content itself can be classified into four distinct types which are behaviour, beliefs, attitude and attributes."*
>
> Dillman, 1978.

In a questionnaire a descriptive approach or an explanatory approach are possible. The former would ask what was going on in real situations, and the latter would ask why that was happening.

To obtain these answers to the questions a direct investigation would impact on individual privacy of people in the households. The successful survey would depend on the attitude of the people, and their willingness to respond.

With these factors in mind, the questionnaire was designed for simplicity and with the minimum number of multiple choice questions.

In this research, the questionnaire contains 16 questions with an introductory first page, and was distributed by electronic mail (e-mail). This permitted direct delivery of the questionnaire to the recipient, and elicited a high return of the questionnaires, achieving a 72 % return rate of the 250 questionnaires distributed. 181 responses were collected in three weeks (see also Appendix - IX).

Each question is described below:

1. **Settlement Location**

   The settlement location was divided into three; a tourism community, inner city or suburban/rural area. The location of a dwelling in one of these areas is the first step in understanding the expected thermal performance.

2. **Accommodation's Ownership**

   Owner, family owner and tenant were the accommodation's ownership classifications. Ownership will have a direct bearing on current and future comfort developments.

3. **Household Identifier**

   The household can consist of international, Indonesian or Balinese people. Their identity helps to analyse the cooling technique pattern for achieving a comfortable dwelling.

4. **Marital Status**

   Marital status, whether single or married is an aid to identify the number of occupants, and then their level of energy use for comfort.

5. **Number of Children**

   This question was closely related to the previous one, and intended to analyse energy use within the dwelling.

6. **Education**

   Their educational background will assist the study, in relation to their attitude to energy conservation.

7. **Main Occupants' Age**

   Age is closely allied to activity level, which in turn is related to energy use.

8. **Household Occupation**

   Whether government officer, private company staff or other, such as employee, each occupation is closely related to the dwelling occupation pattern that may influence different comfort requirements and energy use.

9. Spouse Occupation

This has similar purpose to question 8 above, in order to sort out the same characteristics and requirements for a comfortable dwelling.

10. Do you think air conditioning (AC) in the house is vital?

In this question, the aim was to obtain the expectation of the people when thinking about using air conditioning.

11. Which one would you like for convenience in the house?

This was a paramount question, designed to analyse their opinions related to comfort in a dwelling, whether they would feel most comfortable after installing air conditioning (AC), taking advantage of natural ventilation or possible utilising both air conditioning and natural ventilation in their houses.

12. What type of house do you like?

This question was intended to analyse the preferences of people when choosing a dwelling. Each dwelling has an impact on energy consumption.

13. Why do you live in your current house?

Their reason behind occupancy of their current dwelling can help provide information about their comfort expectations.

14. How much do you spend on energy monthly?

This was a clear question designed to analyse their spending on energy to achieve a comfortable dwelling environment.

15. If you do not mind, which is your annual income range, please?

This was a most crucial question that might not always be answered. However, this is very important to achieve the result of making comparison between income and energy expenditure to achieve a comfortable dwelling.

16. What do you think is the ideal house?

This was also a significant question, designed to analyse their aspiration for a comfortable dwelling in the future. The results of this analysis can be used as ideas for some new, proposed design. It could be a traditional house, a modern house or combination of both.

Each question has its principal goal, but they also have interrelationships with one another. Cross-checking between questions enables consistency to be established in individual questionnaires.

The basic parts of the questionnaire were to investigate the current contemporary phenomenon within an environmental dwelling, with thermal sensation contexts to be analysed.

The method of analysis concentrated on describing the recent patterns of respondent behaviour, and their future options for cooling techniques, as well as the argumentation of the input data in relation to energy consumption and thermal comfort performance.

The results could then be used in the design stage of the research as a way of exploring the achievement of thermal efficiency for a comfortable dwelling.

Particularly, in consideration of the cooling system, this questionnaire has taken into account the following important elements for a comfortable dwelling;

- Natural ventilation
- Natural ventilation and air conditioning in combination
- Air conditioning

The questionnaire form, both in English and Indonesian versions is attached in the appendices (Appendix-VIII).

5.6. DATA MANAGEMENT, ANALYSIS AND PROCESSING

5.6.1. Data Management and Method of Analysis

The data is divided into two groups; one contain the factual information, and the second consist of the opinion of the occupant about an ideally comfortable house.

The former data is used to identify the occupants' activity pattern and the latter is applied to examine the future performance of a comfortable house design.

In order for ready analysis, the data was input to the Database Table of Microsoft Access program. The program was used to filter the data to extract the relevant information. The outcomes from this data were then analysed and graphically presented by using the Microsoft Excel.

5.6.2. Data Processing

As described previously, the Database Table of Microsoft Access was used to organise data responses of the survey into the readable tables (see Appendix IX).

In order to find out the survey research outcomes, the Microsoft Excel program analysed the data by the following factors, related to thermal performance and energy cost:

- Cooling system that was used on the dwelling.
- The need for air conditioning within the dwelling.
- Comfort, energy saving, and natural ventilation that the dwelling required.
- Natural ventilation demand and air conditioning demand.
- Monthly spending on energy per dwelling.
- Annual income and energy per dwelling comparison.
- Cooling method and annual income correlation.
- Cooling method and annual income in an ideal dwelling.
- Typical options for a traditional dwelling and contemporary dwelling.
- Comfort of the traditional dwelling.
- Comfort of the contemporary dwelling.

With respect to these processes, each result can be determined and any interdependence between them can be examined. Moreover, the outcomes will form part of the thermal performance analysis design strategy.

5.7. SURVEY ANALYSIS OUTCOMES

250 electronic survey forms were distributed, achieving a total of 181 responses. This response rate was remarkably good, and met the aims and objectives of the survey research (see point 5.3 above and Appendix - IX).

The conclusion that can be drawn regarding email survey research is that it shows significant efficiency.

5.7.1. Dwelling Location

In general, from the total of 181 responses 45% were living in the urban inner city, 50% in the suburbs, while only 5% lived in tourism areas (Chart 5.1).

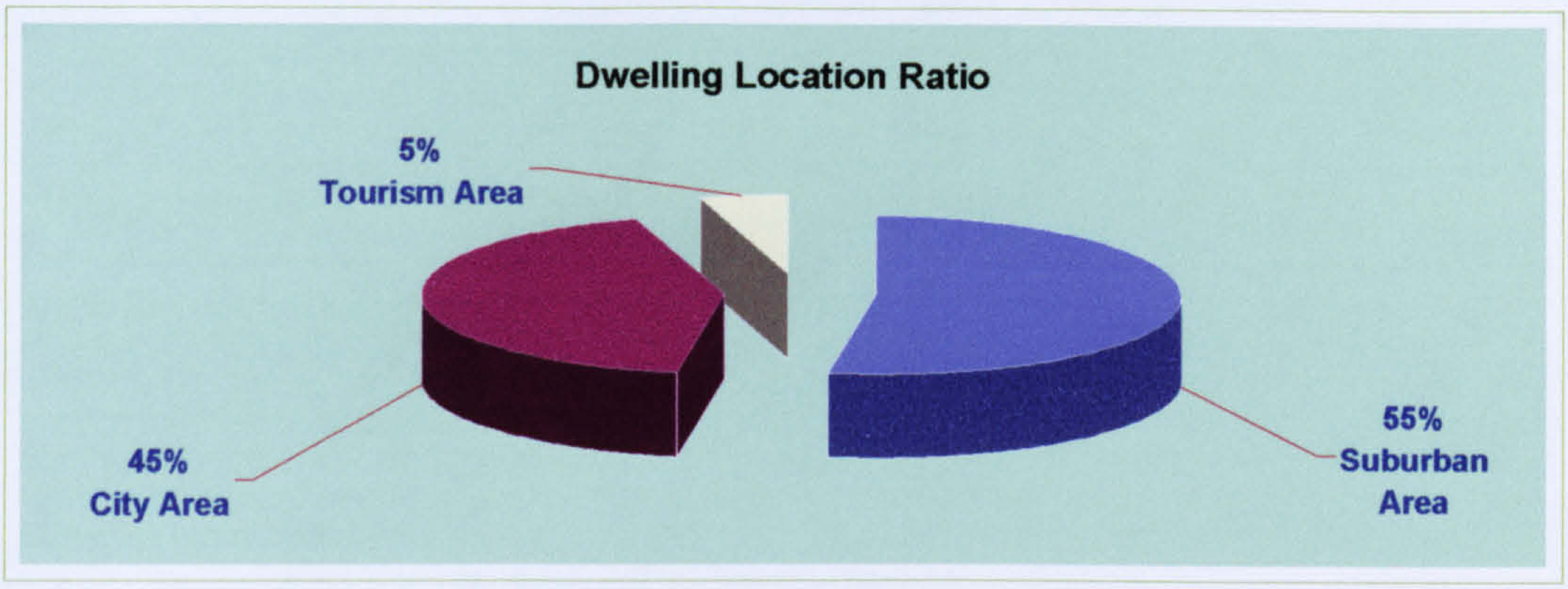

Chart 5.1. Dwelling Location Ratio

From this can be concluded that respondent numbers from city and suburb were balanced, while those living in tourism centres were under represented.

5.7.2. Comfortable Dwelling

Chart 5.2. shows what cooling system makes for a comfortable dwelling in general terms. From 181 respondents 55% wished to use natural ventilation, 40% wished to combine air conditioning and natural ventilation, and 5% wished to install air conditioning.

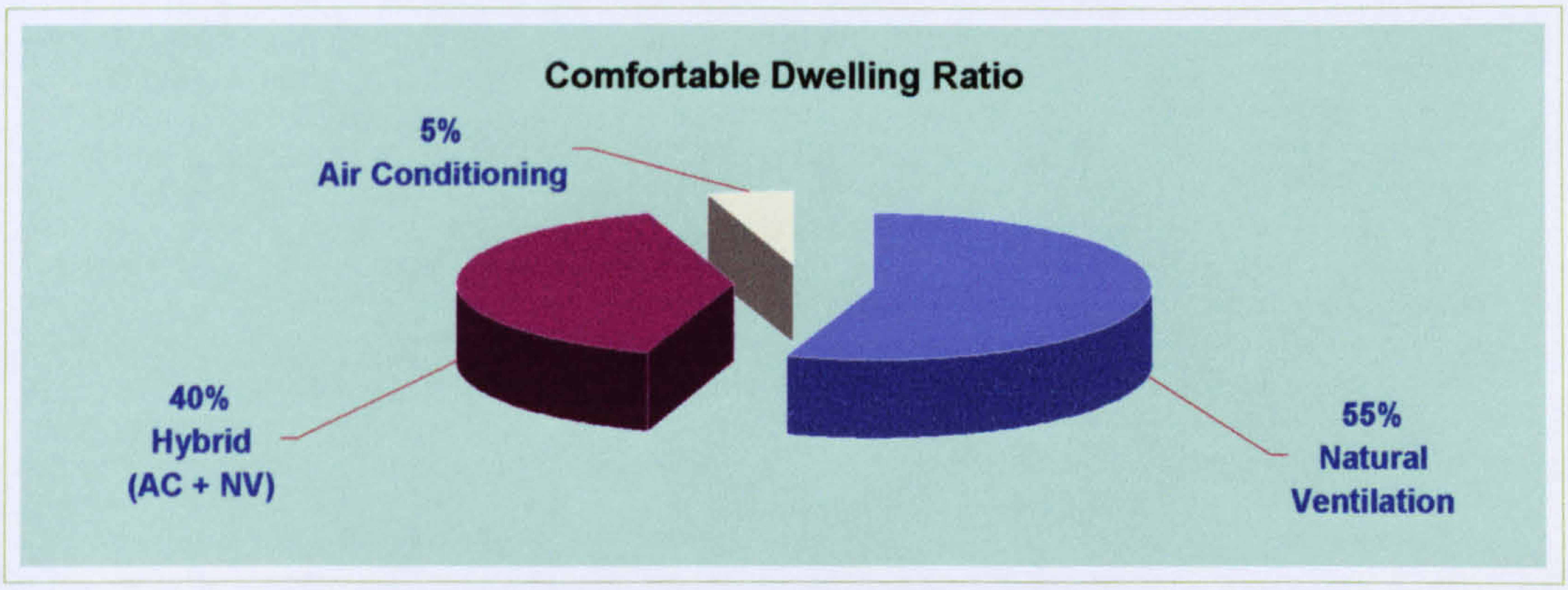

Chart 5.2. Comfortable Dwelling Ratio

This indicates that a preference for natural ventilation was dominant; however, the hybrid system was significant. While air conditioning was quite rare, this distribution is as expected, with limited air conditioning being introduced and being used alongside natural ventilation.

5.7.3. Comfortable Urban Dwelling

In the urban area, from 82 replies; 50% wished to use natural ventilation, 40% wished to combine air conditioning and natural ventilation, and 10% wished to install air conditioning Chart 5.3.

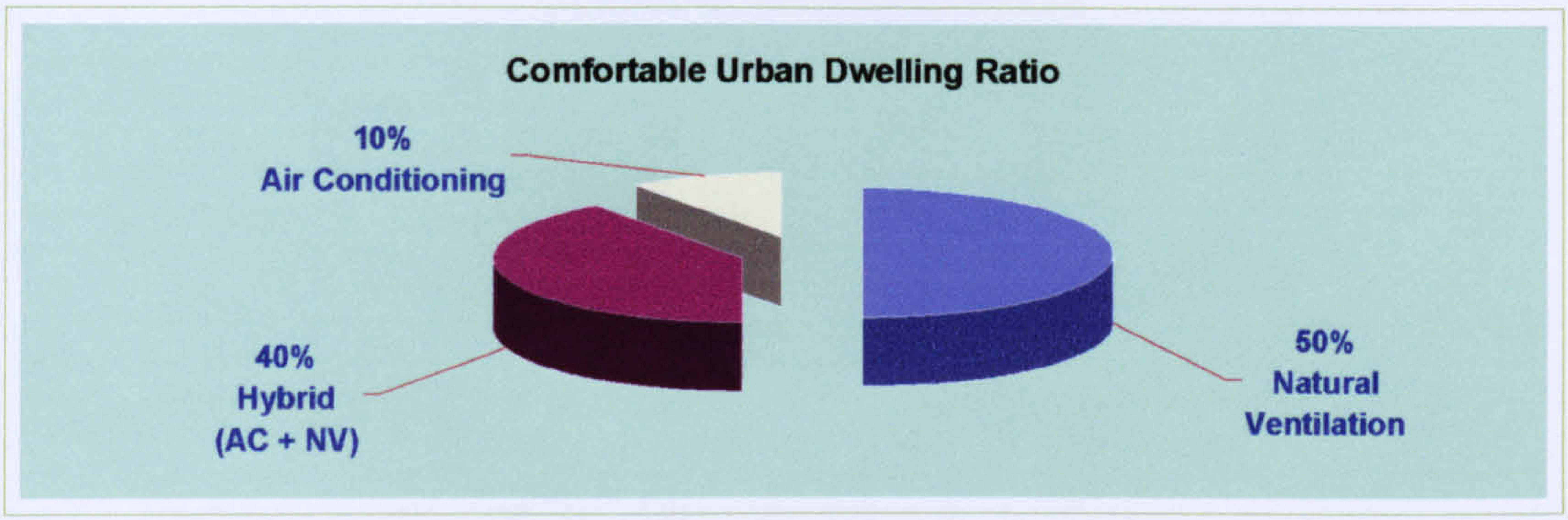

Chart 5.3. Comfortable Urban Dwelling

In these regards, the result shows a similar indication to the general view of a comfortable dwelling; that natural ventilation was still able to exclude discomfort, with a slightly increased use of air conditioning in dwellings, and the hybrid system comparable with the whole survey.

5.7.4. Comfortable Suburban Dwelling

In the suburban area, from 91 replies; 60% wished to use natural ventilation, 40% wished to combine air conditioning and natural ventilation, and no one wished to install air conditioning (Chart 5.4).

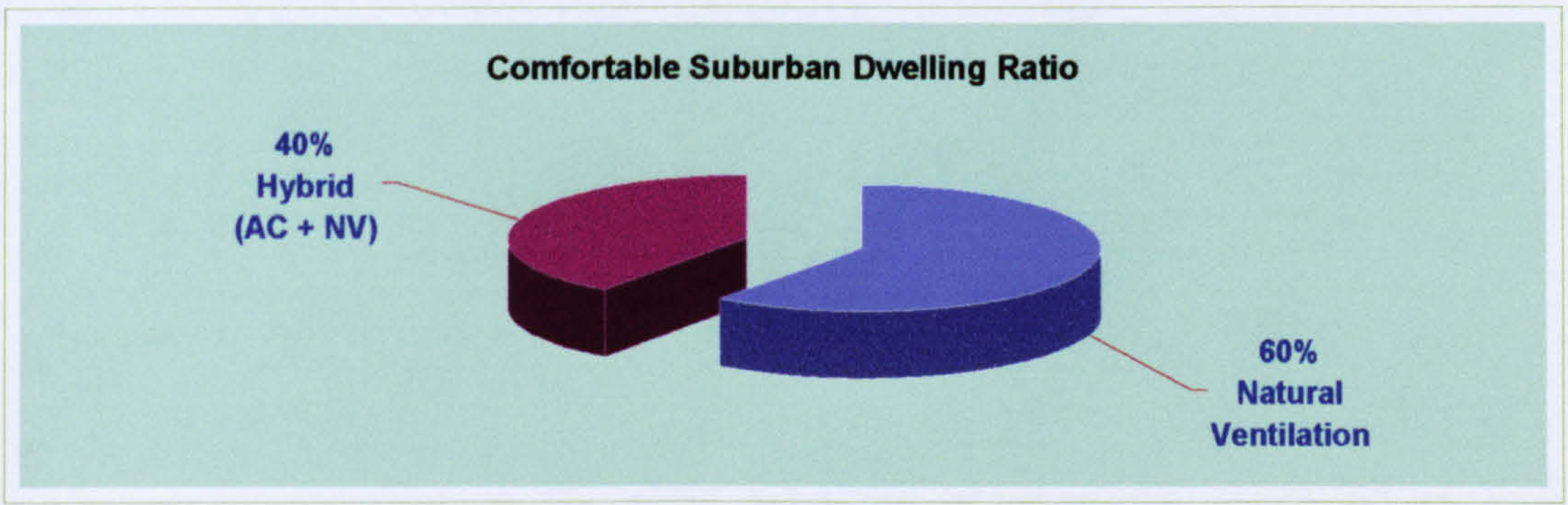

Chart 5.4. Comfortable Suburban Dwelling

It was understandable that in suburban areas, air conditioning in a dwelling was considered unnecessary. Natural ventilation was the highest, and the hybrid cooling technique for a comfortable dwelling in suburban areas was the same as for urban areas. Clearly within the more open environment of the suburbs, the use of natural ventilation dominated.

5.7.5. Comfortable Dwelling In Tourism Areas

In the tourist area, from 8 replies 75% wished to use natural ventilation, 25% wished to combine air conditioning and natural ventilation, no one wished to install air conditioning (Chart 5.5).

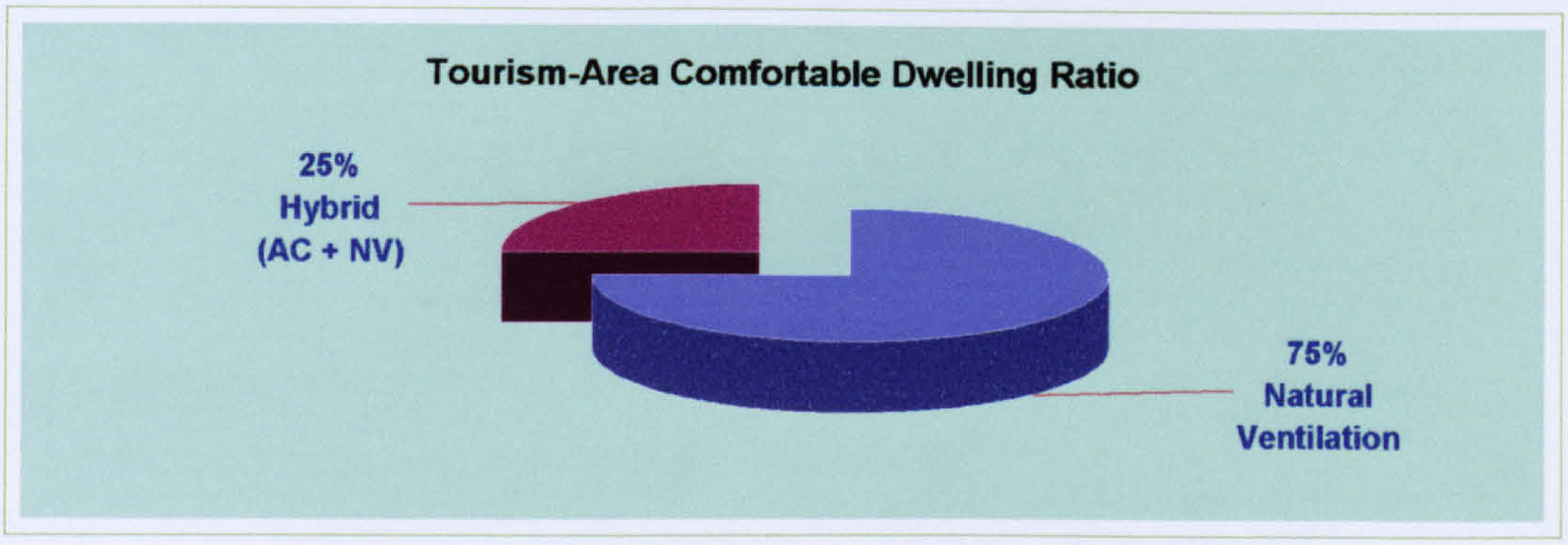

Chart 5.5. **Comfortable Dwelling In Tourism Areas**

The number of replies is small; this data shows without any air conditioning, most people in this area felt comfortable with natural ventilation, a quarter of them tended towards a combination of natural ventilation and air conditioning. However, from such a small sample little can be realistically determined.

The general conclusion is that most people in these three different locations still use natural ventilation and combined both air conditioning and natural ventilation (hybrid) for a comfortable dwelling, rather than using air conditioning.

5.7.6. Cooling Technique Adopted

Regarding the respondents' selection of convenience of cooling, the result is shown in Chart 5.6, where 55% chose natural ventilation and 45% agreed that both air conditioning and natural ventilation was convenient for their house

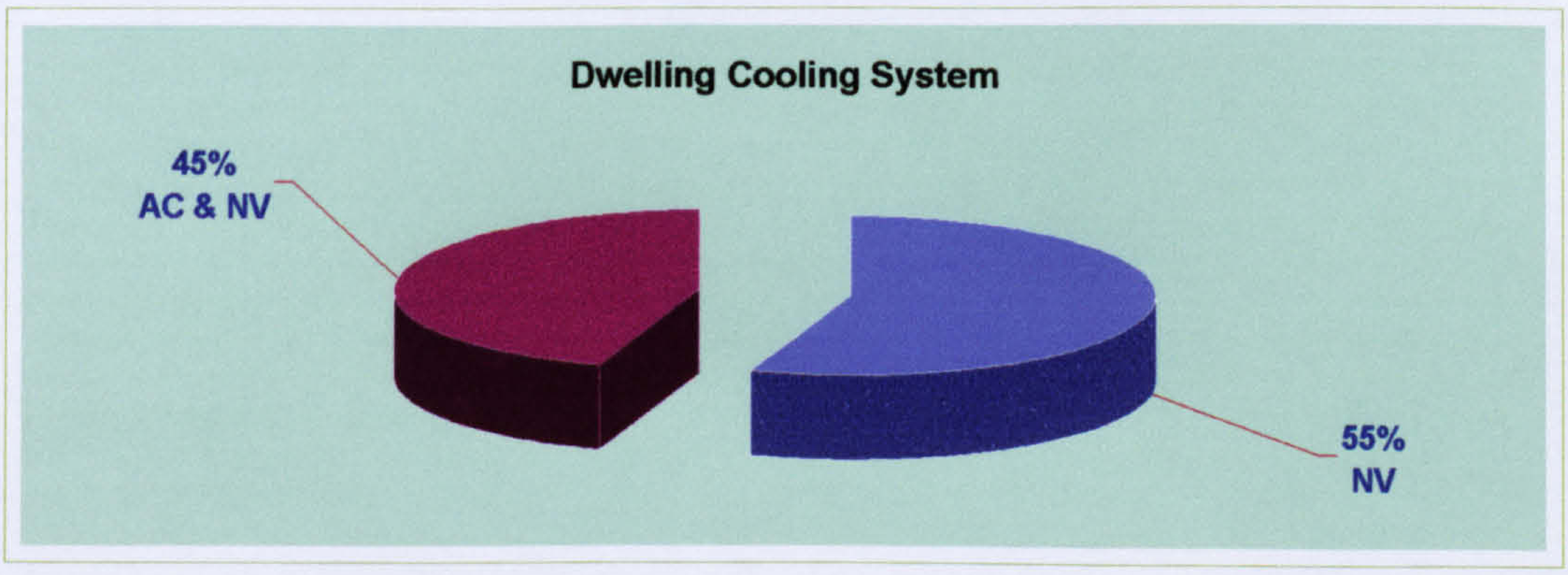

Chart 5.6. **House Convenience**

The chart shows that most of the respondents prefer to use natural ventilation and combined both air conditioning and natural ventilation for comfortable living in the dwelling.

This indicates that in a warm humid climate, a well-ventilated and well-conditioned house is necessary for comfortable living.

In the ideal house, 60% of respondents agreed that comfort is best achieved by natural ventilation.

However, 20% agreed that it was appropriate to achieve a comfortable dwelling by air conditioning.

Furthermore, in terms of the ideal house, 20% of people agreed it best to achieve a comfortable dwelling by using both air conditioning and natural ventilation.

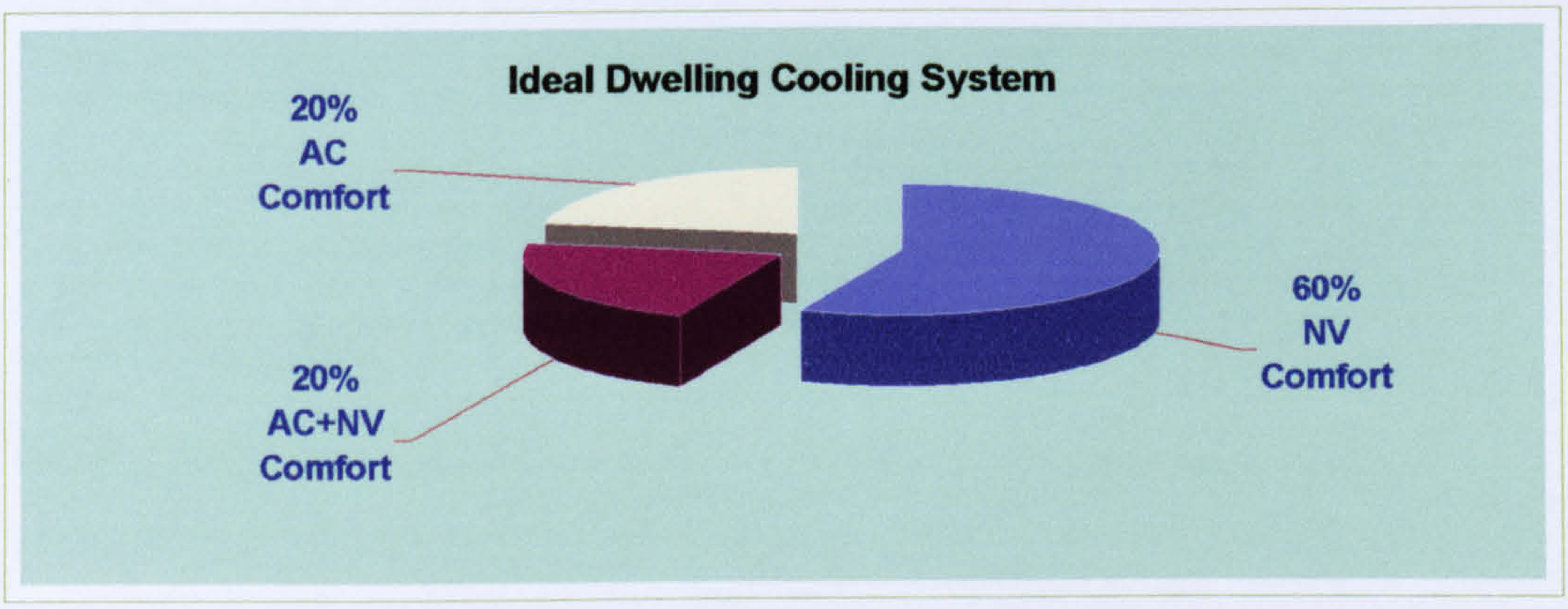

Chart 5.7. Ideal Dwelling Cooling System

The pie Chart 5.7. shows that using natural ventilation for a comfortable dwelling is the preferred requirement (e.g. two thirds of the respondents).

Looking at air conditioning, and the combination of air conditioning and natural ventilation there is a balance, with the ratios showing that one third of the respondents require air conditioning, and one third need both air conditioning and natural ventilation for their ideal thermally comfortable dwelling.

The reply here is interesting. In an ideal situation, as opposed to the real situation, there was still a high requirement for natural ventilation. This perhaps reflects the perceived value of the traditional approach to achieve comfort.

5.7.7. Natural Ventilation & Air Conditioning In Suburb and City

5.7.7.1. Natural Ventilation

Of the people who live in suburban areas, 30% wished for a natural ventilation system in their house. Of the people living in the city, 10% used natural ventilation for cooling purposes. This reflects the greater potential of natural ventilation to be used for cooling in the more open suburban areas (Chart 5.8).

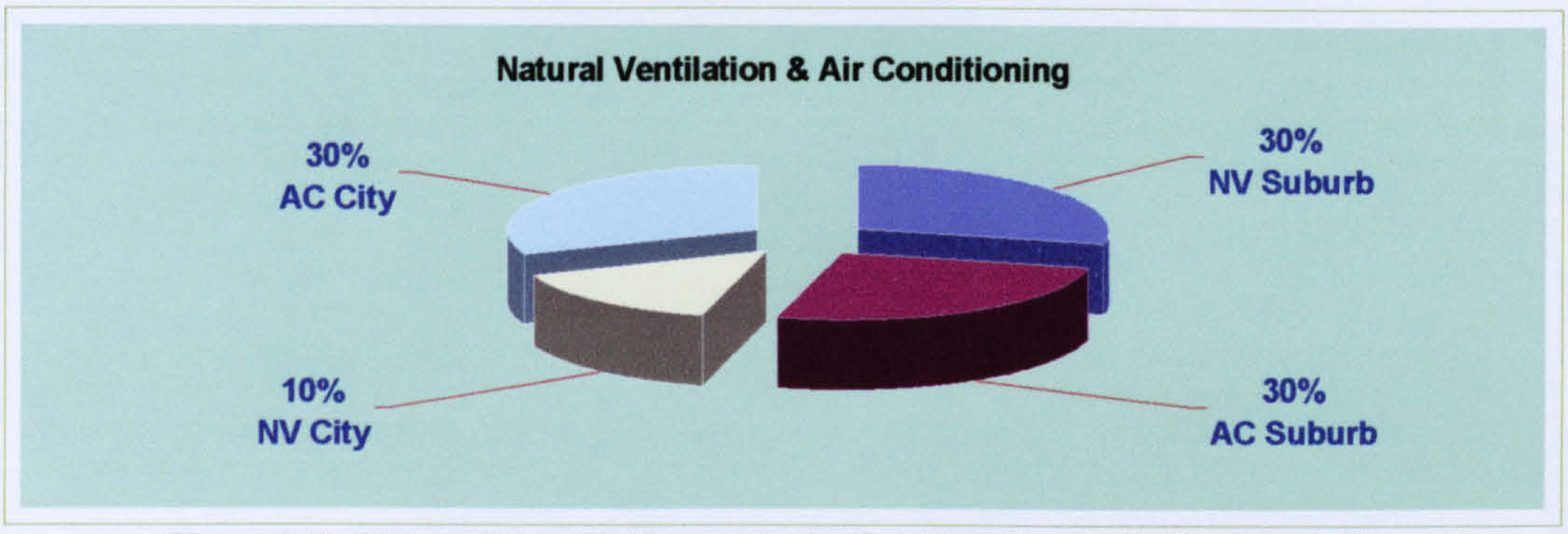

Chart 5.8. **Natural Ventilation and Air Conditioning in Suburb and City**

5.7.7.2. Air Conditioning

Of the people living in suburban areas, 30% would like an air conditioning system in the house. Of the people living in the city, 30% also want air conditioning for their home (Chart 5.8).

By comparison, the preferred use of natural ventilation in suburban areas is threefold that of the urban areas, reflecting the greater compactness of urban living which inhibits the use of natural ventilation.

5.7.8. Dwelling Ownership

Chart 5.9. below indicates that ownership of houses is still limited, being less than half the total. However, this ownership figure was greater than the tenantship and parentship of the dwellings.

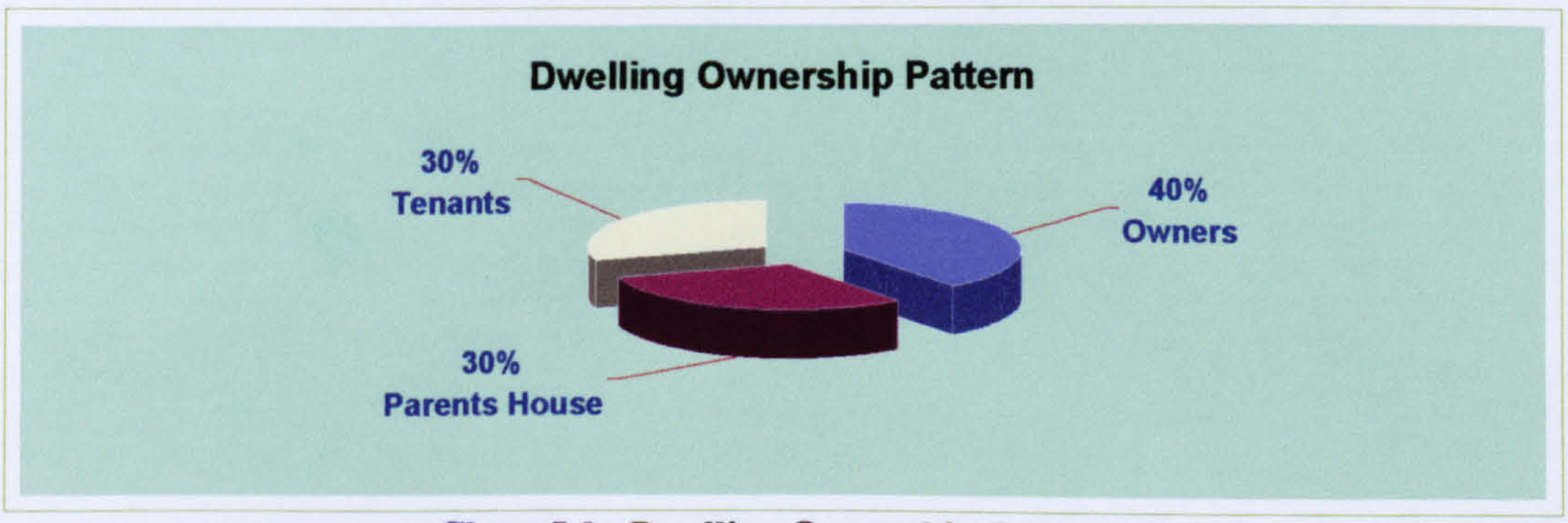

Chart 5.9. **Dwelling Ownership Pattern**

5.7.9. Monthly Spend On Energy per Dwelling

The respondents' monthly expenditure figures, on energy for the house are that 40% spend up to US$ 25, 20% spend up to US$ 45, 10% spend up to US$ 50, 10% spend up to US$ 35, 10% spend between US$ 15 to US$ 20, and 10% spend up to US$ 60.

The average energy cost spending is US$ 40 monthly (Chart 5.10), and annually, US$ 480. In order to understand properly about energy expenditure, this spending per month must be compared to the incomes of the respondents.

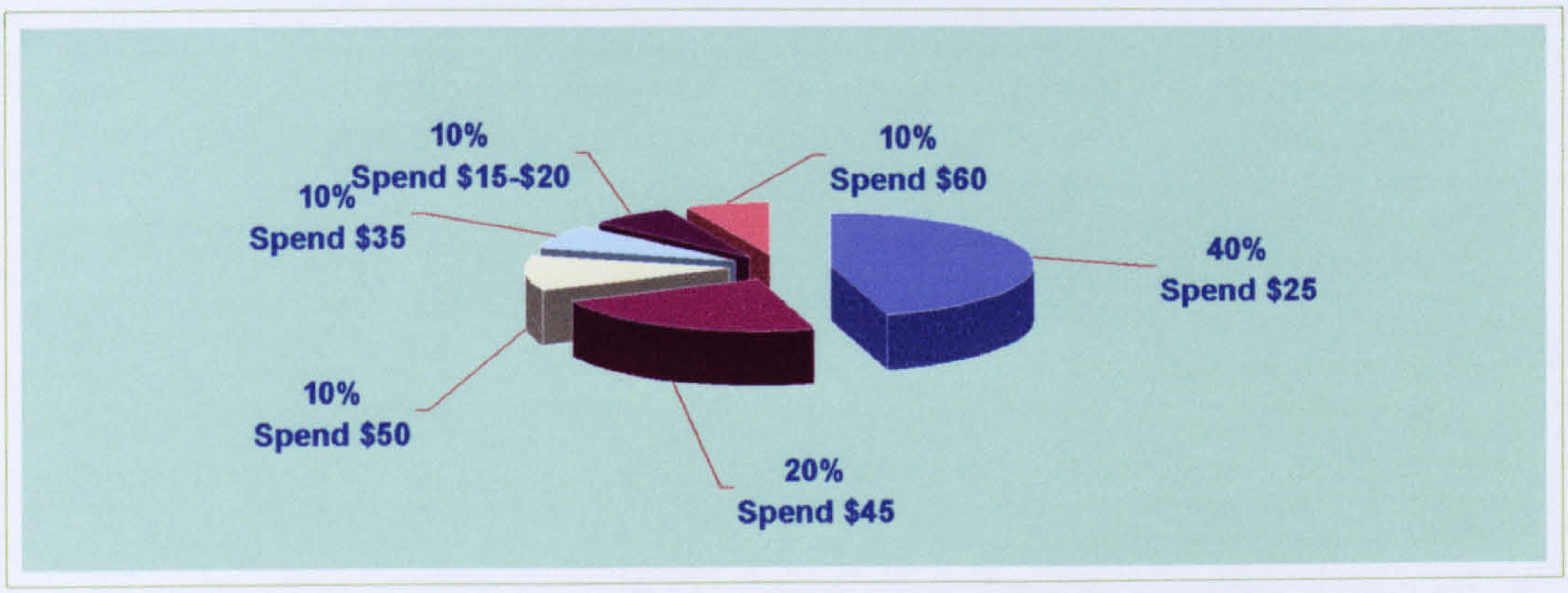

Chart 5.10. **Monthly Spend on Energy per Dwelling**

5.7.10. Annual Income

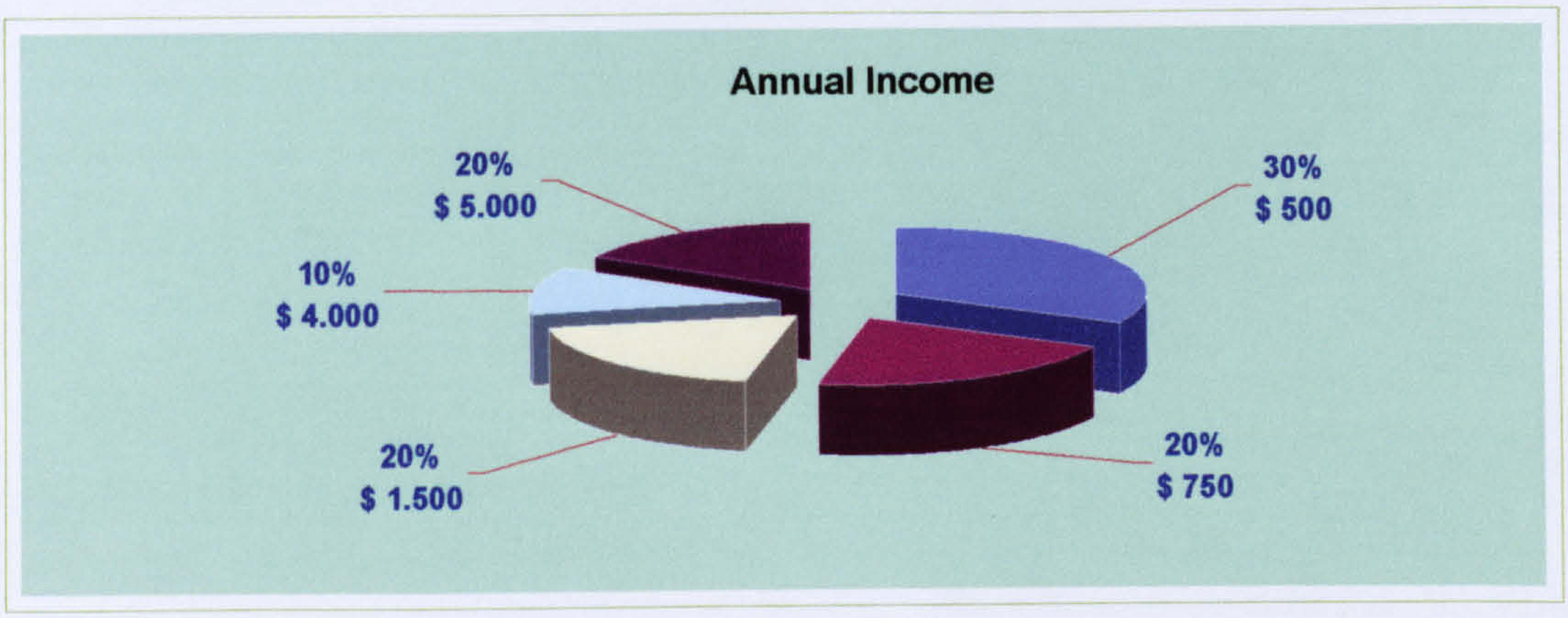

Chart 5.11. **Annual Income**

The annual income ratio can be seen on Chart 5.11. above. Starting from the lowest to the highest, 44 occupants have income of US$ 500, 28 have income of US$750, 26 have income of US$ 1,500, 15 have income of US$ 4,000, and 22 have income of US$ 5,000. The average income is US$ 2,350 per year, however, 70 % of respondents have an income less than US$ 1,500 per annum.

5.7.11. Annual Income & Energy Dwelling Ratio

Comparing incomes and energy costs, the average expenditure on energy is about 20% of income (Chart 5.12).

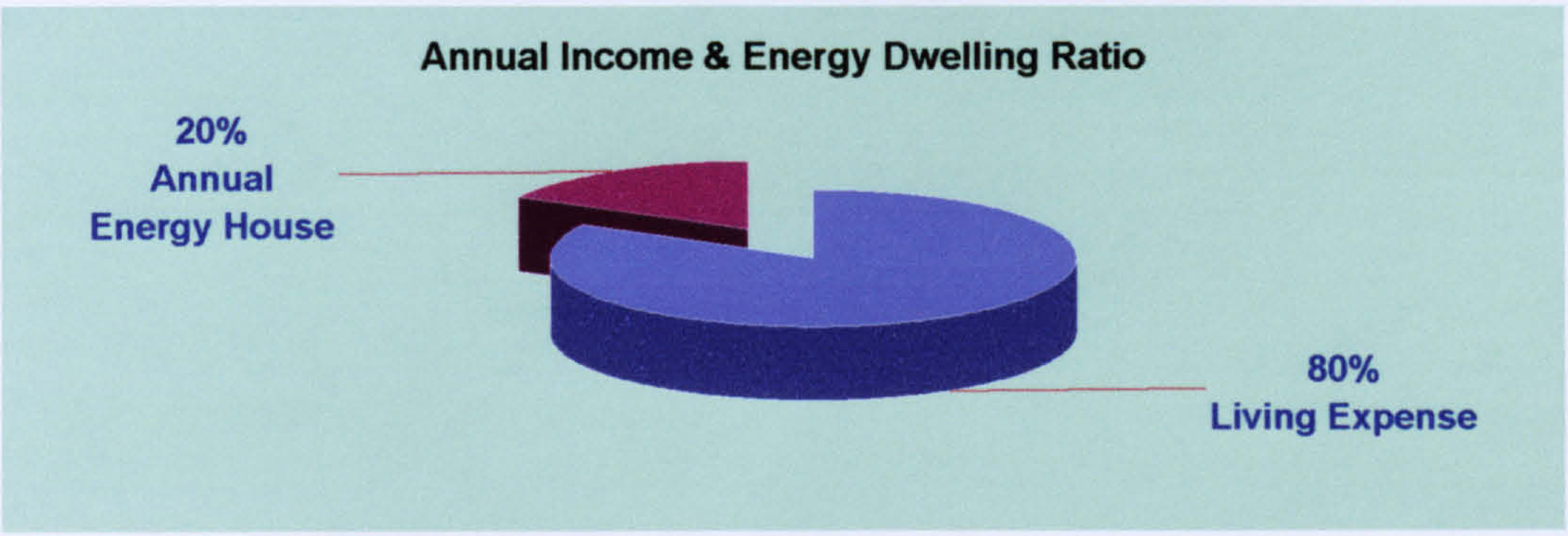

Chart 5.12. Annual Income & Energy in the House

5.7.12. Cooling Method and Annual Income Relationship

In Table 5.1., the cooling method, city location, and income are presented. The table shows that for annual income in the inner city, the number of people wanting AC increased as the income increased.

In contrast, people who lived in suburban and tourism areas stated that it was unnecessary to use air conditioning for a comfortable dwelling.

In term of both air conditioning and natural ventilation for the dwelling, the information shows that people like to use them to achieve primary comfort in the house, without any relation to annual income.

COOLING HOUSE	SETTLEMENT LOCATION	COMFORT NEEDS and ANNUAL INCOME < US$ > RATIO					TOTAL	
		500	750	1500	4000	5000		
AC	Inner City	1	2	0	0	3	6	6
	Suburban	0	0	0	0	0		
	Tourism	0	0	0	0	0		
AC & NV	Inner City	10	6	4	2	6	28	57
	Suburban	6	4	10	7	10	37	
	Tourism	0	0	2	0	0	2	
NV	Inner City	16	4	10	5	3	38	95
	Suburban	22	14	9	3	3	51	
	Tourism	3	0	0	0	6	6	

Table 5.1. Comfort Needs and Annual Income < US$ > Ratio

Natural ventilation is the most popular form of cooling, and the table shows that the lower the annual income the more they would prefer to use natural ventilation for living comfort in their dwelling. This is true for all locations except the tourism areas.

From this may be concluded that for a comfortable dwelling, natural ventilation is affordable and air conditioning is unaffordable.

5.7.13. Ideal Cooling House and Annual Income Relationship

In relation to the ideal house, it can be seen in Table 5.2. that in the city, suburban, and tourism areas, irrespective of location, respondents need for air conditioning depends on the annual income range.

Regarding the combination of both air conditioning and natural ventilation for conditioning the house, the table shows that people tend to use them to achieve comfort in the house in same way as they use air conditioning.

Natural ventilation is favoured by the respondents for cooling the house and the table shows that, except in tourism areas, the lower the annual income of the people the more they would like to use natural ventilation for living comfort in their accommodation, in any area.

HOUSE COOLING SYSTEM	HOUSING LOCATION	IDEAL HOUSE COMFORT NEEDS and ANNUAL INCOME < US$ > RATIO					TOTAL	
		500	750	1500	4000	5000		
AC	Inner City	14	6	4	3	6	33	63
	Suburban	6	6	7	5	4	28	
	Tourism	0	0	2	0	0	2	
AC & NV	Inner City	14	6	4	3	6	33	63
	Suburban	6	6	7	5	4	28	
	Tourism	0	0	2	0	0	2	
NV	Inner City	27	11	13	7	11	69	165
	Suburban	26	18	19	10	13	86	
	Tourism	3	0	2	0	3	8	

Table 5.2. Ideal House Comfort Needs and Annual Income < US$ > Ratio

This points to the conclusion that even though air conditioning is technologically the preferred cooling method for the dwelling, natural ventilation is still favoured for comfortable living in the ideal house.

5.7.14. Traditional and Modern Houses

In respect of an ideal house 60% of the respondents tended to choose traditional, and 40% modern houses (Chart 5.13).

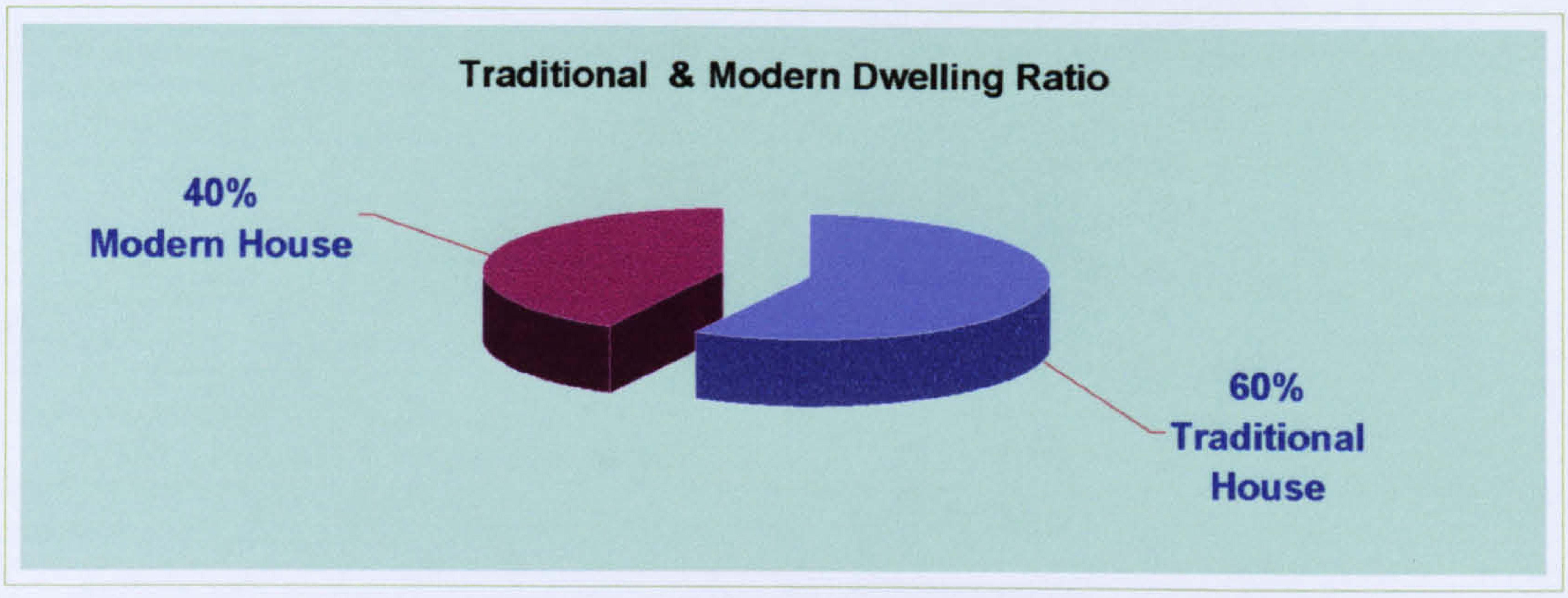

Chart 5.13. Traditional and Modern House Ratio

In this respect, the conclusion to be drawn is that people feel comfortable living in the traditional dwelling, however, due to this type of accommodation becoming unaffordable, people are selecting the cheaper dwelling (e.g. contemporary type).

5.7.14.1. Comfort From The Traditional Dwelling

For comfort within a traditional dwelling, the result shows that; 60% of the respondents would like natural ventilation system, 20% of would like an air conditioning system and 20% of the respondents would like a combination of air conditioning and natural ventilation system for the house (Chart 5.14).

This figure shown that most of the respondents demand for comfortable living is based on their past experience (i.e. natural ventilation), and this is understandable.

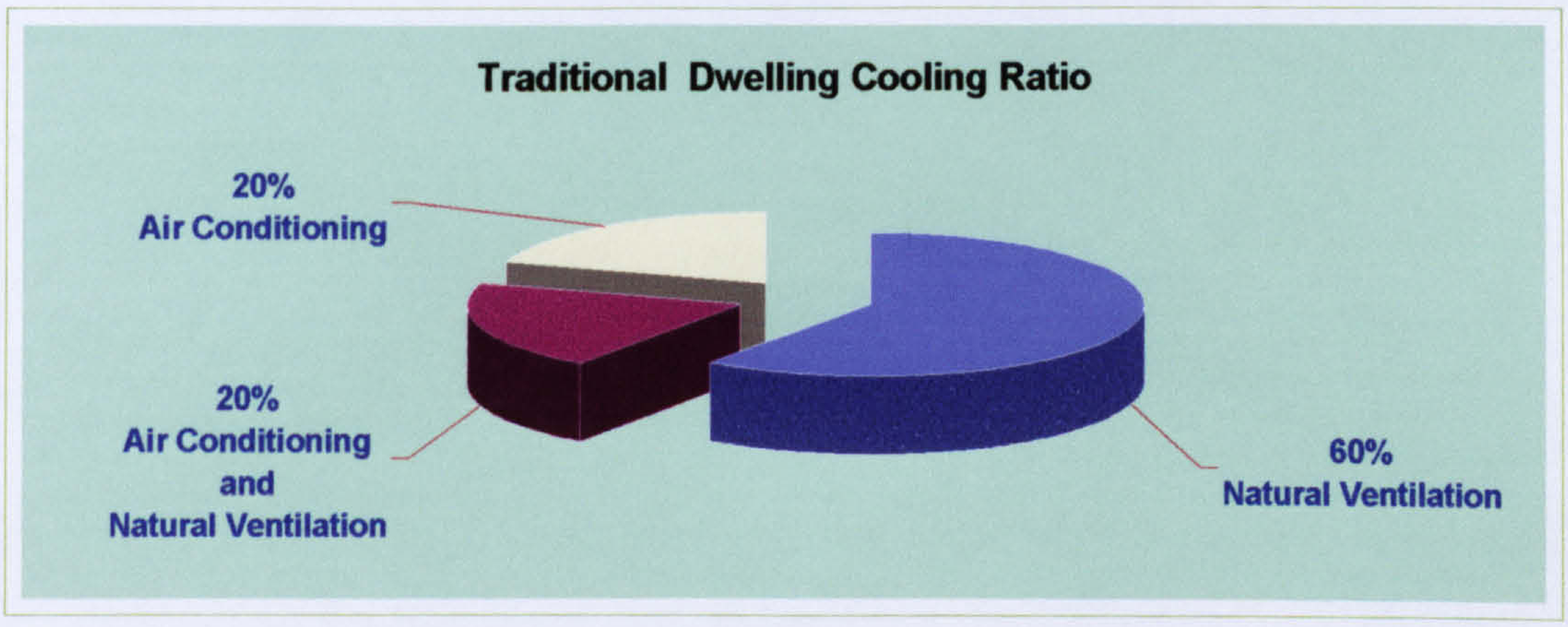

Chart 5.14. Traditional Dwelling Cooling Ratio

However, for this traditional dwelling, respondents also combine traditional cooling means and technology using air conditioning within their dwelling.

5.7.14.2. Traditional House Typology

The outcome indicated that 40% would like a small house type, but 60% of those who answered would like a large dwelling (Chart 5.15).

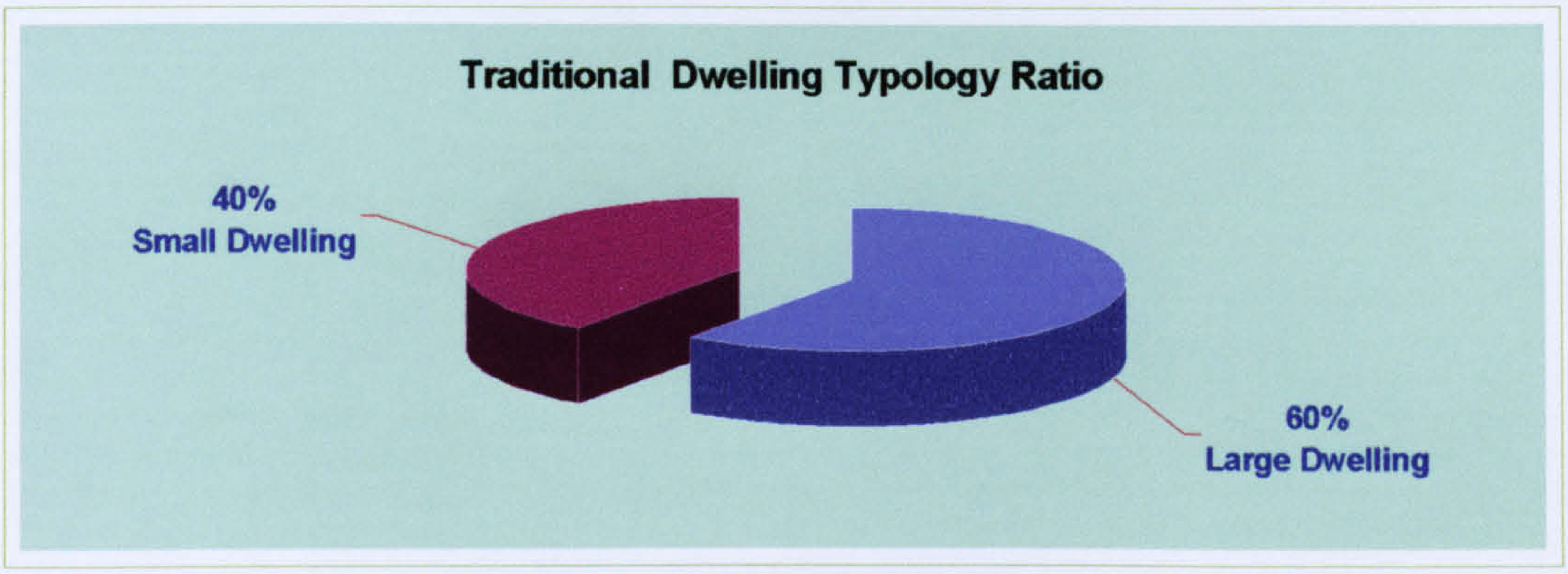

Chart 5.15. **Traditional House Typology Ratio**

In these terms, a little more than half of the respondents were thinking about the comfortable traditional dwelling and prosperous development, while one third of the people responding were concerned about cost and physical comfort.

5.7.14.3. Comfort From The Modern House

The summary records that for comfort, health and to conserve energy within a modern house, 50% of the people would like a natural ventilation system, 25% would like an AC system and 25% would like a combined air conditioning and natural ventilation system for the house (Chart 5.16).

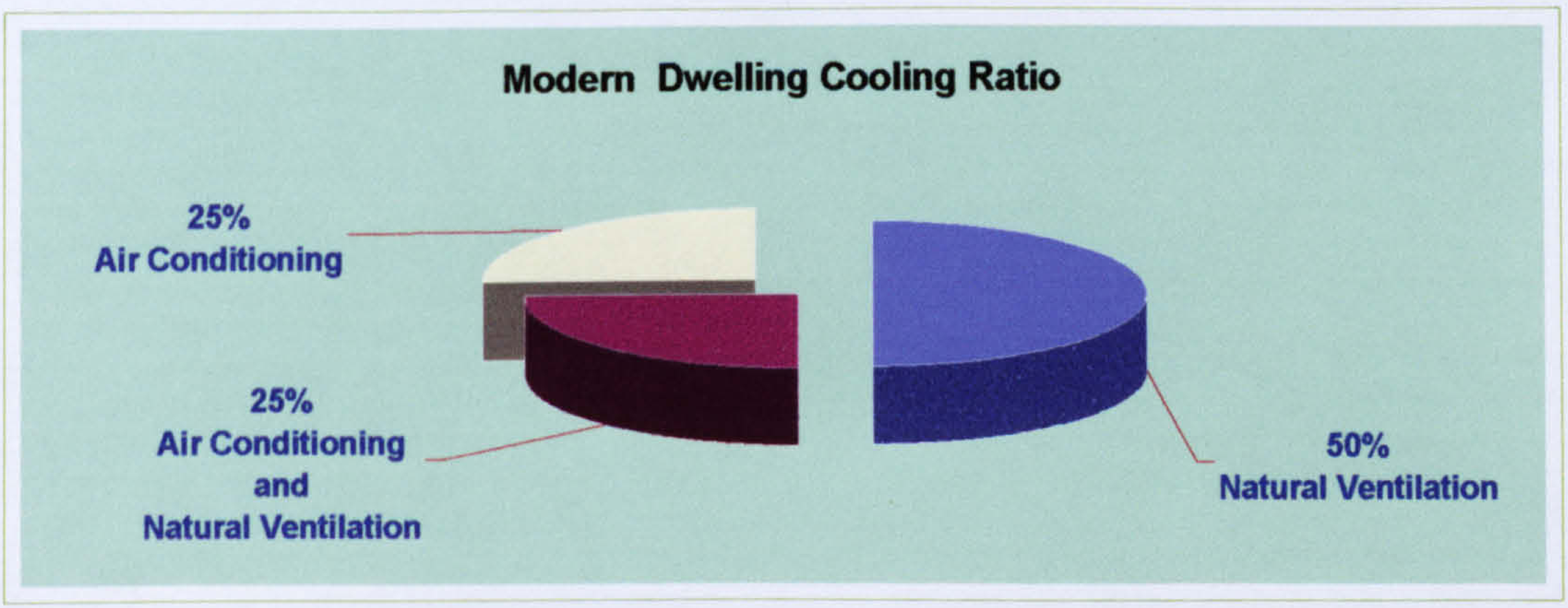

Chart 5.16. **Modern Dwelling Cooling Ratio**

From the figure above, even in the contemporary house, demanding natural ventilation for cooling and energy conservation dwelling is still favoured.

Yet, particularly for modern dwellings, a quarter of the respondents felt comfortable with the use of air conditioning and another quarter were happy to combine natural ventilation and air conditioning.

Clearly, within the context of a modern dwelling 50% of the occupants would use some room with air conditioning, but natural ventilation as a cooling mechanism plays a significant part in the cooling process.

5.7.14.4. Modern House Typology

They shows that 40% of respondents would like a small house type, but 60% from their answers would like a large house (Chart 5.17).

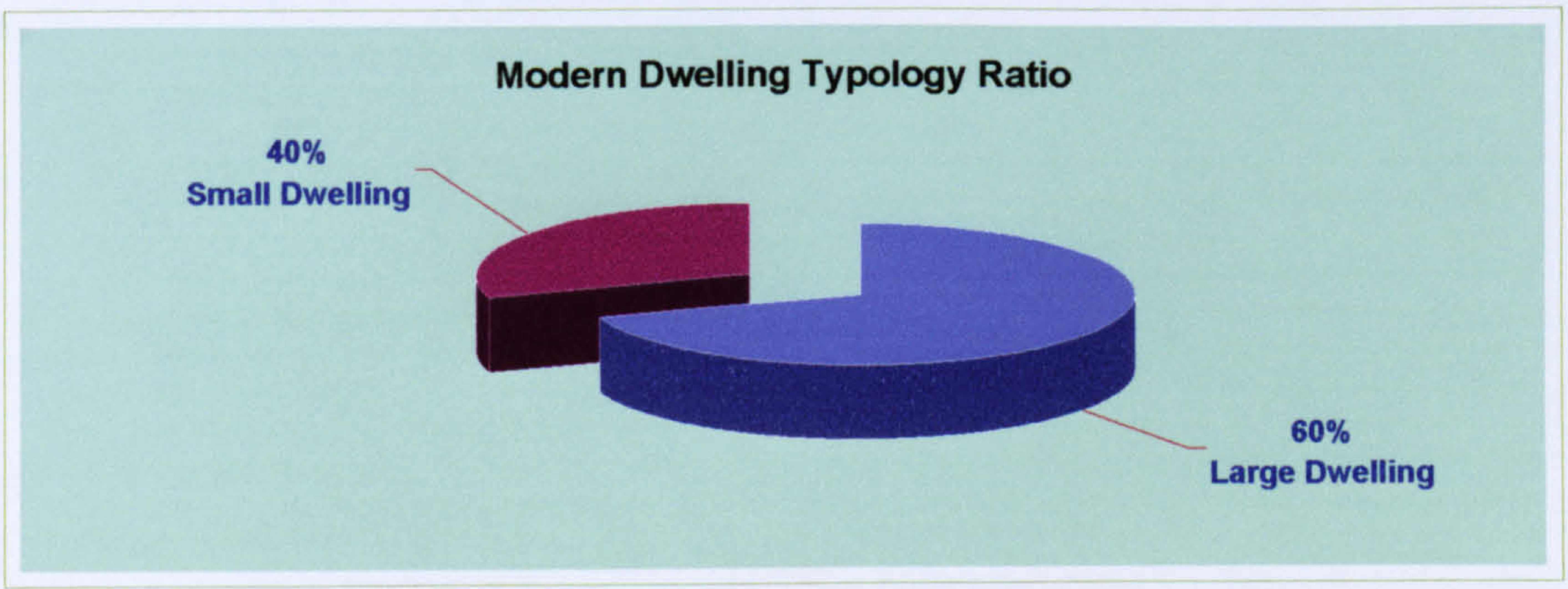

Chart 5.17. Modern Dwelling Typology Ratio

From this can be concluded that people are for the most part, desirous of living in a prosperous dwelling. One fifth of them are thinking small but nice. On the other hand very few or more likely none, can afford an exclusive dwelling.

5.8. CONCLUSION

There are two points that can be highlighted in this research survey which are the outcomes of the survey as the main points and the technical methodology (e.g. electronic-mail survey).

Therefore, the important points and the main aims of this methodology are to obtain the outcomes of what were experienced in the current dwelling and what are comfort demands for ideal home in the future.

The findings concerning comfortable living in dwellings of all areas, in the city, suburban and tourism settlements showed that demand for natural ventilation (NV) was greater than for both air conditioning (AC) and NV/AC combined.

The combination of AC and NV was seen as the best way to achieve a comfortable dwelling. As greater as the AC and NV combination, AC is only more desired to convenience the ideal house.

Yet, the need for an AC system to make their dwelling comfortable was far less apparent in the current usage pattern, in contrast to expectations of the ideal house.

These results indicate that traditional and technological methods need to be proportionally applied, for comfortable dwellings.

This is supported by the findings that the levels of demand for combined natural ventilation and air conditioning, in both traditional dwellings and modern houses were comparable.

However, as indicated in the result of energy expenditure and annual income, it is necessary to reduce the amount of energy consumption. This is related to the finding that most people would like to have a large dwelling, which would result in a greater amount of energy consumption.

The results of this electronic investigation could be used to help meet the design requirements for thermal-comfort dwellings in warm humid climate conditions. Outcome of this research survey, coupled with results from the computer-simulation thermal performance analysis and works-undertaken review, will be used to formulate conclusions of the research.

In addition to this process, in order to achieve efficiency in energy conservation, architectural features must also be considered. This is essential, as it has been found that the great advantage of vernacular architecture to modify the climate was shown in the favourite selection by most of the respondents who would prefer to have a traditional dwelling than a modern house.

In technical terms of this survey research, the conclusion drawn is that despite the simplicity of the questionnaire design in obtaining the goals, an electronic survey has shown significant success. Of course, there are also limitations in this regard which will be discussing later.

However, it indicates that an e-mail survey could encompass both the common mail survey and door-to-door survey researches.

This survey also showed advantages over other data collection methods, in that such information data taken from the respondents by means of questionnaire's responses were carried out without any great disturbance for the people concerned.

In this respect, taking data of buildings from those readily available for the common type dwelling standard built by the national housing authority in Indonesia including Bali, was another way to achieve the goal of the research. That, too is usually a crucial problem on a direct investigation.

Chapter Six

THERMAL CONDITIONS AND ENERGY USAGE PATTERNS IN EXISTING BUILDINGS: ANALYSIS OF PREVIOUS STUDIES

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Chapter Six

THERMAL CONDITIONS AND ENERGY USAGE PATTERNS IN EXISTING BUILDINGS: ANALYSIS OF PREVIOUS STUDIES

6.1. INTRODUCTION

This chapter will discuss the thermal comfort conditions and energy usage within the house, analysis of previous studies. Specifically, it will focus on human thermal comfort requirements in warm humid climates in relation to the quality of indoor thermal conditions and the energy usage patterns in the building. The study mostly focuses on the recently standardised, compact contemporary house, which is being built in urban areas where building density, land availability, environment and living comfort in dwellings are crucial problems. The emphasis on contemporary houses reflects a much greater uncertainty about their thermal comfort which can vary considerably with their design. The research houses both traditional and contemporary were selected to cover a wide a range of comfort characteristics as possible. Due to their similarity in climate and thermal conditions, the result is representing and will be cross-analysed to the outcomes of simulation study, so that the dwelling design in Bali can become much more widely understood.

The house types in Bali, Indonesia were commonly designated as follows:

- *"0-wall attached; none of the external wall sides of the building is attached to the plot perimeter (i.e. free standing or detached building).*
- *1-wall attached; one of the external sidewalls of the building is attached to one of the four sides of the plot (where the same development takes place on the neighbouring plot, they will form a semi-detached house).*
- *2-wall attached; two of the external sidewalls of the building are attached to any two of the four sides of the plot (where the same development takes place on the neighbouring plot, they will form a terrace house).*
- *3-wall attached; three of the external sidewalls of the building are attached to any three of the four sides of the plot (where the same development takes place on the neighbouring plot, they will form a back-to-back house)."*

Antaryama, 2000.

As a comparative study, the studies on thermal comfort performance, and building energy consumption in the warm humid climate of Jakarta by Karyono (2000), in Surabaya by Funo and Silas (2000), and in Denpasar Bali by Antaryama (2000), Indonesia are now briefly introduced.

Jakarta is the capital of all Indonesia, Surabaya is the capital of the East Java province and Denpasar is the capital of the Bali province of Indonesia. In their locations, the warm humid climate conditions are the same with a minimum average temperature of 23°C and maximum average of 32°C. The average relative humidity is between 70 and 90%, and the average wind velocity is between 0.2 and 0.8 m/s.

The first is a field study in Jakarta concerning thermal comfort and building energy consumption. Although based on an office environment, it gives pointers to thermal comfort in a warm humid climate. The study investigates the neutral temperature for the occupants working in office buildings. It reveals that comfort conditions can be achieved without unnecessary cooling in air conditioned buildings.

The second study is about an experimental passive house designed for the tropical climate in Surabaya. By using locally produced construction materials, building a model house, it investigates integrating passive cooling technology suitable to the warm humid climate condition. This study suggests that comfortable conditions may be achieved by indigenous building materials, and natural ventilation cooling the dwellings.

The last research uses simulation and field study to ascertain the climatic response of house forms in Bali. It investigates the thermal performance of traditional and contemporary houses that control their internal climate. The housing study focuses on the question of how to gain better understanding of climatic response of buildings, in warm and humid situations. Specifically, to identify the different characteristics, thermal comfort performance, morphological factors and influence of the physical properties between traditional and contemporary dwellings, that control indoor climate. This research found that comfort performances in traditional dwellings were better achieved than in contemporary houses.

In the rest of this chapter, the previous studies are simultaneously reviewed and analysed. In order to draw conclusions on thermal comfort performance and energy usage pattern of building in the warm humid climate of Bali, Indonesia, the study and analysis are designed given the following considerations:

- A naturally ventilated building is a dwelling where natural ventilation is applied to achieve comfort.
- A hybrid-ventilated building is a dwelling where both natural ventilation and air conditioning are combined together; the dwelling is designed to use either natural ventilation or air conditioning to achieve comfort.
- An air-conditioned building is a dwelling where air conditioning is fully utilised to achieve comfort.

6.2. THE QUALITY OF INDOOR THERMAL CONDITIONS

6.2.1. Indoor Air Temperature

Figure 6.1. shows the monthly air temperature in the warm humid climate throughout the year. Identical, warm conditions were experienced between the months of October and April, with December as the hottest month. In these months of the year, the indoor thermal conditions were as warm as the outdoor air temperature (see Chapter Three at point 3.3). The hot period extends from midday to early evening (see also Chapter Three at point 3.4.3.3). Thermal comfort was only experienced during the night, when normally most people are asleep.

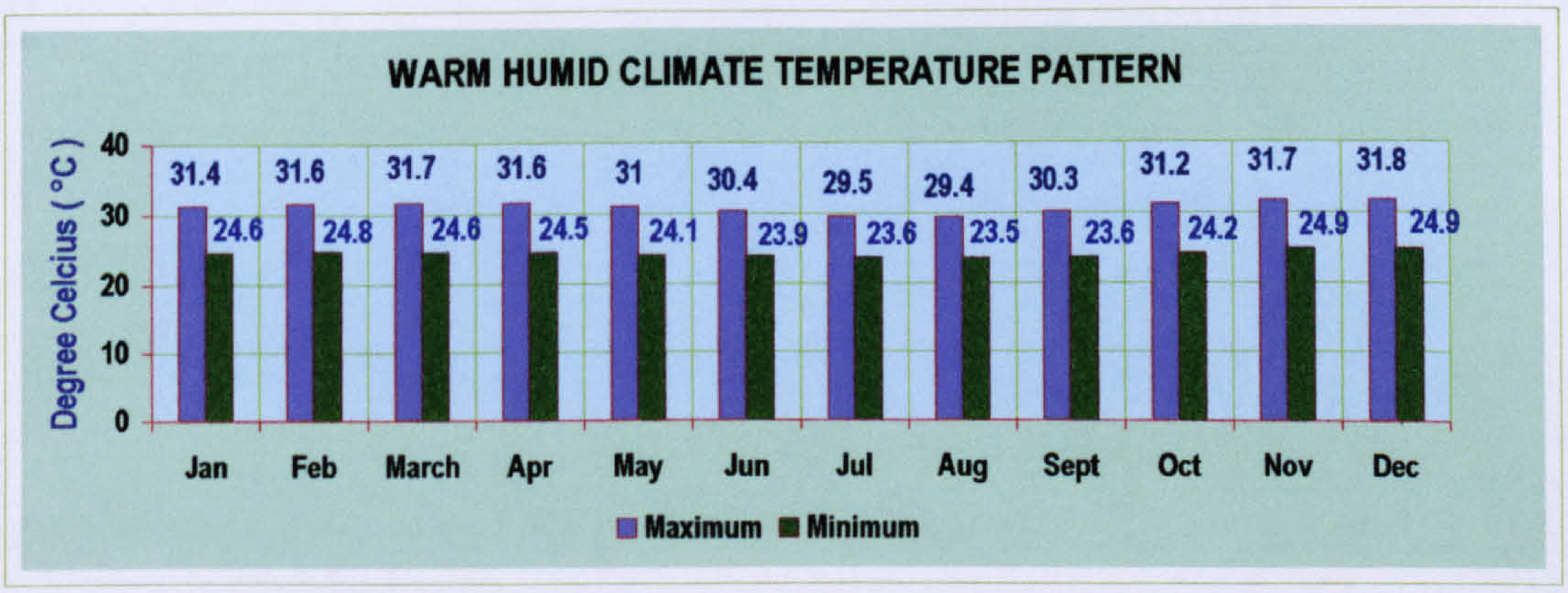

Figure 6.1. Warm Humid Climate Temperature Pattern

However, high indoor air temperature occurs, especially during the night and early morning when the wind speed is calm, making dwelling conditions uncomfortable.

This worst situation at night, coupled by heating pressures from the occupants, electrical equipment, lighting, building surfaces (floors, walls, windows, ceilings, and roofs), and ground radiation (that has absorbed heat from the sun all day) coming through the floor, from the building components and the surroundings. This produces heat and higher indoor temperatures that are difficult to control.

June, July, August, and September, on the other hand, are relatively cool, with August being the coolest month. During these cool times, the period of comfort is again only experienced from the middle of the night until early morning.

It is clear then, that to overcome this uncomfortable indoor air temperature, building design should ensure that indoor temperatures do not rise above those outdoors.

This can be done by dwelling design to minimise solar gain, by shading devices and providing appropriate volumetric ventilation to remove internal heat and to keep the mean radiant temperature as low as possible.

The daily dry bulb indoor air temperature, which shows the condition between thermal comfort and thermal discomfort ranges, are presented in Table 6.1.

From the point of view of a thermal comfort range (e.g. **24.2 – 28.2 °C**), in general, there is little difference between thermal comfort and thermal discomfort (e.g. **28.2 °C** and 28.1°C, **24.2 °C** and 24.1°C).

However, looking at the daily patterns of the whole year, thermal discomfort occurs when thermal comfort is needed during peak activities.

The table indicates that the daily overheating period (e.g. mostly between 10:00 a.m. to 21:00 p.m.) is much higher than the under comfort period (e.g. between 02:00 a.m. to 07:00 a.m., and limited only to between May and August); the ratio between overheating and under-cooling is 7 :1. As far as passive systems are concerned, considerations of climate are crucial in these circumstances. Ignorance of these particular problems will often lead to an increase in thermal discomfort.

Hour	DRY BULB TEMPERATURE Degree Celsius (°C)											
	Jan	Feb	March	Apr	May	June	July	August	Sept	Oct	Nov	Dec
1:00	25.7	25.9	25.7	25.7	25.3	25.0	24.6	24.5	24.7	25.3	26.0	25.9
2:00	25.2	25.4	25.2	25.2	24.9	24.6	24.2	24.1	24.3	24.8	25.5	25.5
3:00	24.9	25.1	24.9	24.8	24.5	24.2	23.9	23.7	23.9	24.5	25.2	25.1
4:00	24.7	24.8	24.7	24.6	24.2	24.0	23.7	23.5	23.7	24.2	25.0	24.9
5:00	24.6	24.8	24.6	24.5	24.1	23.9	23.6	23.5	23.6	24.2	24.9	24.9
6:00	24.9	25.0	24.8	24.6	24.3	24.0	23.7	23.6	23.8	24.4	25.2	25.2
7:00	25.6	25.7	25.4	25.2	24.8	24.5	24.2	24.1	24.4	25.1	25.8	25.8
8:00	26.5	26.6	26.4	26.2	25.7	25.3	24.9	24.9	25.3	26.0	26.7	26.8
9:00	27.6	27.7	27.5	27.4	26.8	26.4	25.9	25.8	26.3	27.1	27.8	27.9
10:00	28.7	28.9	28.7	28.6	28.1	27.6	27.0	26.9	27.5	28.4	29.0	29.1
11:00	29.8	30.0	29.9	29.8	29.2	28.6	28.0	27.9	28.6	29.5	30.1	30.2
12:00	30.6	30.9	30.8	30.8	30.1	29.3	28.8	28.7	29.5	30.4	30.9	31.0
13:00	31.2	31.4	31.4	31.4	30.8	30.1	29.3	29.2	30.0	31.0	31.5	31.6
14:00	31.4	31.6	31.7	31.6	31.0	30.4	29.5	29.4	30.3	31.2	31.7	31.8
15:00	31.3	31.6	31.6	31.5	30.9	30.3	29.4	29.4	30.2	31.2	31.6	31.7
16:00	31.1	31.3	31.4	31.3	30.7	30.1	29.3	29.2	30.0	30.9	31.4	31.5
17:00	30.7	31.0	31.0	30.9	30.3	29.8	29.0	28.9	29.6	30.5	31.0	31.1
18:00	30.2	30.5	30.5	30.4	29.9	29.3	28.6	28.5	29.2	30.1	30.6	30.6
19:00	29.7	29.9	29.9	29.9	29.3	28.8	28.1	28.0	28.6	29.4	30.0	30.0
20:00	29.0	29.2	29.2	29.2	28.7	28.2	27.5	27.4	28.0	28.8	29.3.	29.4
21:00	28.3	28.5	28.5	28.4	28.0	27.5	26.9	26.8	27.3	28.0	28.6.	28.6
22:00	27.6	27.8	27.7	27.7	27.3	26.9	26.3	26.2	26.6	27.3	27.9	27.9
23:00	26.9	27.1	27.0	27.0	26.6	26.2	25.7	25.6	25.9	26.6	27.2	27.2
24:00	26.2	26.4	26.3	26.3	25.9	25.6	25.1	25.0	25.3	25.9	26.5	26.5
Min	**24.6**	**24.8**	**24.6**	**24.5**	**24.1**	**23.9**	**23.6**	**23.5**	**23.6**	**24.2**	**24.9**	**24.9**
Avg	28.0	28.2	28.1	28.0	27.6	27.1	26.6	26.5	26.9	27.7	28.3	28.3
Max	**31.4**	**31.6**	**31.7**	**31.6**	**31.0**	**30.4**	**29.5**	**29.4**	**30.3**	**31.2**	**31.7**	**31.8**

Table 6.1. Comfort and Discomfort Temperatures Data of Denpasar Bali
(Antaryama, 2000).

= Comfort Temperature ranges (24.2 – 28.2 °C) **= Discomfort ranges**

Indoor air temperatures (T_a) and operative temperatures (T_o) are measured as a combination effect of air and mean radiant temperature, and equivalent temperature (T_{eq}) is measured as a combination effect of air temperature, mean radiant temperature and air velocity. Indoor air temperatures and humidity ranges are given in Figure 6.2.

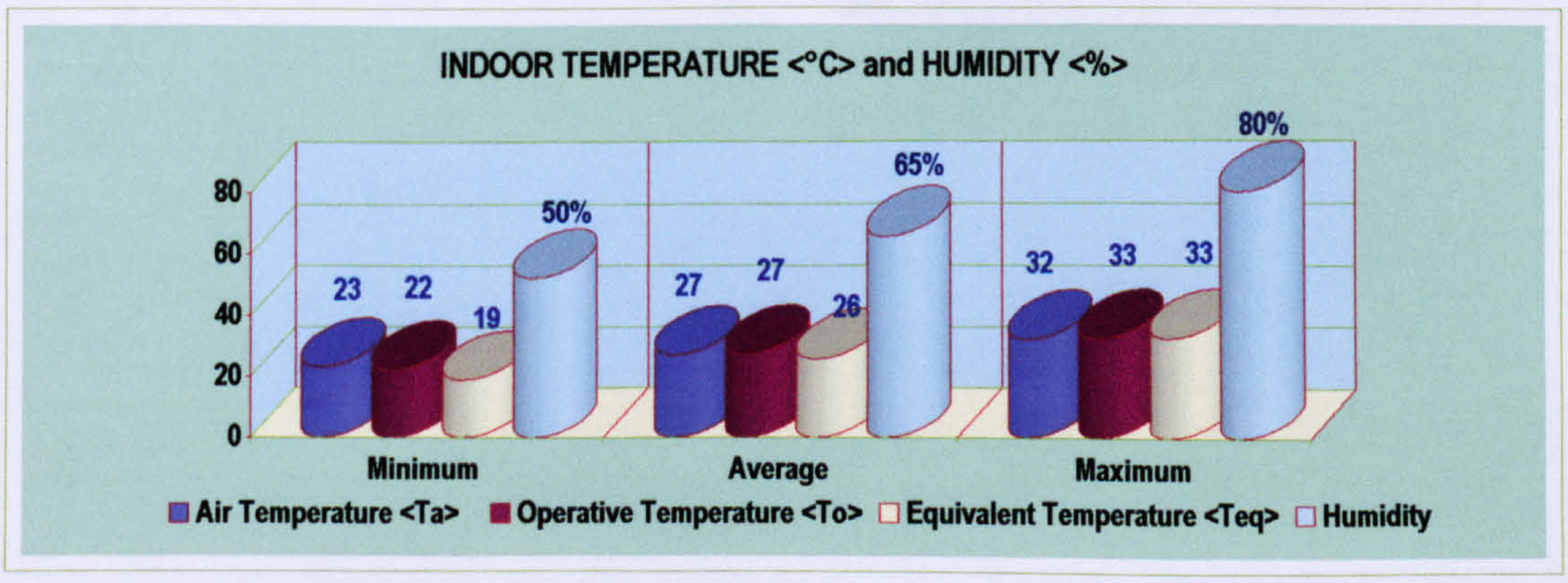

Figure 6.2. Indoor Temperature and Humidity Conditions

6.2.2. Indoor Relative Humidity

In warm humid climates, the high indoor air temperature is coupled to high humidity (Figure 6.2), where *"skin evaporation is limited, and evaporation cooling is not effective"* (Marsh, 1999).

Traditionally, this can be eliminated by good natural ventilation, especially between late at night and the morning (see Table 6.1). The remaining hours of the day, between 10:00 a.m. and 21:00 p.m., when overheating and temperature are over the comfort range, mechanical cooling solutions either by using fan or air conditioning are used as further ways to diminish humidity problems.

The former can only run well when the wind pressure is available, and of course the latter requires more energy.

6.2.3. Indoor Thermal Conditions

From the point of view of thermal comfort, these two problems above (sections 6.2.1 and 6.2.2) are paramount. The traditional dwelling addresses these conditions satisfactorily but the contemporary house, however, needs careful design to satisfy the two.

As was clearly stated, *"the main indoor thermal problems in warm humid regions are high temperature and humidity, causing internal conditions that may be too warm for comfort"* (Evans, 1980).

Thermal discomfort in the dwelling arises from the fact that temperatures are too high, over the comfort range, coupled with immoderate solar radiation and also internal heat gains over the dwelling. At these conditions as Koenigsberger et.al. (1974) recognised, occupants in the dwelling are heated. Furthermore Lippsmeier (1969) identified, high humidity simultaneously aggravates these conditions, making the indoor climate of dwelling very difficult to tolerate.

During the hot months, due to outgoing radiation, there is only a slight drop in the indoor temperature at night. With such small diurnal temperature variations, indoor thermal conditions often exceed those outdoors and thermal discomfort will almost eventually be occurred at any time.

Traditionally, as many previous researchers recommended (e.g. Szokolay, 1993; Van Strasten, 1967; Atkinson, 1960), natural ventilation can be used to some extent, to lower the indoor temperature, as it is not always possible to cool the dwelling to below the outdoor temperature.

During the cool months, air movement is the only way to achieve natural cooling in these indoor thermal conditions for only limited period of the day (Koenigsberger et.al. 1974; Ballantyne and Spencer, 1972; Smith and Tamakloe, 1970; Lippsmeier, 1969; Fry and Drew, 1956), otherwise, the indoor thermal condition is heated. Yet this can be unpleasant, and cause thermal discomfort indoors.

In these circumstances, mechanical cooling can be used to assist and accelerate air temperature and humidity, creating the indoor air temperature is lower than the outdoor air temperature, therefore producing the indoor thermal condition in the comfort range.

As discussed previously however, this is not always a straightforward solution, particularly if the building was designed without any plan for it to be air-conditioned, because dwellings which were originally designed for passive cooling would typically be unsuitable for air conditioning, making an active cooling system inefficient and costly to operate (Adamson and Aberg, 1993; Muncey, 1964; Danby, 1963).

According to Antaryama, (2000), examining the aforementioned indoor thermal conditions confirmed that overheating is the most important problem; the combination of high temperatures and high humidity, coupled with high solar radiation, leads to high required rates of ventilation and air movement. This points to mechanical cooling as the only practical way of restoring indoor thermal comfort.

He further noted when considering these points of view, that compound dwellings clearly offer a comfortable adaptation to those characteristic indoor thermal conditions. The use of open attics, little external walling, raised floor level and separated buildings signifies the sophisticated range of comfort preferences.

Apart from building protection, the pitched roof provides shading, lowering the impact of high solar radiation. Dwellings typically have open wall construction, giving maximum potential for natural ventilation and air movement. The courtyard plan layout allows cross ventilation whatever the wind direction even when the dwellings are close to each other, hence providing at least the possibility for reduction of internal air temperature and air humidity. In these dwellings where thermal discomfort might possibly occur in the hot months, air movement may be induced by the continuous cross ventilation resulting from there being a gap between walls and roof.

Antaryama (2000) further criticised, the indoor thermal performance of contemporary dwellings, which are different from the compound dwelling. Although a pitched roof with wide overhangs is employed to reduce overheating, the compact form may not have any greater environmental benefit than that achieved through the roof design. Although there are windows along the perimeter, they may be ineffective due to internal wall subdivisions which can prevent natural cross-ventilation.

In these circumstances, the rate of airflow will be inadequate to dissipate any excess heat from the building envelope and will result in a considerable reduction of the air movement that is used for natural cooling.

Therefore, there is a likelihood of an increase in air temperature, creating uncomfortable thermal conditions indoors.

Closeness of buildings and incorrect building orientation are other contemporary dwelling characteristics that may deflect, obstruct or lose the potential benefit of wind driven natural ventilation to the internal thermal conditions.

In this case Olgyay (1963) criticised the closeness of buildings in urban areas:

> *"Where building are in close proximity to one another such as in urban areas, similar problems are likely to arise due to the obstruction of the surroundings."*
>
> Olgyay, 1963.

Furthermore Saini (1970) described the consequence of having spatial and building arrangements of contemporary houses:

> *"Study of a consequence of having spatial and building arrangements like those of the contemporary house has found that cross ventilation could not be promoted in a compact plan form building, when rooms were arranged back-to-back."*
>
> Saini, 1970.

The conclusion can be drawn that in the compound pattern whose dwellings are sparsely arranged, the open forms commonly adopted are liable to present greater responsiveness to the climate for comfortable indoor thermal conditions.

Contemporary forms, on the contrary, tend to be excluded from their potential environment. A very limited plot size occupied by a compact dwelling can actually create greater obstacles, especially in promoting air movement and natural ventilation.

On this point, it can be argued that the contemporary house is potentially at greater risk of producing thermal discomfort than the traditional pattern dwelling.

During the day, the dwelling in the sun absorbs solar radiation, the outer surface temperature of the building increases above air temperature and a considerable heat gain through the building envelopes occurs, resulting in high indoor thermal conditions and increased operating temperature. During a clear night and early morning, only the long wave radiation to the sky may decrease the outer surface temperature of the building.

The thermal conditions of a house are influenced by outdoor solar radiation, and heat produced indoors by people and appliances.

Cooling is required to remove the heat gain through the dwelling envelope, and the heat produced indoors.

To improve the indoor thermal climate, notwithstanding internal ventilation and air movement, thermal insulation of the building envelope is an important measure to reduce the heat transfer and high internal temperatures.

Without insulation in the building envelope, heat gain through the floors, walls, windows, ceiling, and roof will cause discomfort indoors and increase the energy load required for cooling the dwelling.

The obvious way to decrease cooling requirements in order to maintain a desired room air temperature is to reduce the high heat indoors and the solar heat produced through the building envelope by better insulation, shading devices and cooling techniques integrated into the architecture of the dwelling.

Despite natural ventilation and air movement described previously, better indoor thermal conditions can be produced by air conditioning; cool air which is produced by a cooling machine, electrically driven.

However as noted, the cooling machine delivers about three times more cooling energy than the electrical energy supplied to the compressor.

6.3. ENERGY CONSUMPTION PATTERNS

6.3.1. Energy of Naturally-Ventilated Buildings

That naturally ventilated buildings are ecologically sound, thermally acceptable and use less energy, is commonly agreed (Rapoport, 1969), and the average they require 10% of the energy consumption compared to that of air-conditioned buildings (Karyono, 2000). In this respect, Karyono (2000) further reached a conclusion:

> *"Even though according to the survey research, most (60%) people tend to use natural ventilation, however, 50% of occupants were feeling discomfort on the warm side, and less than 50% were feeling comfort."*
>
> Karyono, 2000.

As previously described above (at point 6.2.3), the most comfortable conditions were only experienced on the traditional compound dwellings.

The overheating found in the compact dwellings may also be due to the fact that it lies within the city (e.g. Denpasar, the capital city of Bali), *"like in the other urban areas where the temperature can be mostly high"* (Evans, 1980).

The reduction in overheating is particularly important because it creates conditions of thermal comfort. This overheating can also be related to the lack of ventilation, particularly when a room in the dwelling is surrounded by other rooms.

The compact layout coupled with other compartmentalised rooms will obviously impose an obstruction on airflow, hence reducing natural ventilation.

Even where the position of the room allows direct contact with the exterior, there may still be little induced airflow, as most of the opening windows used are of casement type with a limited opening width. The conditions may further deteriorate when the buildings are not correctly oriented to the prevailing winds. Doors are often left open to increase the ventilation rate during the extremely hot period.

In particular, overheating problems might be also associated with a northerly orientation of the glazed façade of the room; this could be the case because the sun position is low in the north during the months of June, July and August, making the roof shading ineffective.

6.3.2. Energy of Hybrid Buildings

The average energy consumption in a hybrid buildings were found to be 4-kW/m^2 month (Karyono, 2000). This was only twice the energy consumption of a building with natural ventilation (see Chapter Four section 4.4.8).

Looking at these figures, by means of correct building design there is a great opportunity for the hybrid ventilated building to be mechanically cooled when necessary without consuming five times as much energy, as occurs in a fully air-conditioned building (see also Chapter Four section 4.4.8).

It can be inferred that during the year, to combine both natural ventilation and air conditioning in the dwelling is energy efficient and will be thermally acceptable for much of the day.

6.3.3. Energy Use of Air-Conditioned Buildings

On the other hand, air conditioning units consumed large amounts of energy.

> *"In comparison with natural ventilation and hybrid, the average energy consumption of the well design air-conditioned buildings, i.e. 20-KW/m^2/month."*
>
> Karyono, 2000.

This energy demand is five times higher than hybrid cooling energy consumption.

6.4. THERMAL COMFORT INDEX

Human thermal comfort is complex, especially in warm and humid climates. While much research has been carried out in this field, particularly since the advent of air conditioning, *"there has been less progress in dealing with higher heat stress conditions such as those experienced in warm humid tropical climates"* (de Dear and Auliciems 1985).

As recognised by Antaryama (2000), a number of human heat stresses and thermal comfort indices have been developed, but most were complex research tools and require data not readily available to building designers.

Many of the thermal comfort indices being developed for non-air conditioned buildings focus on a dry bulb air temperature to define the thermal comfort zone, with little possibility to accommodate the influences of airflow or humidity.

One exception was the method developed by Macfarlane (1958) who identified comfort zones for locations below and above 30° latitude;

> *"The thermal comfort zone for latitudes less than 30° is centred on a dry bulb temperature of 27°C and spanned from 24°C to 30°C. This thermal comfort zone is then adjusted downward for relative humidity greater than 60% (0.8°C for each 10% greater than 60%) and radiant heat from indoor surface temperatures greater than 38°C (0.55°C for each 2.8°C greater than 38°C)."*
>
> Macfarlane, 1958.

The beneficial influence of airflow raises the thermal comfort zone (0.55°C for each 0.15 m/s) since dry bulb air temperature does not exceed 37°C. A nominal upper limit of 1.0 m/s was suggested, as loose papers tend to be disturbed above that velocity.

However, residents in the warm humid tropics often operate fans at speeds that deliver velocities from 2 to 4m/s, to improve their indoor thermal comfort.

6.4.1. Thermal Comfort Standard

The thermal comfort standard was established according to a formula recommended by Coldicut et.al. (1991) and Szokolay (1991, 1987).

Particularly it is to specify the combinations of indoor thermal environmental factors, and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space.

The former factors addressed are temperature, thermal radiation, humidity, and air speed; the latter factors are those of activity and clothing.

However, *"this standard does not address such non-thermal environmental factors as air quality, acoustics, and illumination; or other physical, chemical or biological space contaminants that may affect comfort or health"* (ASHRAE, 2000).

The standard is calculated on the basis of thermal neutrality (T_n) of people (i.e. the temperature averaged for a large sample, when the individuals feel neither cold or hot), which is dependent on the outdoor mean temperature. As Antaryama (2000) suggested:

> *"For the calculation, annual mean temperature (T_{ao}) is taken as a base temperature, which is 27.6° C. Having calculated the thermal neutrality, the range of comfort temperatures is then established by adding 2 K to T_n, giving the upper comfort limit and by subtracting 2 K to obtain its lower limits."*
>
> Antaryama, 2000.

6.4.1.1. Thermal Neutrality (T_n)

$T_n = 17.6 + 0.31\ T_{ao}$,

where T_{ao} is annual mean temperature ($T_{ao} = 27.6$ °C)

This calculated thermal neutrality is close to that derived from either field surveys or laboratory studies conducted in other parts of Indonesia, as well as other warm humid countries. The results support use of the recommended formula in the climate of Bali (Antaryama, 2000).

6.4.1.2. Thermal Comfort Range (T_{cr})

Lower limit = 26.2 – 2 = 24.2 °C

Upper limit = 26.2 + 2 = 28.2 °C.

These comfort ranges give a thermal comfort standard for Bali between 24.2 and 28.2 ° C (Antaryama, 2000).

These thermal comfort standards for Bali are particularly supported by the Karyono (2000) study in Indonesia. This study has examined the percentage of occupants being comfortable at about the suggested range of comfort temperature. The temperatures were measured in three different forms: air, operative, and equivalent temperatures. Occupants' neutral temperature (T_n) and comfort range (T_{cr}) were expressed accordingly.

The calculations of neutral temperatures and comfort ranges were derived from linear regressions of actual individual votes against temperatures. Based on these regressions, T_n and T_{cr} for all the occupants in all buildings (e.g. naturally ventilated, hybrid, and air-conditioned buildings) were defined. The neutral temperature and thermal comfort range for the occupants of a building were defined; $T_n = 26°C$, lower limit $T_{cr} = 22°C$ and upper limit $T_{cr} = 29°C$.

As indicated previously that at the thermal comfort range between individuals' comfort sensations of -1 and +1; air temperature (T_a), at operative temperature (T_o), and at equivalent temperature (T_{eq}), more than 80% of occupants were comfortable, which is slightly higher than those predicted by the PMV/PPD model in ISO-7730 (1994), i.e. that in which 75% of subjects are expected to be comfortable (see Chapter Three at section 3.4.3.2).

Concerning this aspect several thermal comfort studies, particularly those conducted in warm humid environments, are summarised in Table 6.2. below.

The table indicates that in thermal chamber study, simulation or field studies in the different countries but in the same warm humid regions were found a similar thermal comfort range.

These comfort ranges give a standard range of thermal comfort for Bali between 24.2 and 28.2 °C, are accepted and encompass the temperature range specified in the book given by the researcher.

This can be easily achieved in the traditional compound dwelling pattern by using natural ventilation, but the comfort standard will be more difficult to achieve in a compact dwelling.

Researcher	Date	Type of Study	Country/Regions	Group	Neutral Temperature Comfort Range (°C)
Mom	1937	Thermal Chamber	Bandung Indonesia	Indonesian, European	26.0
Webb	1950	Field Study	Singapore	Malay, European	26.2 ET
Ellis	1952	Field Study	Singapore-Hongkong	No data	26.1 ET; 30.0 Ta
Ellis	1953	Field Study	Singapore	Eurasian, Indian Chinese, Malay	22.0-22.5 ET 24.5-27.8 Ta
Ballantyne	1967	Field Study	Port Moresby	Caucasian	25.6 Ta
Ballantyne	1979	Thermal Chamber	Port Moresby	Melanesian, Caucasian	25.6 Ta, 25.0 Ta
Bush	1988	Field Study	Bangkok, Thailand	Thai	28.5 ET
Santosa*	1988	Field Study	Surabaya, Indonesia	Indonesian	27.1 Ta
De Dear	1990	Thermal Chamber	Singapore 1	Singaporean	25.4 Ta
De Dear	1990	Thermal Chamber	Singapore 2	Singaporean	Lower 27.6 Ta, Upper 27.9 Ta
De Dear	1990	Field Study	Singapore 3	Singaporean	28.5 OT
Karyono	1993	Field Study	Jakarta Indonesia	Indonesian	26.4 Ta, 26.7 To, 25.3 EqT
Antaryama*	2000	Field Study and Simulation Study	Bali Indonesia	Indonesian	27.6 °C.Tao 26.2 °C Tn Lower 24.2 °C.Tcr Upper 28.2 °C.Tcr

Table 6.2. Thermal Comfort Warm Humid Climate Studies
Sources: T.H. Karyono (2000), except M. Santosa * (1988) and I.G.N. Antaryama * (2000).

6.4.2. Thermal Comfort Building Performance

6.4.2.1. Thermal Comfort In Dwellings

Concerning thermally comfortable dwellings in the warm humid climate of Bali, the study indicated that the compound dwelling pattern offers greater thermal comfort than that available in the compact dwelling design.

A previous thermal comfort study in Bali looking at both the compound dwelling (e.g. traditional dwelling) and the compact dwelling (e.g. contemporary dwelling) have also drawn a similar conclusion as follows;

> *"As revealed from both the field and the simulation studies, thermal performance of the traditional dwellings is better than that of contemporary houses."*
>
> Antaryama, 2000.

Only during the cool months of the year are thermal comfort conditions of both the compound and compact dwellings found to be thermally acceptable, although the latter are less satisfactory.

The annual thermal comfort performance of compact dwellings shows greater internal overheating than compound dwellings.

In the warm humid climate, thermal discomfort is endemic, particularly during the day and in the afternoon (Karyono, 2000; Antaryama, 2000).

With reference to the Antaryama (2000) study, it is noted that the compound pattern provides constant ventilation and little internal heat gain. Using building materials of high thermal capacity in the compound dwellings can provide good protection from both solar radiation, and high temperatures.

During the hot months, however, under a small range of diurnal temperatures, the long time-delay of these materials often prolongs the periods of overheating from the day well into the night.

Conversely, the rapid response of building materials employed in compact dwellings appears to be more effective in encouraging direct heat dissipation (see Appendix-V).

However, this does not much help the overall thermal performance of the dwelling, because ventilation in the compact dwelling is so much lower than that in the compound dwelling.

As observed from the study, from the solar heat gain point of view, building orientation does not much affect the overall thermal performance. This is largely because both walls and windows are generally well shaded.

Moreover, in an area of low latitude, solar radiation from the north and south, particularly in the months of June and December, can have an impact roughly equal to that from the east and the west.

Building orientation does, however, exercise a significant influence on the degree of ventilation that can be achieved in the dwellings.

Owing to the complex interaction of many different variables, the effect of dwelling type on thermal performance is difficult to measure precisely.

However, the results of the study reveal that thermal performance of dwellings deteriorates as the number of exposed external wall increases.

The study suggests this is mainly a consequence of the decreased ventilation associated with larger exposed walls.

Nevertheless, compact dwellings types are able to achieve a thermal performance comparable with that of compound dwellings by arranging their exterior in such a way that a long length of exposed wall can be preserved.

The indigenous design solutions, through the dispersal of activities into separate rooms, can be considered appropriate to warm humid climate conditions. In this respect, to a certain degree the compound dwelling design can serve a function similar to the indigenous dwelling.

6.4.2.2. Thermally Responsive Dwelling Form

Studies of climatic response by dwelling forms have indicated that the climatic aspects of the compound pattern (i.e. traditional dwelling) prove to be more responsive to the local climate than those of compact design (i.e. contemporary dwelling) (Antaryama, 2000; Karyono, 2000; Funo and Silas, 2000; Davey 1991; Waterson 1990; Supic, 1982; Koenigsberger, 1974; Rapoport, 1969).

> *"This is shown by the compound dwelling cooling degree-hours (<250 Kh), which is typically lower than that of contemporary compact dwellings (>350 Kh)."*
>
> Antaryama, 2000.

In the compound dwelling, the high level of wind exposure, permeability, and external penetration, coupled with low density are wholly responsible for the high ventilation rate in the dwelling, and hence the low cooling degree-hours.

In the compact dwelling, by contrast a reduction in the level of all the aspects above is believed to give rise to the high cooling degree-hours.

Since wind exposure and permeability generally tend to be lower and density tends to be higher in compact dwelling, their cooling degree-hours tend to be higher.

The increase in fenestration found in the compact dwelling, as compared with the compound dwelling, also contributes to their poorer thermal performance, although the contribution is small owing to the continuous shading.

As Antaryama (2000) found, although cooling degree-hours in the compact dwelling are likely to increase from 450 Kh (mean) in 0-wall to 650 Kh in 3 attached-wall types, the less frequent use such sprawling shapes in compact dwelling types has allowed these dwellings to obtain similar thermal performance to 0-wall attached dwellings.

This case is different from the compound dwelling, whose configuration and climatic aspects are all almost relatively uniform (see also Appendix - VII).

In the characteristics of both compound and compact dwellings, permeability can be considered the most significant factor governing thermal performance.

Yet because this is actually related to ventilation, other aspects such as wind exposure, external penetration, density and orientation need to be considered along with permeability, as they are all interrelated.

6.4.3. Thermal Comfort Performance of the Dwellings

6.4.3.1. Thermal Comfort Performance of the Naturally-Ventilated Dwelling

> *"In the warm humid climate, growing concern over the future global environmental problems and a possible drain on energy resources, requires to place importance on development of the passive dwelling design, especially natural ventilation technology."*
>
> Funo and Silas, 2000.

In the contemporary compact house, the thermal performance of the dwelling is only relatively good during the cool months between June and September, as indicated in the low cooling degree-hours and long periods of comfort.

In the contrary, Antaryama (2000) described the thermal comfort performance of naturally ventilated dwelling, especially for the compound traditional dwelling:

> *"In the traditional dwelling, the first impression gained was that the heating degree-hours range was low, where the dwelling experienced comfortable conditions for at least 10 hours in the day, and overheated periods were generally short, less than 4 hours. The most comfortable conditions were generally experienced between late evening and early morning."*
>
> Antaryama, 2000.

In summary, it can be concluded that indoor conditions particularly during the cool months (except during the afternoon, see Chapter Three section 3.4.3.3) are acceptable in both compound and compact dwellings, and this indicates that those dwellings have successfully modified the outdoor conditions to provide greater comfort for the occupants. With respect to annual performance, the compound dwelling clearly shows the beneficial relationship between building design and thermal comfort performance.

The overall thermal performance of compact dwellings reveals that in terms of the influence of dwelling type on thermal performance, the cooling degree hours for the dwelling show a tendency to increase over 0-wall to 3-wall attached types.

A similar tendency is found with respect to the total overheating and indoor comfort periods in compact dwellings. In the 0-wall attached type, overheating conditions generally occur. In the 1-wall attached and 2-wall attached types the periods are wider, extending towards higher values. Finally, in the 3-wall attached dwelling there is a marked shift upwards, with the dwelling experiencing overheating conditions. Since none of dwellings suffers from cooling, the indoor comfort period among the dwelling types is more or less that observed for overheating (see also Appendix - VII).

Hence, 0-wall and 1-wall attached houses will experience relatively long periods of comfort, while the period will decrease sharply for 2-wall and then 3-wall attached types.

This analysis shows that the thermal performance of the compact dwelling will deteriorate as more of the external walls of the building are set against the boundary of the plot.

As has been suggested, this tendency has something to do with ventilation in the dwelling. An increase in the number of wall attachments will reduce the area of openings, which in turn will reduce the ventilation rate. Since ventilation is one of the primary means of heat dissipation in warm humid climates, any reduction will always result in heat build-up in the dwelling.

Nevertheless, since wall area by definition does not necessarily imply a complete contact of the whole area of the external wall, there will always be scope for obtaining larger opening areas in a dwelling with a greater number of wall attachments.

Consequently, the less-compact dwelling of either 2-wall or 3-wall attached type can sometimes achieve a performance comparable with that of dwellings in the 0-wall and 1-wall attached types.

In terms of cooling degree-hours and overheated conditions, the compound dwelling has lower figures than the compact house. *"The former has cooling degree-hours of 250 Kh and overheating periods of 10 hours, while the latter has value above 300 Kh and 20 hours"* (Antaryama, 2000).

Consequently, the compound dwelling will experience acceptable conditions for a much longer period, e.g. 14 hours rather than that compact dwelling at 4 hours.

In general, internal conditions in compound dwelling tend to be much closer to the outdoor conditions than those in compact dwellings, indicating that the design has successfully control over heat build-up. The split wall-roof construction, the thermally heavyweight building materials, good orientation and an abundance of surrounding space all help in reducing overheated conditions. Overheating is noticeable only in the exceptional case, where the ventilation rate is low.

In the compact dwelling, lack of ventilation often overcomes the advantages of thermally appropriate building material, making it difficult for the heat to be dissipated. The cause of such problems is related either to the size and positioning of openings, poor orientation or limited surrounding space. Nevertheless, where there is high induced ventilation, the thermal performance of a compact dwelling may approach that of a compound dwelling.

It is quite clear from the analysis that accepted thermal performance using natural ventilation can be better achieved by the compound dwelling than the compact dwelling.

However, studies of the application of natural ventilation cooling system in a hot and humid climate show that by applied natural ventilation, *"the cooling system could only drop the maximum indoor air temperature from the maximum outdoor air temperature by 1.12°C"* (Sukanaya, 1999).

According to the standard for thermal comfort, a thermally comfortable dwelling can be accepted as one where 80% of the occupants are satisfied.

Nevertheless, thermal comfort performance of the naturally ventilated dwelling is lower than that of standard thermal comfort performance.

This is indicated from the comfortable sensation of the occupants, where 50% of occupants expressed discomfort on the warm side, and less than 50% were feeling slightly warm but comfortable in the dwelling (Figure 6.3).

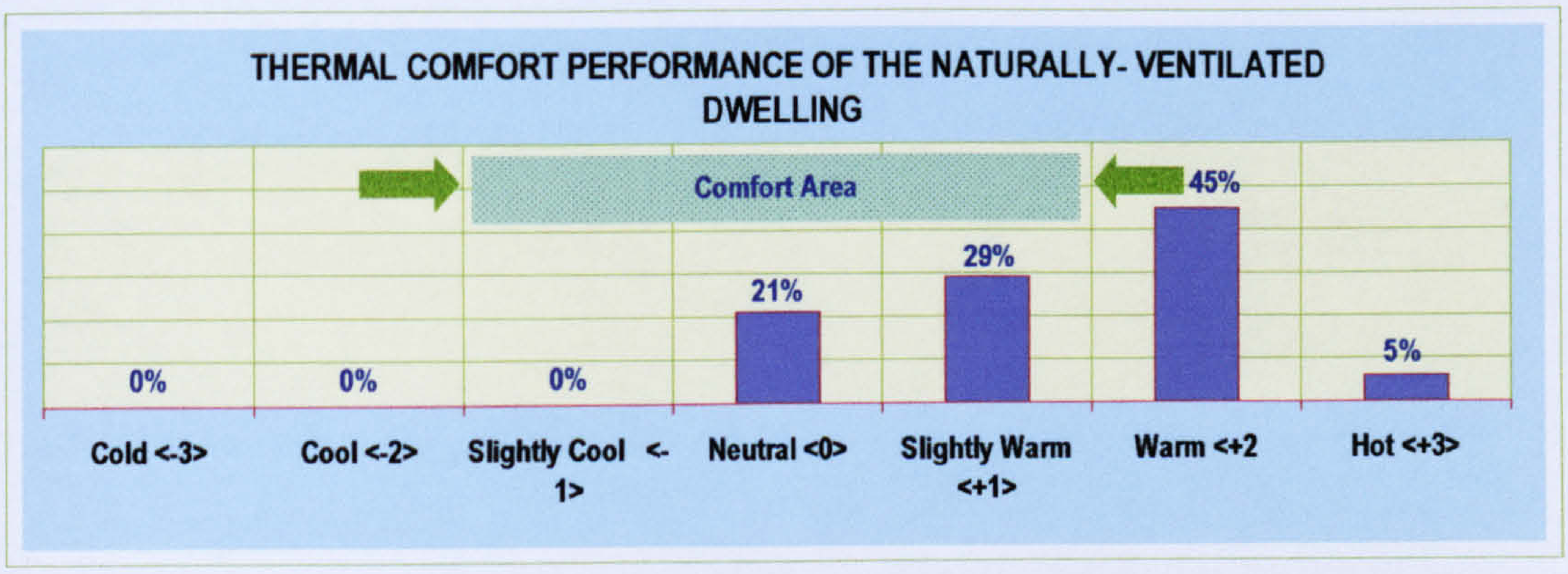

Figure 6.3. Thermal Comfort Performance of the Naturally-Ventilated Dwelling (Karyono, 2000).

6.4.3.2. Thermal Comfort Performance of the Hybrid Dwelling

The dwelling which combines natural-ventilation and air-conditioning (hybrid) allows a greater proportion of occupants to be thermally comfortable, and this provides comfort with an average air temperature of 4°C lower than those in a naturally ventilated building.

Figure 6.4. shows thermal comfort performance of the dwelling with combined natural ventilation and air conditioning in the warm humid climate, with 90% of the occupants feeling comfortable and 10% feeling uncomfortable (Karyono, 2000).

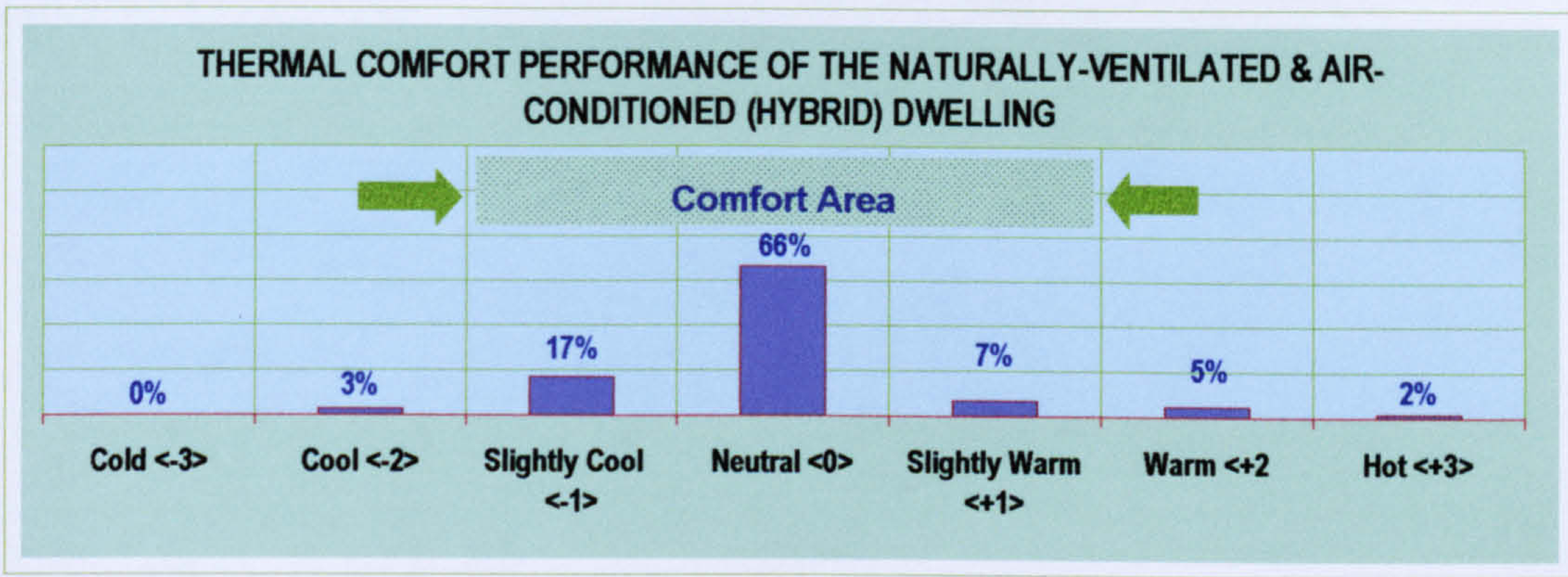

Figure 6.4. Thermal Comfort Performance of Combined the Naturally-Ventilated & Air-Conditioned (Hybrid) Dwelling (Karyono, 2000).

This result is the greatest achievement for thermal comfort performance, as this is higher than the standard comfort range, *"where 80% of people are supposed to be satisfied"* as described by Markus and Morris (1990).

This study is also supported by the previous study which suggested that, *"the cooling techniques known as hybrid cooling alternative appears to be effective, and in this hybrid indoor environment it was found that most of the occupants were feeling comfortable, while few of them were feeling discomfort"* (Mat, 1993; Grace, 1997).

6.4.3.3. Thermal Comfort Performance of the Air-Conditioned Dwelling

In the design study for acclimatisation house in warm humid areas, Adamson and Aberg (1993) give the following recommendations to achieve comfortable dwelling conditions when installing air conditioning.

In order to improve the indoor climatic conditions, the floor, wall and ceiling should be thermally insulated to reach the range of comfortable air temperature, and rooms must be airtight to reduce energy consumption for cooling.

In practical terms, the rooms with air conditioning have to be made particularly weather tight, windows adjusted and carefully weather-stripped, joints between windows and walls, wall and ceiling or roof sealed and the ceiling insulated with a carefully applied vapour barrier on the upper side.

The indoor temperature thermal comfort performance of an air-conditioned dwelling is influenced by the building design and building orientation. In this respect, Karyono (2000) described:

> *"An air-conditioned dwelling that has the north-south orientation and had a maximum protection from the sun possesses quite low indoor temperature, between 23 and 25°C."*
>
> Karyono, 2000.

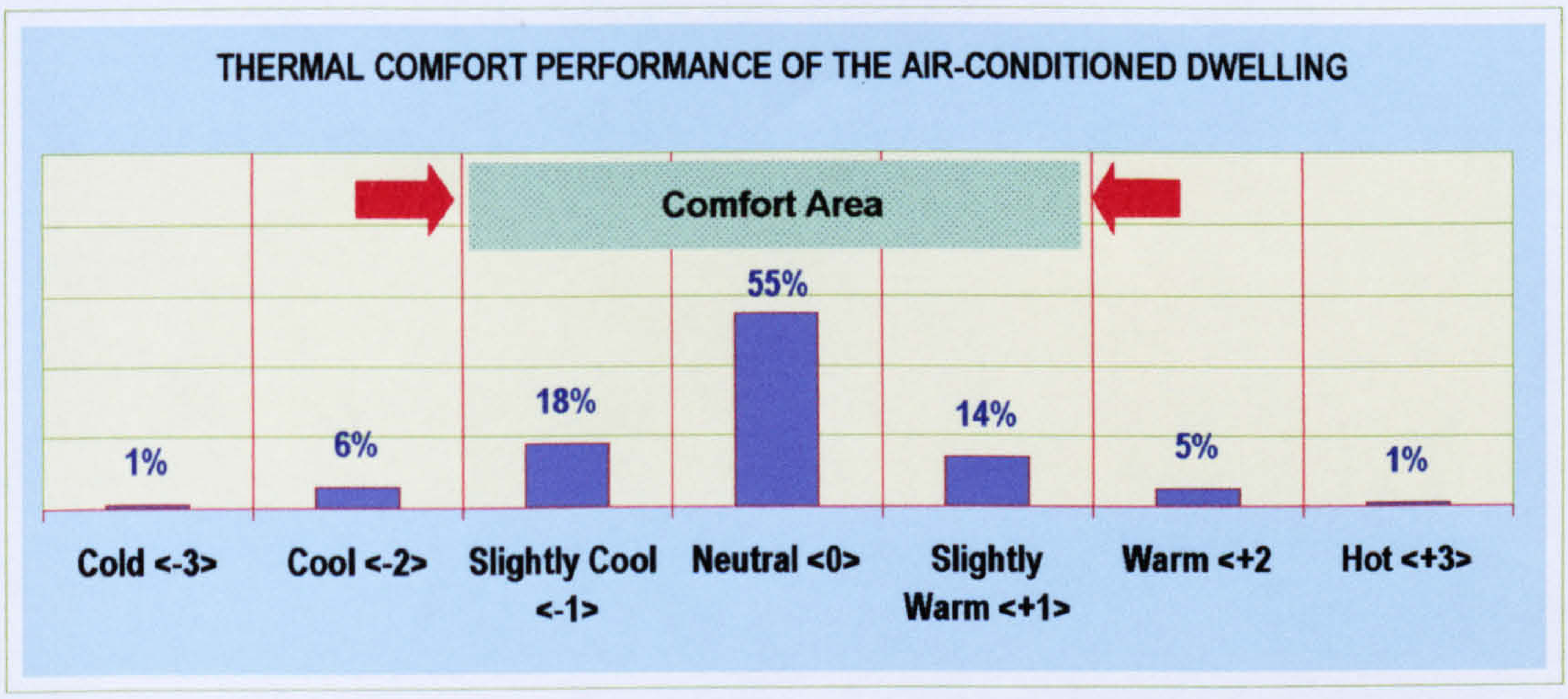

Figure 6.5. Thermal Comfort Performance of Air-Conditioned Dwelling (Karyono, 2000).

Figure 6.5. above shows thermal comfort performance for a dwelling with air conditioning and where most of the occupants, more than 85%, are feeling comfortable and few of them, less than 15%, feeling discomfort.

6.4.3.4. Summary of Thermal Comfort Performance of the Dwellings

A conclusion could be drawn from the analysis above that the occupants in the three different cooling strategies have three different comfortable conditions, and hence, there are three characteristics for thermal comfort performance of the different dwellings.

The persons in the state of 'just above and just below neutral' who have thermal comfort sensation between 'neutral' (0) 'slightly cool' (+1) and 'slightly warm' (-1), are still within the range of thermally comfortable, which means they are in the state of being 'comfortably cool and comfortably warm'.

Between those thermal comfort performance characteristics, Figure 6.6. indicates that on neutral temperature comfort range, the greatest comfortable condition is found in the hybrid dwelling (66%), the second is the air-conditioned dwelling (55%) followed by the naturally-ventilated dwelling (21%).

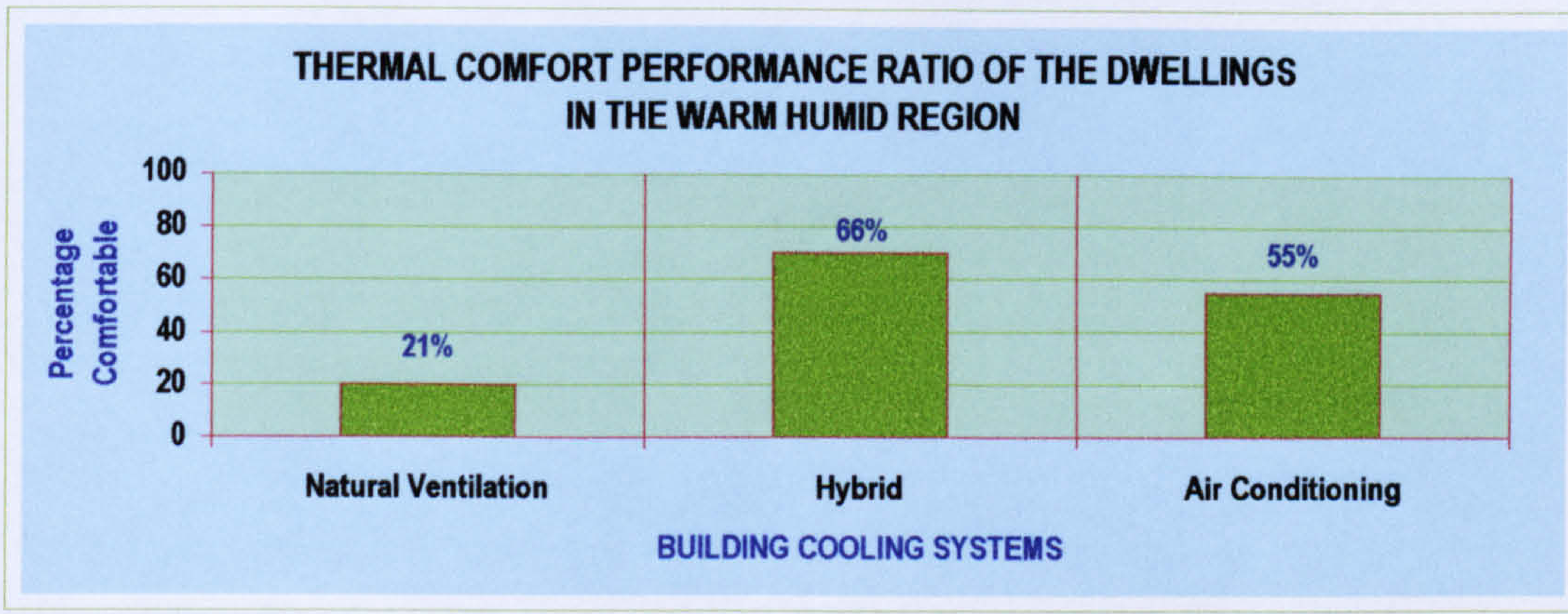

Figure 6.6. Thermal Comfort Performance Ratio of the Dwellings in a Warm Humid Region

However, the highest number of occupants feeling discomfort is found in the dwelling with natural ventilation, about 50%, with 13% in air-conditioned. Therefore, only 9% of those in hybrid dwellings express being in an uncomfortable condition.

6.5. ECONOMIC ANALYSIS

In an economic analysis related to the energy consumption of the dwelling (see section 6.3 above), it is clear that the naturally ventilated dwelling has acceptable efficiency.

In respect of both thermal comfort performance and energy efficiency nevertheless, the hybrid dwelling is appropriately strong.

However, air conditioning is another economic stress that has to be taken into account for the comfortable dwelling.

Referring to the previous chapter (Chapter Five at section 5.7.9), the average energy cost in a natural-ventilation dwelling can reach US$ 40 monthly or annually, US$ 480.

The hybrid dwelling expenditure can be two times that of the naturally-ventilated, cost of US$ 80 monthly and US$ 960 annually, while the air-conditioned dwelling expenditure can be five times that of the naturally-ventilated cost, at US$ 200 monthly and US$ 3,000 annually (Figure 6.7).

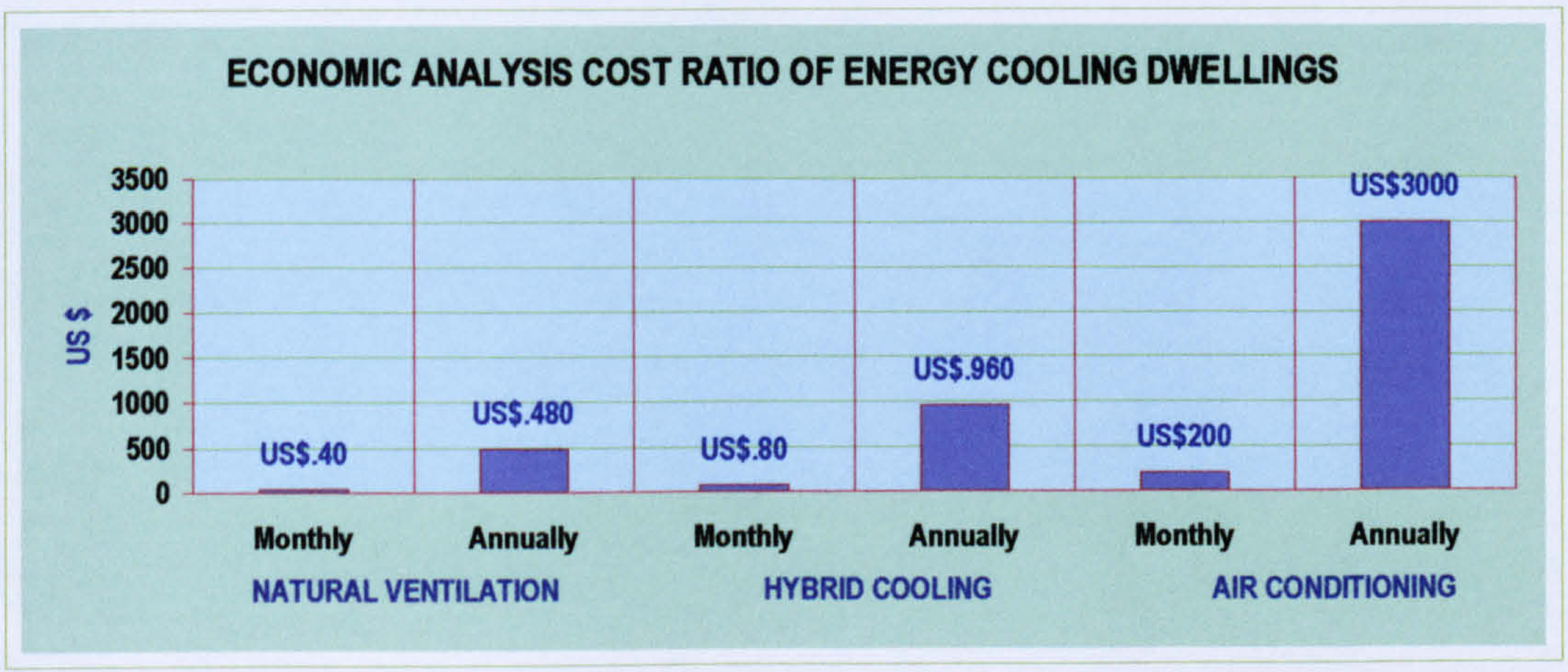

Figure 6.7. Economic Analysis Cost Ratio of Energy Cooling Dwellings

This energy cost can still be reduced, particularly in the hybrid system, by only switching on air conditioning at times when absolutely necessarily.

However, comfortable conditions in the dwelling could be extended when the energy cost of air conditioning becomes more affordable to the homeowner.

To achieve a comfortable dwelling in general, however, these energy costs are between 20% and 40% of the average income at US $ 2,350 per annum.

For cooling the dwelling as a whole, it was found by the research that any expenditure greater than 20% was regarded as too high a cost.

In this respect, there is a need for strategies to make efficient use of energy by dwelling designs which can mitigate the warm humid climate, achieving comfort and energy conservation.

6.6. CONCLUSION

Human thermal comfort, especially in a warm humid area is a complex matter.

Taking thermal comfort into account in the dwelling design is absolutely necessary, particularly when considering the natural ventilation and air conditioning that are used to deal with the stressful high heat and humidity experienced by those who live in warm humid climates.

As far as comfortable dwelling indoors is concerned, the thermal comfort standard in the warm humid climates is in the range shown in Figure 6.8.

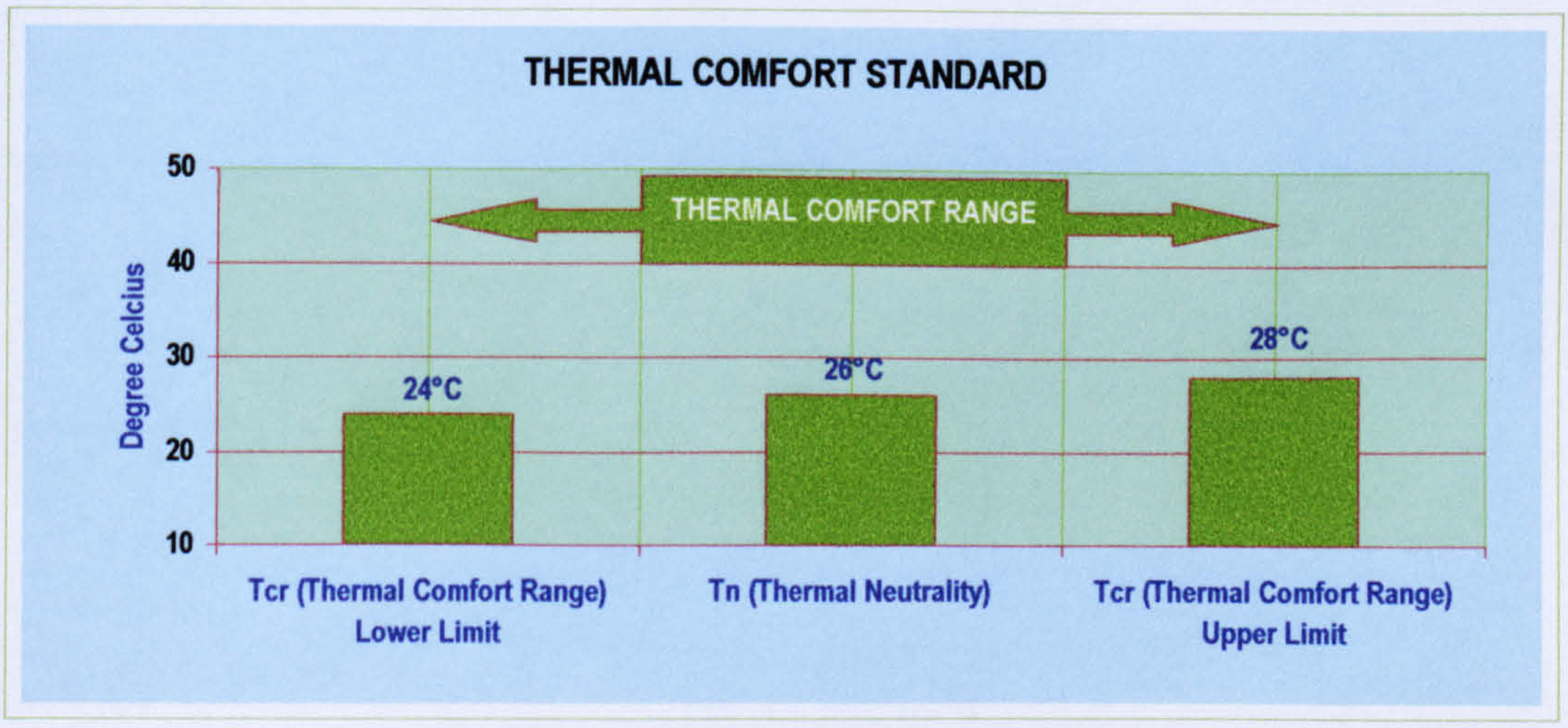

Figure 6.8. Thermal Comfort Standard

In a warm humid climate, the high air temperature and high humidity impact on indoor thermal conditions create an uncomfortable dwelling and cause inefficient energy usage patterns within the house.

Comfort of the occupants in a dwelling can be achieved by one of the cooling techniques which follow:

- Naturally-ventilated dwelling, a dwelling in which full natural ventilation is applied.
- Combined dwelling, a dwelling which combines natural ventilation and air conditioning or "hybrid", which can use natural ventilation as much as possible or use air conditioning when necessary.
- Air-conditioned dwelling is a dwelling that has full air conditioning installed.

For the thermal comfort and energy consumption perspective, the study reveals that comfortable conditions can be achieved without unnecessary cooling in air-conditioned dwellings, by integrated building design; using locally produced materials suitable to the warm humid climate conditions, and combining passive-active cooling technology.

In terms of cooling the buildings, the naturally-ventilated dwelling experienced a high air temperature of 30°C, which on average was about 4°C higher than that in hybrid and air-conditioned buildings.

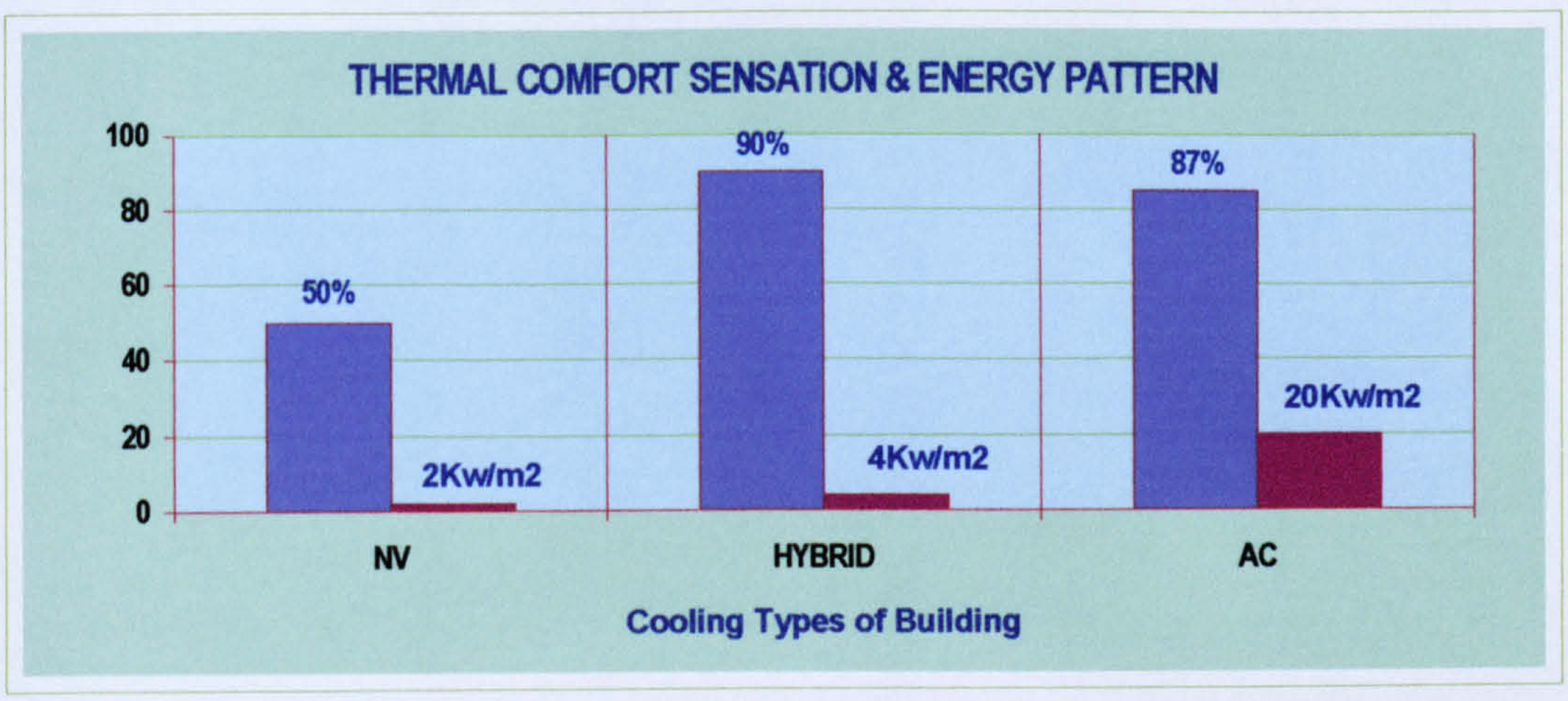

Figure 6.9. Thermal Comfort Sensation of Occupants & Energy Pattern in the Buildings

The significant achievement in thermal performance of the dwelling can be indicated from the greater sensation of comfort experienced by the occupants of the dwelling, and the energy cooling efficiency for comfortable dwellings (Figure 6.9).

This is further evidence that a comfortable dwelling can be achieved using relatively small energy consumption, if the building is suitably well designed to modify the effects of the climate.

In respect of both thermal comfort performance and energy efficiency, the hybrid dwelling is remarkable. The hybrid-conditioned dwelling allows a greater proportion of occupants to be thermally more comfortable than those in the naturally-ventilated dwelling, and slightly more comfortable than those in air-conditioned dwelling while having less energy consumption.

Despite the most comfortable conditions being found in the hybrid dwelling, that is with 90% of occupants feeling thermally comfortable, the energy consumption in this dwelling is only one-fifth (20%) of the energy consumption of the air-conditioned dwelling.

However there is still a need to reduce energy consumption further, to enable its greater affordability.

The dwelling design is another consideration that influences indoor thermal comfort performance. The dwelling envelope should be thermally insulated to promote temperatures within the standard level of comfort range, and rooms made should be airtight to reduce energy consumption especially when planning for air conditioning.

As many researchers have found previously, the traditional compound dwelling has better thermal performance than that of compact contemporary house. The traditional compound dwelling of Bali clearly offers a comfortable adaptation to the warm humid climate over the year.

In the contemporary house, the thermal performance is only relatively good during the cool months between July and August, as indicated in the low heating degree-hours range, the better cooling degree-hours and long period of comfort. Otherwise, the remaining months of the year are mostly overheated, with the cooling degree-hour showing a tendency to increase from the less compact house (e.g. 0-wall attached type) to the more compact house (e.g. 3-wall attached type). The use of internal solid wall subdivisions in the contemporary dwellings can prevent cross ventilation from taking place, resulting in low ventilation rates and a subsequent built up of heat. Hence, there is the possibility of an increase in indoor temperature.

In this regard, refer to the house types in Bali which were commonly designated as above, it is recommended to design more less compact houses.

During the cooler months, the internal conditions of both compound and compact dwellings are found thermally acceptable, although conditions in the contemporary house are generally less satisfactory.

The effectiveness of better thermal capacity of building materials in providing an adequate resistance to overheating and eliminating high humidity, are only under conditions where there is continuous airflow and little indoor heat build-up in the dwellings. Otherwise, the long time-delay of these materials often prolongs the periods of overheating well into the night.

In terms of annual thermal performance the compact house is found to have greater problems with internal overheating, becoming extremely hot on occasions; likewise, uncomfortable conditions in both dwelling types may be endemic at night and during the day. This creates difficulties, especially in the compact dwelling where airflow is so much less than that in the compound dwelling.

Due to the complex interaction of many different variables in the study, the impact of dwelling type on thermal performance is difficult to measure precisely.

However, the study indicates that there is a correlation between dwelling type and thermal performance. Regarding the matter of solar heat gain, the building orientation has little influence on the overall thermal performance of the dwelling, however, it has great impact on the natural ventilation.

North-south alignment of the dwelling may contribute to their high cooling degree-hours, particularly where buildings are otherwise well designed.

However, orientation of unprotected glazing seems likely to contribute to the higher energy consumption in air-conditioned buildings.

The indigenous design solutions, through the diversion of activities into separate spaces in the compound pattern dwelling design, must be considered appropriate for warm humid climate conditions.

From the forgoing conclusions, despite new dwellings being designed to achieve comfortable conditions, other recommendations are required to improve upon the current compound dwellings and compact dwellings that have been built.

For those indigenous compound dwellings that have already been built, it is necessary to keep them sustainable, since there is no land available to put replacements on a new dwelling scheme.

This kind of dwelling is unlikely to be new-built again, owing to the high cost of land and it is become unaffordable to most people. The recent, mass dwelling developments have no space for buildings of this type.

They can be preserved by a considerate, building conservation strategy for traditional dwellings, while paying appropriate respect to them in the new dwelling schemes.

As for the existing compact dwellings, modification can be made by encouragement to install openable windows for natural cross-ventilation, and improving the insulation of the building envelope when air conditioning has to be installed to achieve suitable comfort levels.

In this regard, application of the basic principles of thermal comfort designed for a warm humid climate is recommended, when people need to refurbish their current dwellings.

Finally, by conserving traditional houses, improving compact homes and including compound hybrid dwellings in new developments are all recommended to achieve efficiency and better thermal performance of residential properties in the warm and humid climate of Bali, Indonesia.

Chapter Seven

THERMAL PERFORMANCE ANALYSIS COMPUTER SIMULATION

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Chapter Seven

THERMAL PERFORMANCE ANALYSIS COMPUTER SIMULATION

7.1. TECHNICAL BACKGROUND

There are two popular methods used to study thermal performance; the first is the model experiment, and the second is the computer simulation. In this regard, Papakonstantinou et.al. (2000) recognised:

> *"The latter has many advantages, for example flexibility in shaping the house layout and in setting the exact parameters of thermal performance."*
>
> Papakonstantinou et.al. 2000.

This chapter draws attention to the physical procedures governing air conditioning in a dwelling through the description of a computational method. As Stevens (1990) defined the simulation:

> *"Simulation is a means of predicting the performance consequences of a set of design decisions."*
>
> Stevens, 1990.

Furthermore, Shaviv (1984) noted the thermal performance simulation:

> *"Since the prediction of the thermal performance of a building generally involves an interplay between a large number of parameters and complex calculations, it is normal that computers should be used to perform such tasks in order to obtain quick and accurate result."*
>
> Shaviv, 1984.

As has been previously discussed in the research methodology, the computer simulation method offers three major advantages (see Chapter One section 1.4.2).

- Firstly, the computer allows predictions to be readily made for any variation or alteration in building-related parameters.
- Secondly, it allows the effect of certain variables.
- Finally, a computer simulation allows predictions to be made not only for a particular month but also for the entire year.

Using simulation software, by inputting data of the latitude and altitude locations of Bali into the program, the whole year monthly weather data could automatically be available for computer simulation.

Therefore, *"thermal building simulation software generates meteorological files in thermal comfort, energetic evaluation studies"* (Adelard, et.al. 2000).

In this respect many researchers confirmed, in the specific case of the single-sided ventilated buildings, the results have been presented and are physically plausible in good agreement with available experiments (Kiranoudis et.al. 1999; Markatos et.al. 1999; Schaelin et.al. 1992; Markatos 1983).

The work demonstrates that numerical solutions for such ventilation problems can be obtained quickly and economically.

It is concluded that computational results are realistic and in agreement with experimental measurements, and that computer simulations are now capable of assisting the designer to optimise ventilation in buildings.

In addition, *"they can dictate new designs from the thermal comfort point of view"* (Papakonstantinou et.al. 2000).

Thermal performance studies that use computer simulation are of two kinds: those using simplified geometrical models (Gupta 1984, 1987; Wilson, 1976) and those of real buildings (Hyde and Docherty, 1997; Malaina and Sharples 1996; Pearlmutter and Etzion, 1993; Tuner and Szokolay 1982).

The former often involves models that may readily be altered to predict their responses or performances under given conditions. The latter are generally intended to provide an appraisal of various aspects of a building (e.g. forms and materials). In terms of thermal performance, Szokolay (1980) further described:

> *"Thermal prediction is normally carried out for specific ends, e.g. to estimate the required heating or cooling capacity of an installation such as air conditioning; to determine the indoor temperatures in a non-conditioned building under periodic outdoor conditions; and to calculate indoor temperature when there is some degree of heat removal, but the cooling capacity is insufficient to maintain a constant indoor temperature."*
>
> Szokolay, 1980.

Moreover, Bromberek (1995) evaluated the thermal building simulation software.

> *"According to the literature, there are over 300 thermal simulation programs is existence, but only a few of them are actually readily available to designers."*
>
> Bromberek, 1995.

There would appear to be several reasons for this: most thermal simulation programs are used for air conditioning load calculations or sizing mechanical plant, and are intended primarily for, and are hence more familiar to, engineers rather than architects; some of the programs involve multiple and complicated calculations as well as requiring quite detailed input data, making them very expensive and time consuming to run. The capability of some of the systems, for this reason, has been limited to large computers such as mainframes or powerful workstations. These programs adopt various calculation methods such as the response factor method, matrix method, finite difference method and the admittance procedure.

References on computer programs for architects such as those by Ahmad (1998), Reynold (1993, 1980), Szokolay and Ritson (1982), Clarke (1979), Thompson et.al. (1979), and Forwood (1977), and references on thermal performance studies such as those by Malaina and Sharples (1996), Bromberek (1995), Pearlmutter and Etzion (1993), and Vakalo and Abdou (1990) give brief descriptions of some of the thermal simulation programs which have been developed in different countries (e.g. UK, US, Israel and Australia).

A researcher Antaryama (2000) stated that the selection of an appropriate program for building design or research is really a question of overcoming the obstacles that are posed by the majority of programs that are currently available. These issues include the applicability of the program for various users, and for various ranges of thermal performance problems and types of buildings. Williamson (1983) added:

> *"It includes the operational characteristics of the program, such as computer requirements memory, processor, data necessary, ease of operation and operating cost; and program precision, i.e. accuracy of the prediction."*
>
> Williamson, 1983.

However, *"the growing use of computers in such fields has led to a development of more user-friendly, cheaper and more importantly, reliable programs"* (Ahmad 1998), all of which were evaluated.

Therefore, the Hevacomp Design Database Version 15.00 falls into this category.

7.2. DESCRIPTION OF ANALYSIS TECHNIQUES

The main aim of this chapter is to research and produce a thermally efficient dwelling design for the warm humid climate of Bali, in relation to air-conditioned building energy consumption referring to the space design, material and insulation as well as the duration of occupancy of the dwellings.

The software Air Conditioning (A/C) Energy Version 15.00 (Hevacomp, 1998) is used to simulate the A/C energy consumption of the houses.

Air conditioning energy consumption of the dwellings is computed on a monthly basis. By specifying the first and last months for calculation, January to December, gives the energy consumption for the whole year. Fresh air load on the central plant can optionally be included in the load calculation.

In relation to the outside weather, dry and wet bulb temperatures and percentage of sun available on these days will automatically be computed for each month of the year from weather data, for the calculation.

Annual A/C energy is computed by considering the month to be made up of a combination of the three-day types for each month: peak, average and minimum days. Fresh air will be supplied to all included rooms using one of the air change rates; 0.5 air changes per hour for the hot months and 1.0 air changes per hour for the cool period.

Evaluation of the thermal performance of buildings is made in terms of indoor temperature, which includes the use of air conditioning. This may take the form of plots of temperature profiles, indoor temperature matrices, the thermal habitability index and cumulative overheating and cooling (Szokolay, 1993, 1983).

The first and second are in graphical form, while the last two are measures:

- *"The first, which is the most widely used method, is obtained by plotting indoor temperatures, outdoor temperatures and the comfort range against time in a single graph.*
- *The second is constructed by arraying indoor temperatures in a 12 month x 24-hour matrix, on which the comfort range contours or band of temperatures are also superimposed. The indoor temperature matrices are usually employed to provide such as necessary information as the time and duration of cooling and overheating (i.e. when indoor temperatures fall below or exceed the comfort limits).*
- *The third is established based on the number of hours when indoor temperatures exceed or fall below the range of comfort temperature, and on cumulative temperature deficit and excess. Two sorts of indoor temperature data are considered to the lower limit, and to the upper limit of comfort temperature.*
- *Finally, the fourth is obtained by summing up any temperature deficits and excesses for each hour of the day, calculated relative to the lower and upper limits of comfort temperature respectively (expressed in degree-hours)".*

Antaryama, 2000.

In this research, the dwelling samples are taken from the standard contemporary house type built by the national housing authority in Indonesia.

The dwelling type is a common house, which is of 36 m^2 and contains two bedrooms, living room, kitchen and bathroom. This dwelling was designed based on the occupancy of a couple with two children, as the national household type for Indonesia.

"This group represents 60% of the total population who live in urban areas of Indonesia."

Indonesia National Housing, 1996.

For a contrast, a large two-storey dwelling of 240 m^2 which is typical of that required by a few exclusive people has been considered. This large dwelling has been included because this represents the type of design demanded by the exclusive real estate industry. The simulation will predict the energy consequences of using this size of dwelling.

The energy consumption of these dwelling types was tested over a range of energy conservation strategies:

- 7-hour occupancy.
- 50 mm of insulation in wall, floor insulation and ceiling insulation.
- 3-hour occupancy.
- Window position and shading devices to eliminate or reduce direct solar gain.

The 7-hour occupancy assumes that the occupant uses the air conditioning in the dwelling from 17:00 – 24:00 p.m. for common rooms and bedrooms, where there is peak occupancy and a likelihood of overheating stress occurring.

The 3-hour occupancy term covers from 19:00 – 22:00 p.m. for the living room and from 22:00 – 24:00 p.m. for bedrooms and refers to an energy conservation measure when air conditioning is only used at a certain time, when absolutely necessarily.

The insulated and uninsulated walls, thermal mass floor and low mass floor, ceiling insulation and uninsulated ceiling will be discussed on detail on the theoretical model of analysis.

For the standard design, to reduce energy, the window orientation is North - South. The standard design window sizes for the living room are 3m x 2m maximum and for the bedrooms 1m x 1.2m. The former was designed for the architectural front elevation, and the latter to create privacy for the dwelling.

7.3. THEORETICAL MODEL OF ANALYSIS

7.3.1. Construction of Model

The models are taken from the current dwellings that are commonly constructed in Bali similar to the normal standard dwelling type in Indonesia.

Figure 7.1. is a small, 36 m^2 dwelling type on a 108 m^2 plot, has two bedrooms, a living room, kitchen and bathroom. Sections of the dwelling are presented in Figure 7.2. This dwelling is a one-wall-attached house (semi-detached house) design where one of the external walls is attached to the neighbouring house at the plot perimeter (see Chapter Six section 6.1).

Each room of this compact dwelling has window opening for natural ventilation. The living room which faces out onto the veranda has a larger window size than other rooms within the house, the bedrooms and kitchen have normal window sizes, while the bathroom has the smallest window ventilation combination.

This dwelling has a flat ceiling at 3-metre standard height and is characterised by the 30° slope pitched roof, with 1 metre overhang to shade the exposed walls, exposed doors, and windows.

Figure 7.3. (Ground Floor) and Figure 7.4. (First Floor) is a large dwelling of 240m^2 on a 294m^2 plot. The property has several rooms downstairs such as living room, family room, dining room, kitchen, bathrooms, garage, veranda and maid's room.

The first floor has a master bedroom, other bedrooms, family room, balconies and bathrooms. This large dwelling is a two-wall-attached house (side-to-side house) design, where two external walls at right angles are attached to the neighbouring house at the plot perimeter (see also Chapter Six section 6.1).

Figure 7.3. (Ground Floor) is similar design configuration to the small dwelling. Rooms in this contemporary dwelling have a large, exposed window opening for natural ventilation and doors with a typical ventilation feature on the top of each door for better airflow performance. The ground floor rooms facing out to the verandas and gardens, living room, family room, dining room, and kitchen have large size windows.

There is a garage and dining room with an indoor patio garden for the natural ventilation of the house. The bathroom has the smallest window ventilation facing to the inner garden. This large dwelling has a flat ceiling with 3.5-metre standard height. The ground floor is protected by the 30° slope pitched roof, with overhang and shading devices of 1.5 metres to protect the verandas, external walls, doors and windows.

Figure 7.4. (First Floor), all rooms on this level have windows and doors that are identical to the ground floor. This first floor has a communal space family room with the stairway placed at one corner, surrounded by a master bedroom and three bedrooms. This large common room has door access at the front and a large window facing out to the balcony, with one side opening to the void inner patio.

A master bedroom complemented by a fitting room, bathroom and private balcony at the back of this contemporary house, has two windows facing out to the back garden. This room is accessible from the family room. The two bedrooms with a balcony between them at the front of the house have windows facing out to the front garden, and their doors have direct access to the family room. The inner bedroom that has the same access from the common room is orientated out to the void patio garden. One other bathroom has window orientation to the inner void patio for better ventilation and health. Just as the ground floor, this level has a flat ceiling, with a 3.5-metre standard height and also characterised by the 30° slope pitched roof, and 1.5 metre shading devices in order to protect balconies, the external walls, unprotected doors and windows.

These two dwelling types, one a single storey and one a two-storey large dwelling have been considered as appropriate models for the simulation. The former, as has been described previously to represent the national standard dwelling type, and the latter to represent the exclusive dwelling that few residents can afford yet which is demanded by the tourist industry.

These are then designated under the test configurations, with and without of both insulation and architectural shading devices in respect of the cooling energy conservation strategies.

Figure 7.1. Small Dwelling

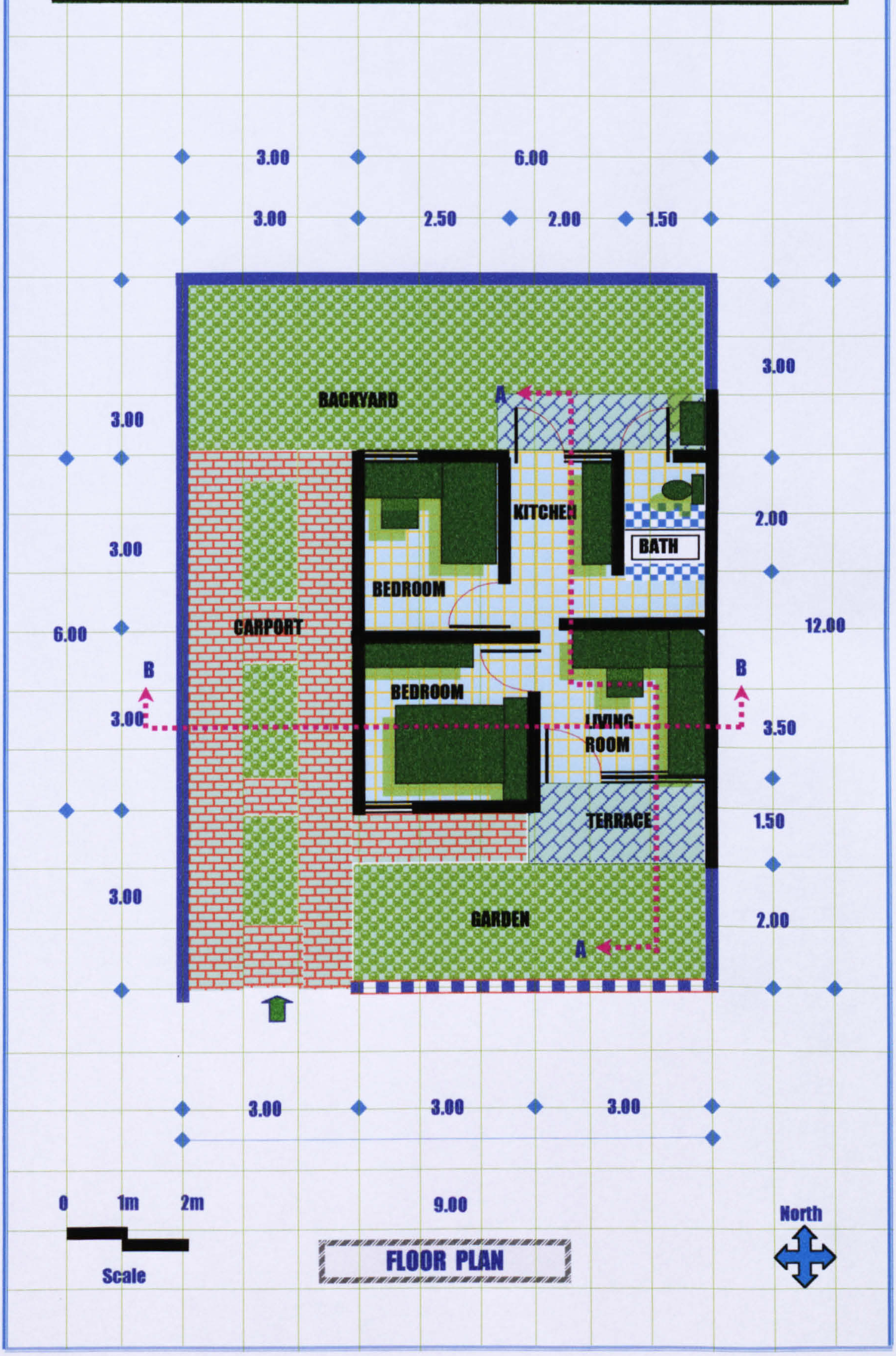


Figure 7.2. Sections of Small Compact Dwelling

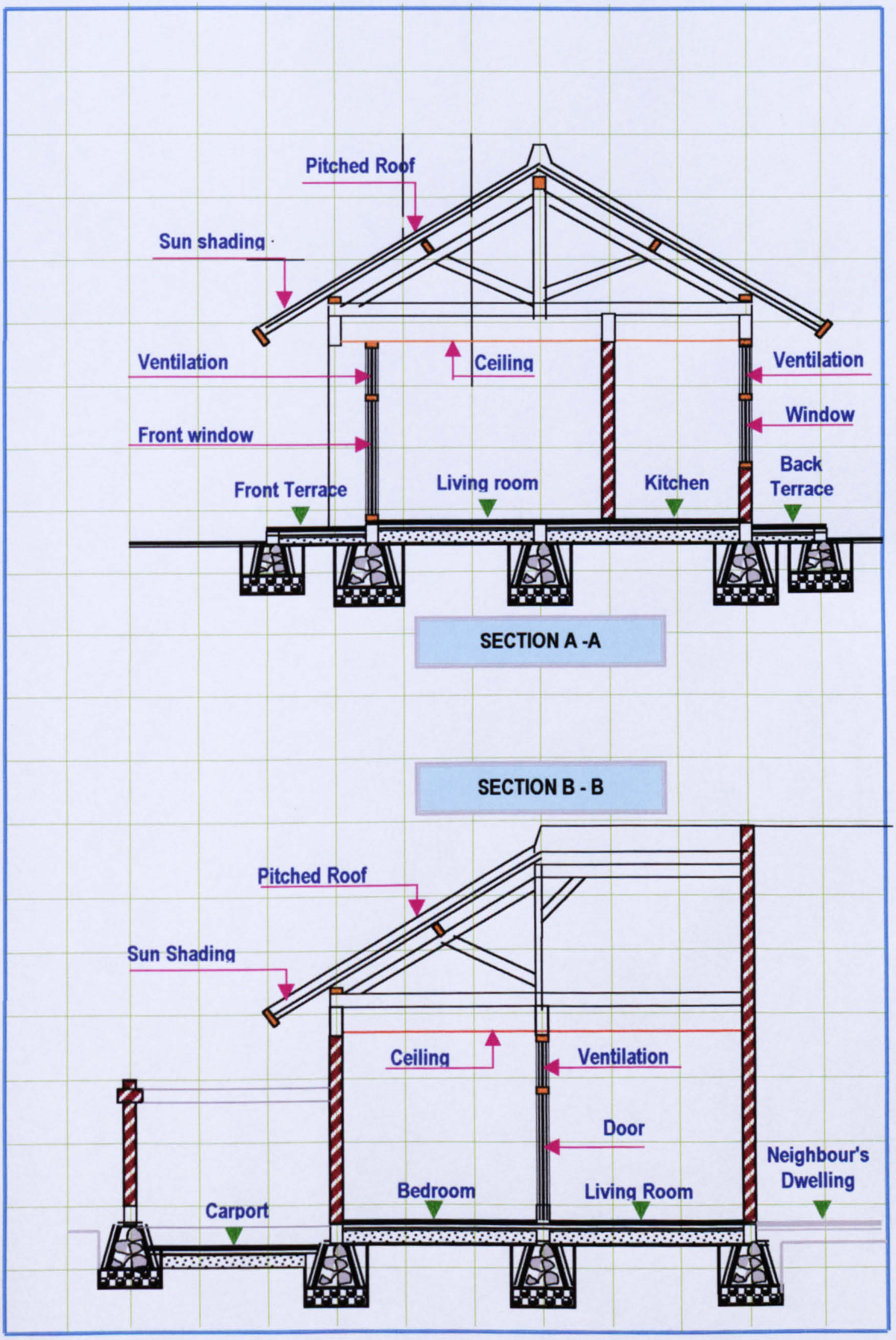


Figure 7.3. Large Dwelling Ground Floor

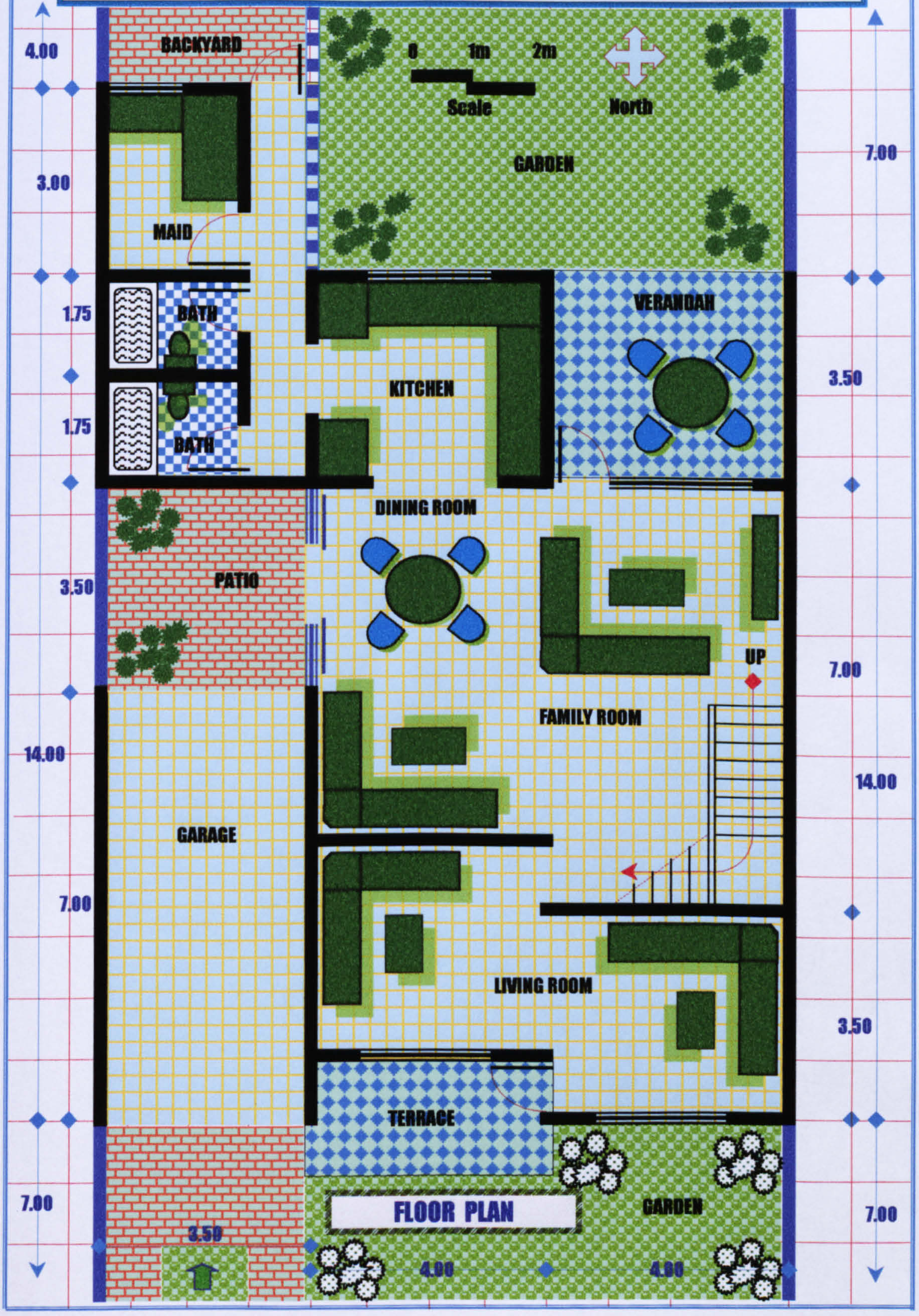
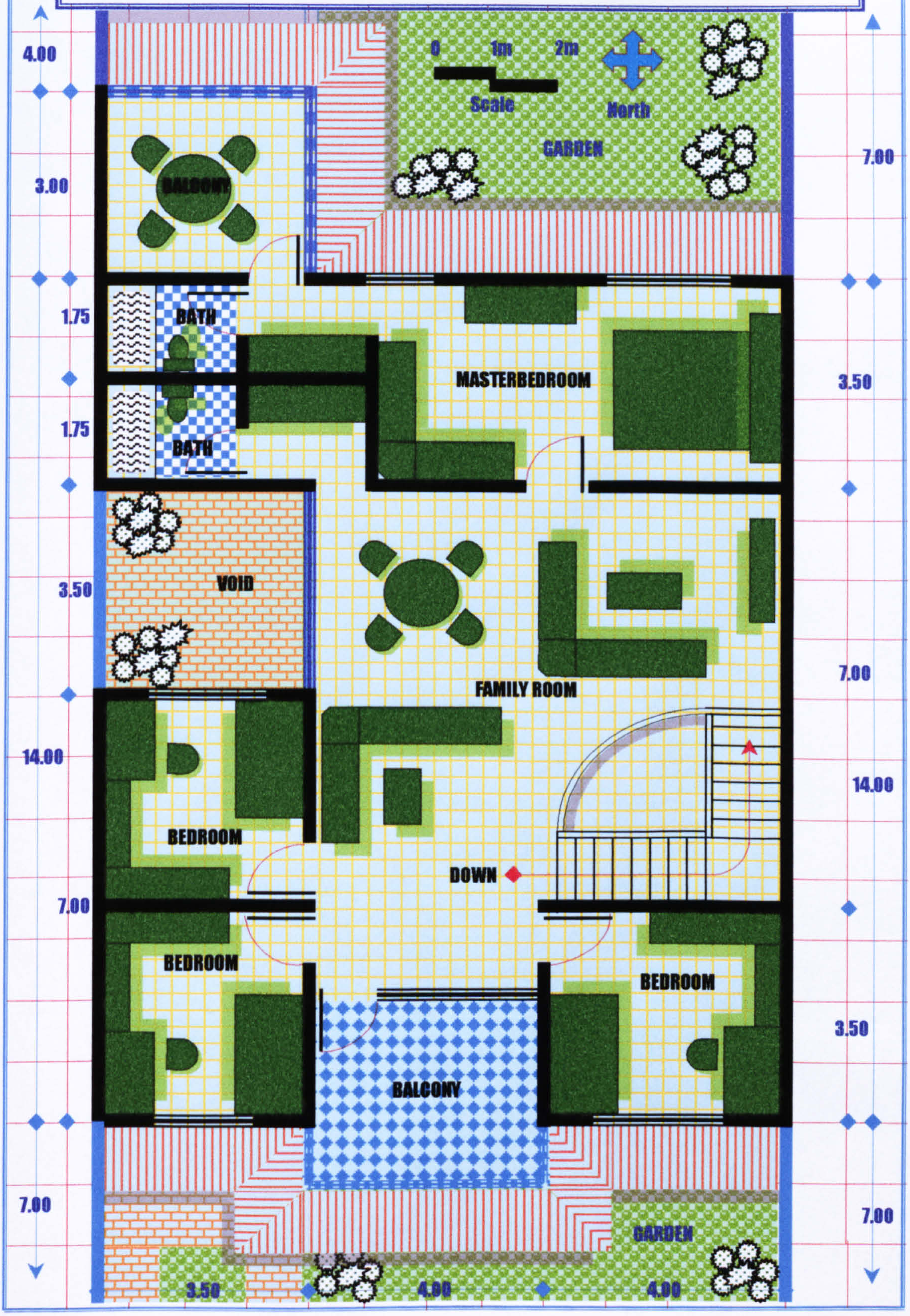


Figure 7.4. Large Dwelling First Floor



7.3.2. Geometrical Data

Type 36/108, i.e. a 36 m^2 building on a plot of 108 m^2, represents small dwellings (Figure 7.1). The bedroom, master bedroom and living room have room sizes and window configuration as shown in Table 7.1. The small dwelling is commonly designed with two bedrooms, and includes a living room, kitchen and bathroom on the footprint which has a basic habitable space module of 3.00 x 3.00 metres.

Table 7.1. Geometrical Data of Air-conditioned Room of the Small Standard Dwelling

Room	Element	Dimension	Orientation from South
Bedroom	Exposed wall no. 1	3.00 m x 3.00 m	90 ° clockwise
	Exposed wall no. 2	2.50 m x 3.00 m	180 ° clockwise
	Window in wall no. 2	1.00 m x1.20 m	
	Distance above window	0.80 m	
	Side recess	1.00 m	
	Top overhang	1.00 m	
Master Bedroom	Exposed wall no. 1	3.00 m x 3.00 m	90 ° clockwise
	Exposed wall no. 2	3.00 m x 3.00 m	0 ° clockwise
	Window in wall no. 2	1.00 m x1.20 m	
	Distance above window	0.80 m	
	Side recess	1.00 m	
	Top overhang	1.00 m	
Living room	Exposed wall no. 1	3.00 m x 3.00 m	0 ° clockwise
	Window in wall no. 1	2.00 m x 2.00 m	
	Distance above window	0.80 m	
	Side recess	0.30 m	
	Top overhang	2.50 m	

In this case study the dwelling living room and bedrooms have a total space of about 27 m^2 which is air-conditioned.

The large two storey dwelling has accommodation on the ground floor of 120 m^2 (living room, dining and family rooms, indoor patio, kitchen, garage, bathrooms and maid's room), and first floor of 120 m^2 organised into a common room, bedrooms, master bedroom, bathrooms and balconies. In this case study dwelling, the living room, family room, dining room and bedrooms have a total space of about 190 m^2 which is air-conditioned.

The large dwelling geometrical data configurations are presented in Table 7.2.

Table 7.2. Geometrical Data of Air-conditioned Room of the Large Dwelling

Room	Element	Dimension	Orientation from South
Bedroom	Exposed wall no. 1	3.00 m x 3.00 m	90 ° clockwise
	Exposed wall no. 2	2.50 m x 3.00 m	180 ° clockwise
	Window in wall no. 2	1.00 m x1.20 m	
	Distance above window	0.80 m	
	Side recess	1.00 m	
	Top overhang	1.00 m	
Master Bedroom	Exposed wall no. 1	3.00 m x 3.00 m	90 ° clockwise
	Exposed wall no. 2	3.00 m x 3.00 m	0 ° clockwise
	Window in wall no. 2	1.00 m x1.20 m	
	Distance above window	0.80 m	
	Side recess	1.00 m	
	Top overhang	1.00 m	
Living room	Exposed wall no. 1	3.00 m x 3.00 m	0 ° clockwise
	Window in wall no. 2	2.00 m x 2.00 m	
	Distance above window	0.80 m	
	Side recess	0.30 m	
	Top overhang	2.50 m	

7.3.3. Time Occupancy and Indoors Climatic Data

The building is a small standard dwelling occupied by a family with 2 children (i.e. 4 persons) with and/or without insulation and architectural shading devices under the 7-hours time occupancy and/or 3-hours time occupancy per day. The indoor thermal conditions, occupants' heat gain and lighting design is presented in Table 7.3, Table 7.4, and Table 7.5.

Table 7.3. Room Design Thermal Conditions.

	Cool Session	Hot Session
Room temperature	26.00 °C	28.00 ° C
Room % saturation	50 %	60 %
Air change rate	1.00 /hr	0.50 /hr

Table 7.4. Occupants' Heat Gains

Sensible body gain	80 W/person
Latent body gain	35 W/person
Lights heat gain	15.00 W/m²
Casual (occupied) gain	300 W
Sensible gain	500 W
Latent gain	210 W
Time gain ON	1 hrs
Time gain OFF	24 hrs

Table 7.5. Lighting Design

Illumination level	100 lux
Glare index	19
Working plane height	0.85 m
Suspension distance	
Ceiling reflection	70 %
Wall reflection	50 %
Floor reflection	20 %

Average outdoor environment dry-bulb air temperature is 30°C. and 28°C. for wet-bulb air temperature. Indoor air environment is 28°C. for dry-bulb temperature and 26°C for wet-bulb temperature. The mean radiant temperature for air-conditioned dwellings is 20°C. Air humidity content is 60 % average outdoors and 80 % for indoors.

7.3.4. Material Data

In the simulation procedure, the building elements of the houses e.g. floors, walls, and ceilings are designated as insulated and uninsulated. The glass windows are clear single glazed units for the uninsulated building and using sun protection glass for the insulated building.

7.3.4.1. The Walls

Exposed insulated walls: outside painted, sand-cement plaster, brickwork, glass-wool insulation, plywood, and painted. Un-insulated walls: brickwork with both sides plastered and painted (Figure 7.5 and Figure 7. 6).

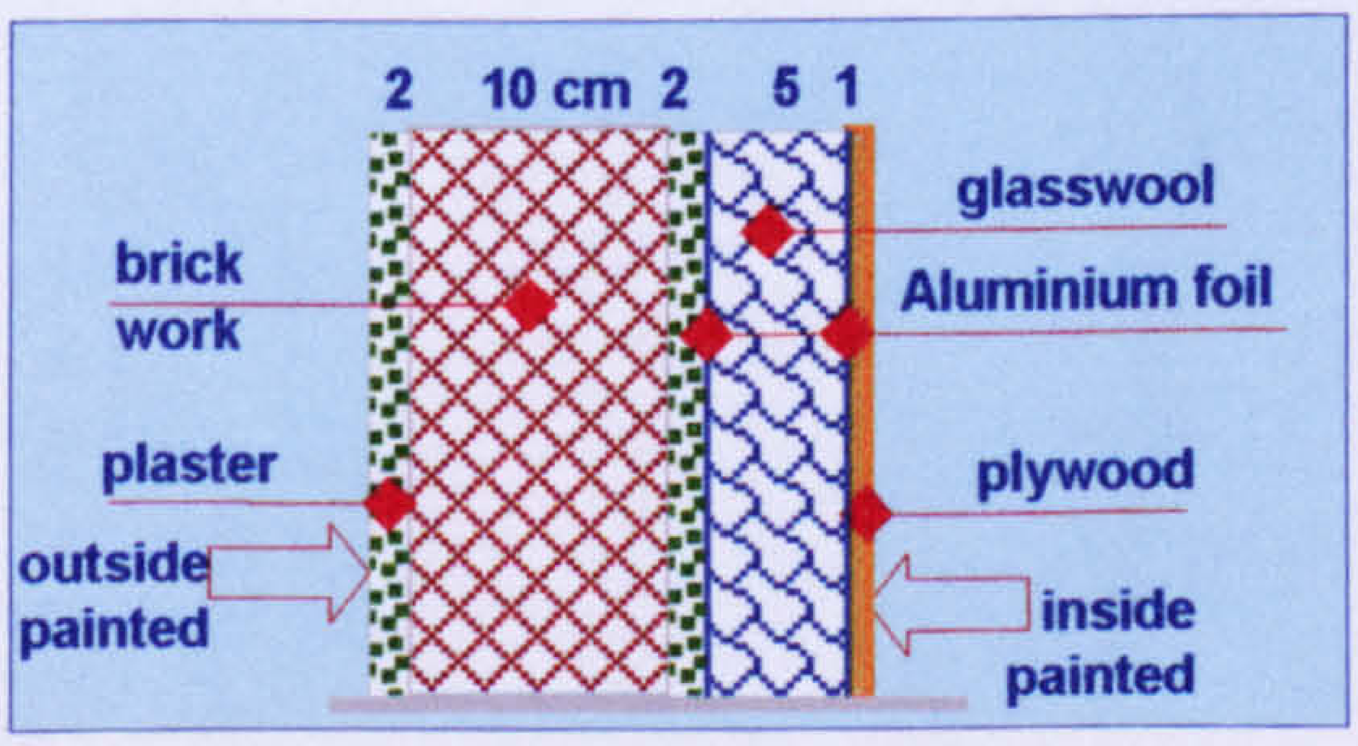


Figure 7.5. Exposed Insulated Wall

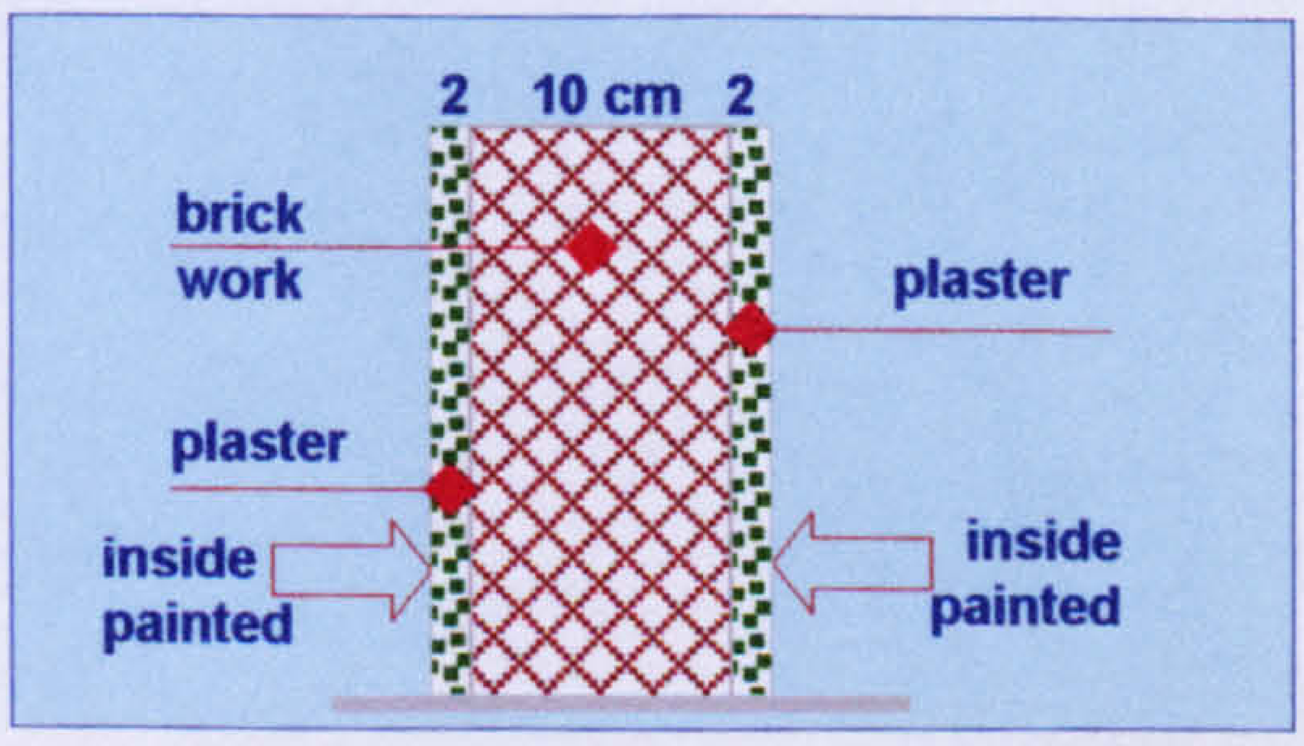


Figure 7.6. Un-Insulated Wall

7.3.4.2. The Ceiling

Insulated ceilings: teakwood; insulated timber frame and aluminium foil is shown in Figure 7.7. Un-insulated ceiling: asbestos and timber frame (Figure 7.8).

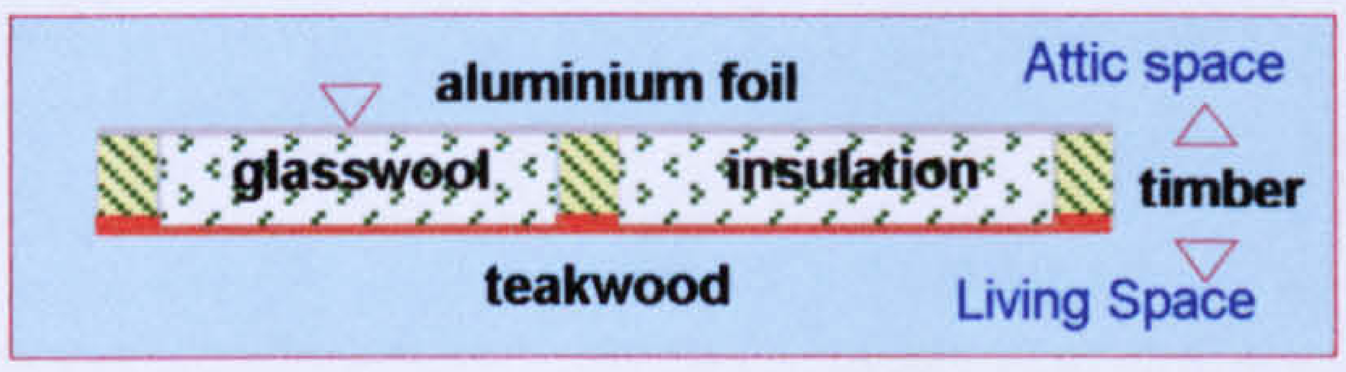


Figure VII - 7. Insulated Ceiling

Figure VII - 8. Un-Insulated Ceiling

7.3.4.3. The Floor

Improved thermal mass floor: marble tile, plaster, concrete, and sand and soil dense base (Figure 7.9). Low mass floor: ceramic tile and screed (Figure 7.10).

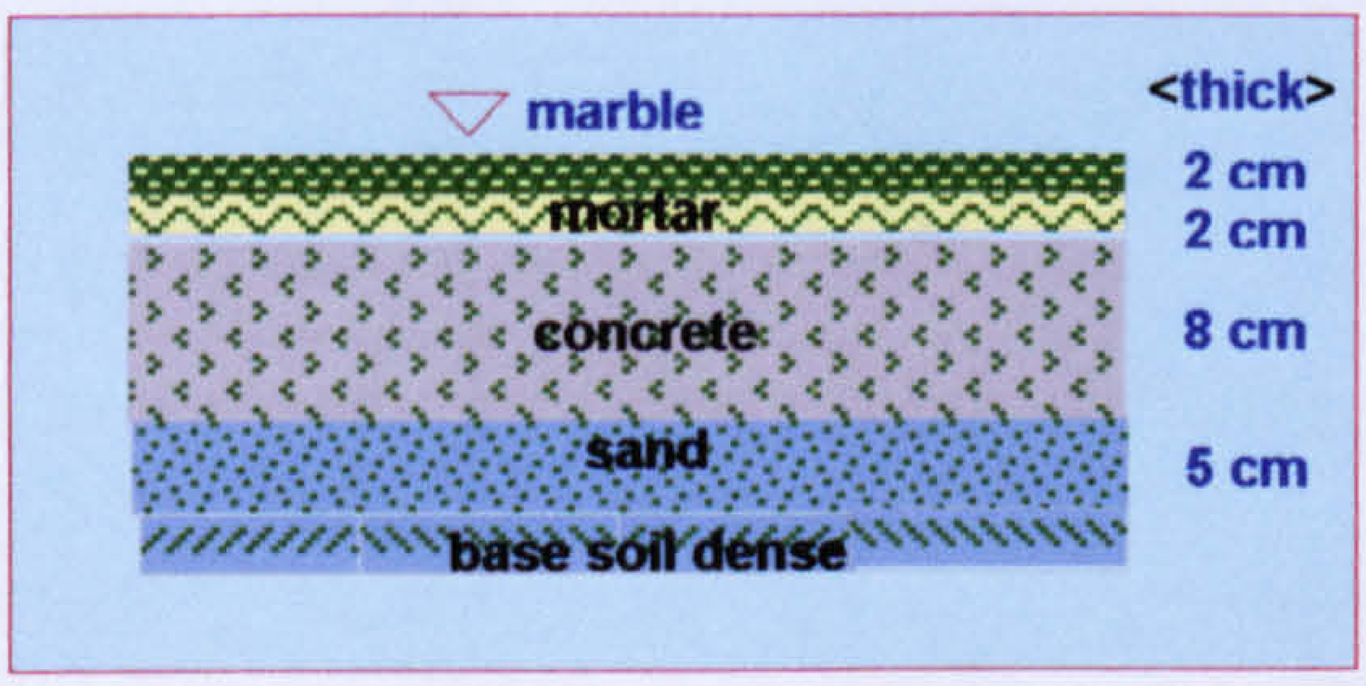


Figure 7.9. Improved Thermal Mass Floor

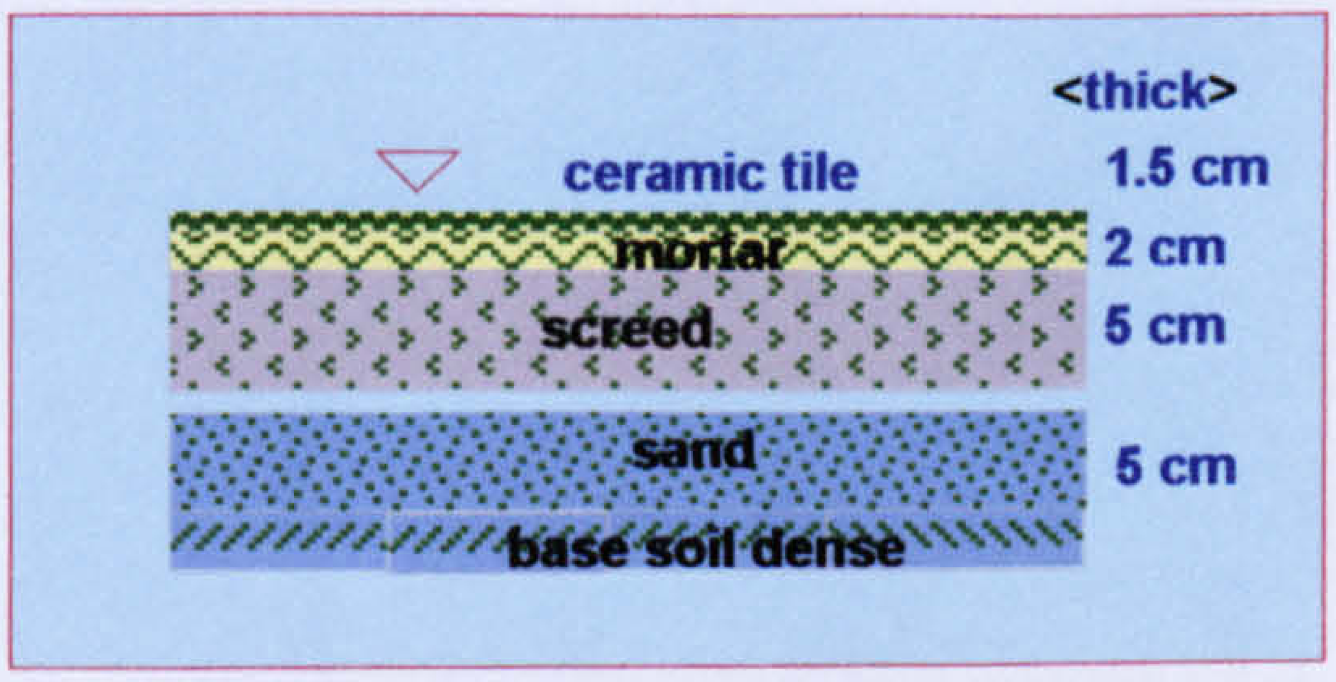


Figure 7.10. Low Mass Floor Material

Both floors are constructed from local material, however, the improved thermal mass floor is thicker; concrete adds mass to the structure to assist cooling. Typically, the ground temperatures are lower than the air temperature in the warm humid climate. If insulation is used, this cooling path would be denied to the room, hence high and low thermal mass floors are used.

7.3.4.4. The Windows

For the standard design, the window orientation is North-South and to reduce energy consumption, avoids facing East-West. The standard design window sizes are 3m x 2m maximum and 1m x 1.2m.

7.3.4.5. Shading Devices

The original standard type of shading devices for this dwelling was an overhang of 1-metre extending out from the exposed walls as part of the pitched roof with 30° slope (Figure 7.11).

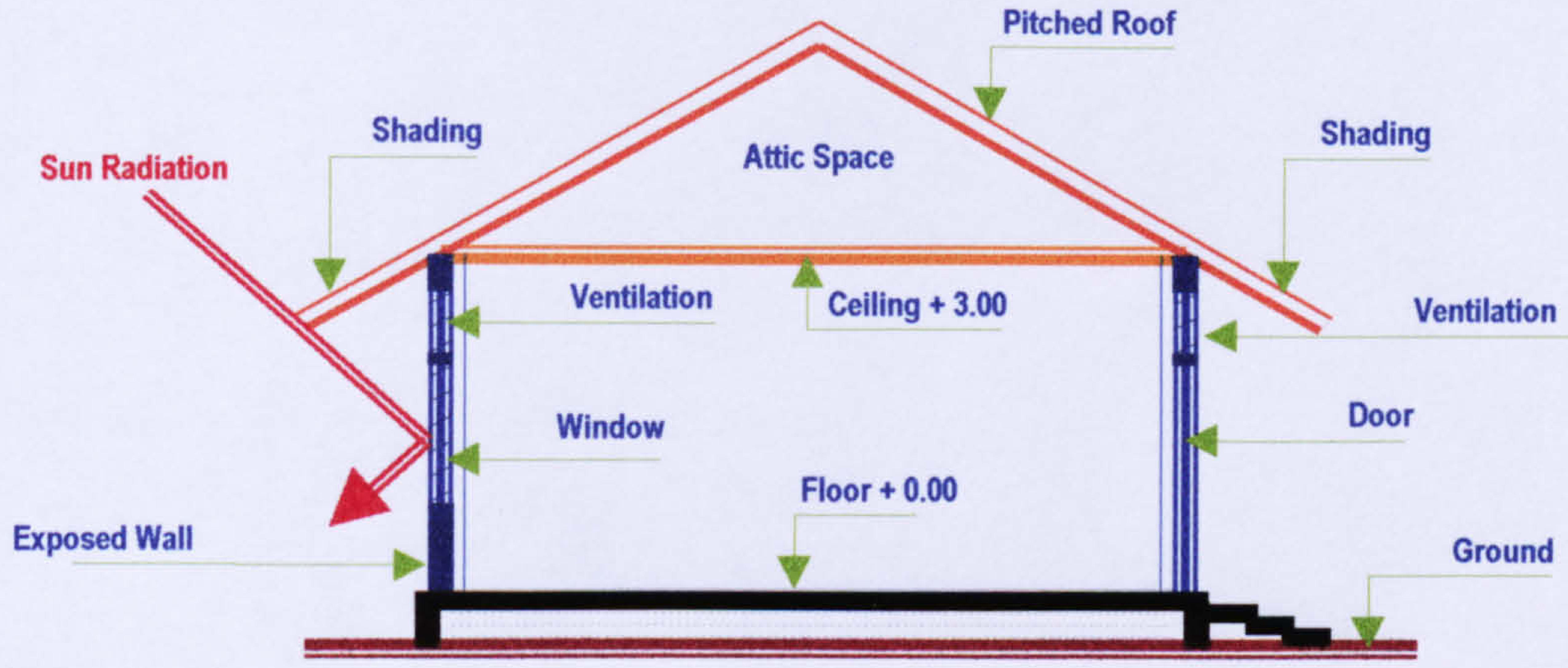


Figure 7.11. Shading Devices of Dwelling

This overshadowing will give protection to the exposed walls, doors and windows, to reduce indoor overheating by excluding direct heat radiation from the sun.

In the computer simulation study, this overhang is simulated at the standard 1.00 metre depth, and is then adjusted to 1.50 metre depth from the original, in order to achieve significant cooling for the dwelling and energy conservation.

7.4. OUTCOMES OF SIMULATION

7.4.1. Small House Air Conditioning Energy Consumption

Concerning air conditioning energy consumption, the small house simulation results are given in Figure 7.12. (see also Appendix - VI). Overall, as can be seen from the detailed results of the monthly consumption value, the energy used is generally quite similar each month.

This is understandable due to the similar high temperature, and humidity conditions experienced all year around, in turn leading to high-energy consumption of both sensible energy and latent energy for air conditioning.

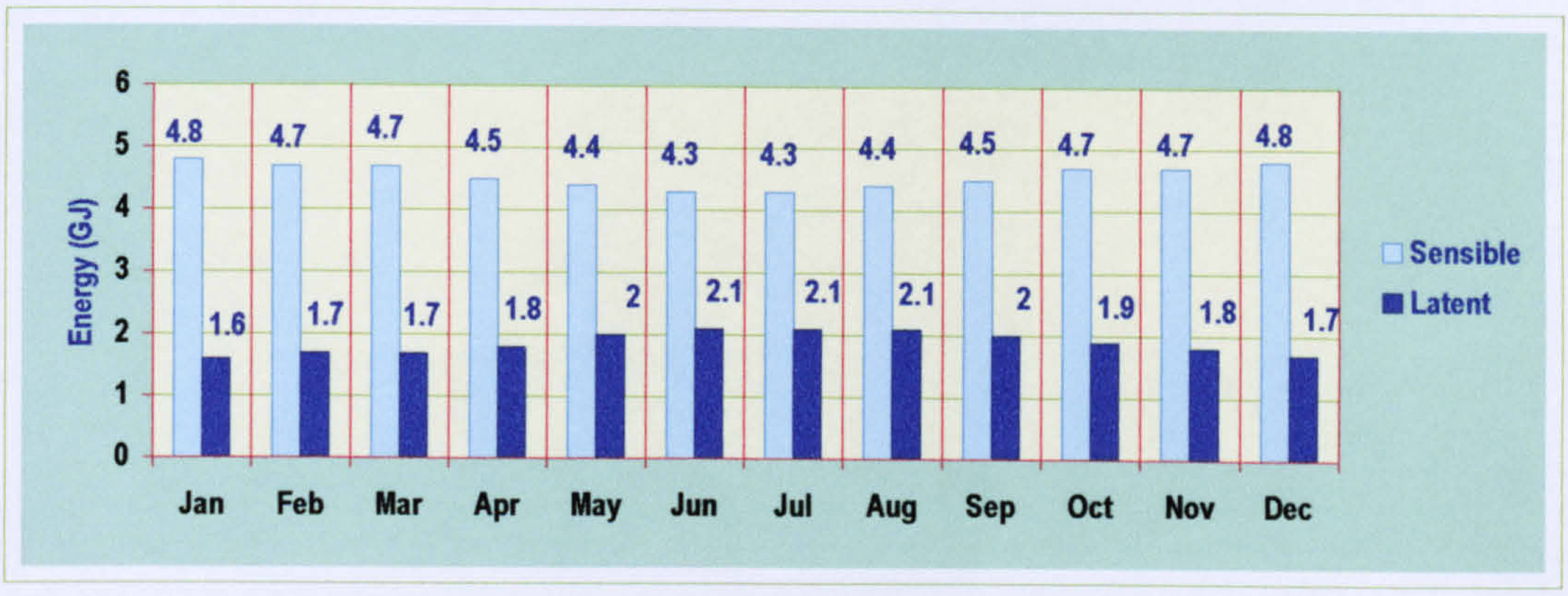


Figure 7.12. Monthly Air Conditioning Energy Consumption

The annual ratio of the total of both sensible and latent energy consumption are presented in Figure 7.13, with the sensible gain being 70% and the latent gain is 30%. This energy load could possibly be reduced by insulating and by shading the dwelling.

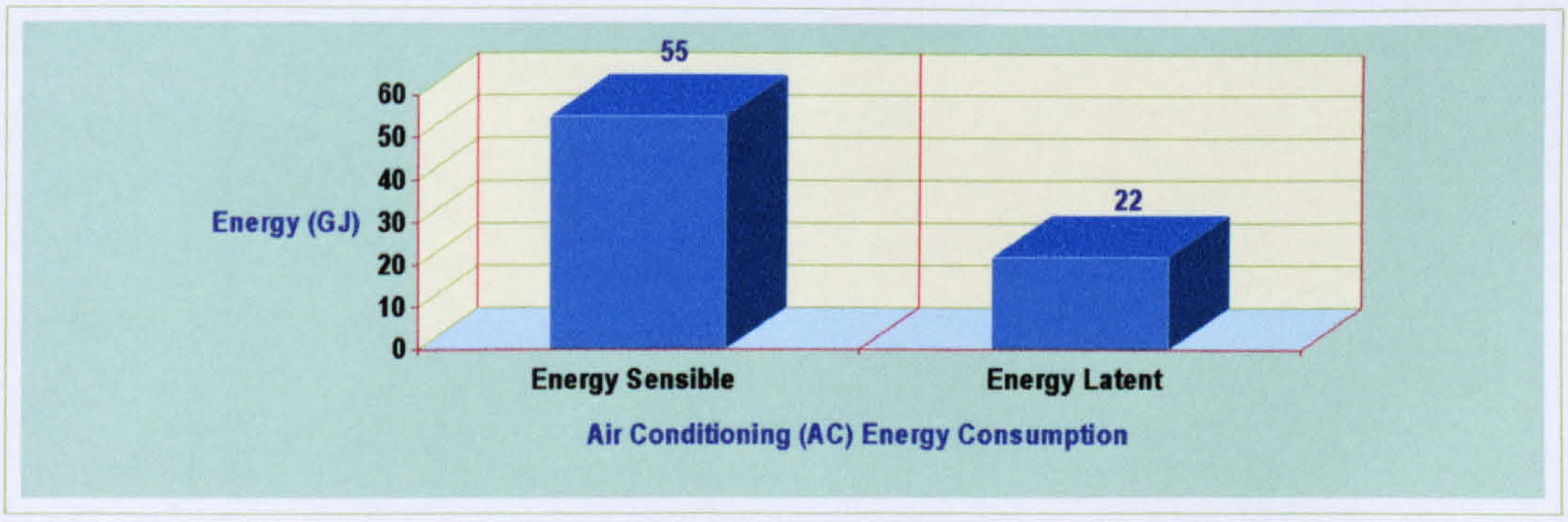


Figure 7.13. Annual Air Conditioning Energy Consumption

Looking at an individual room, in descending order for both sensible and latent energy gain, are the living room, the master bedroom, and then the bedroom (Figure 7.14).

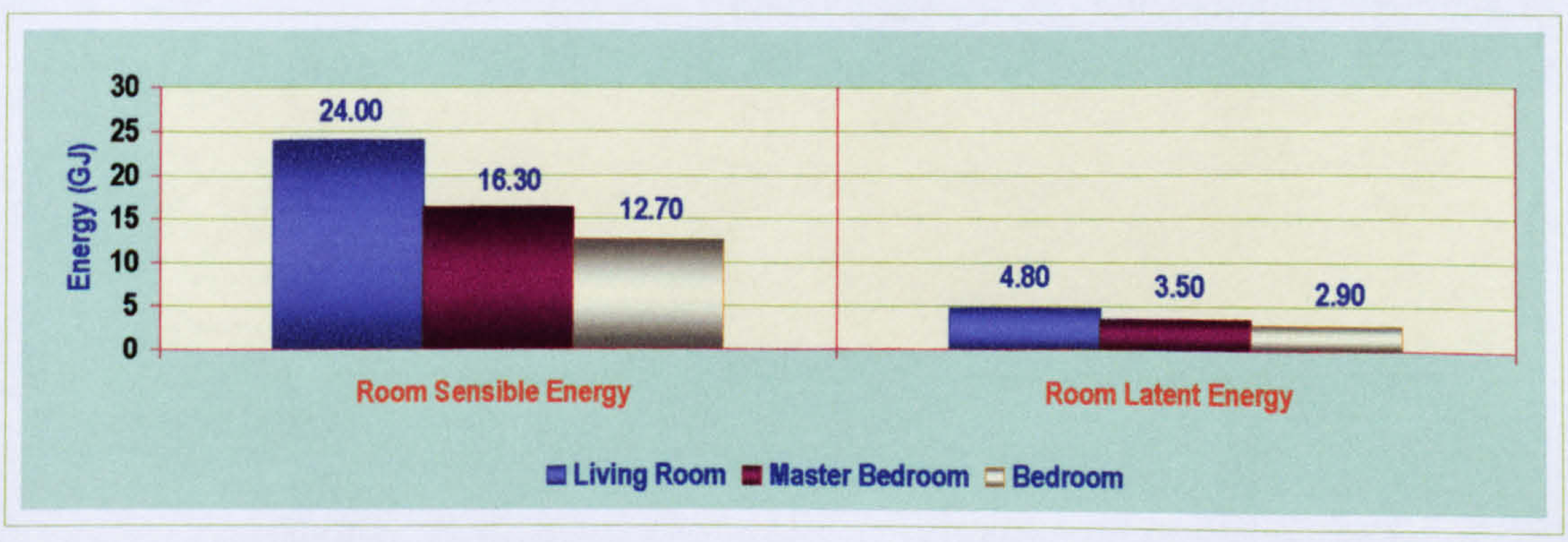


Figure 7.14. Room Air Conditioning Energy Consumption of Small Dwelling

This figure indicates that the larger the room size, the more energy needed for cooling purposes. Especially for the living room, this being the largest room and which also has the biggest exposed window that allows sun radiation into the room.

To reduce energy consumption a series of energy efficiency strategies as previously described were adopted and the results show significant reductions of air conditioning energy used in the dwelling (Figure 7.15).

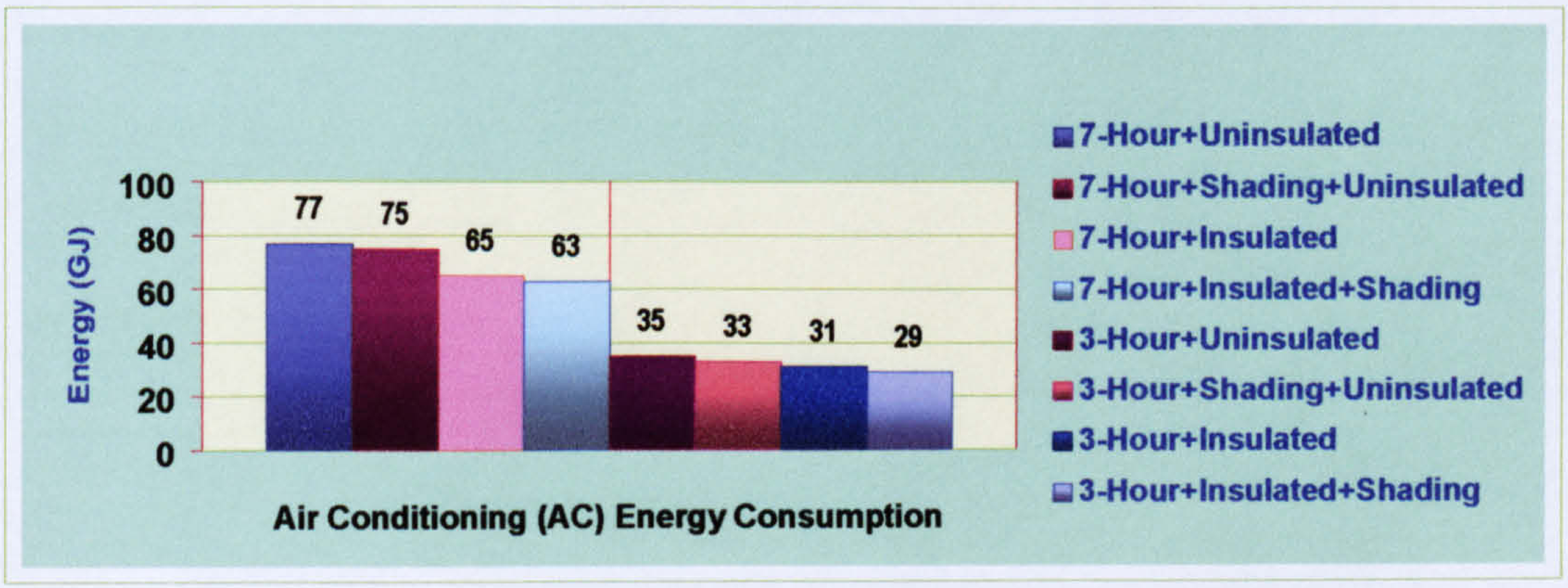


Figure 7.15. Air Conditioning Energy Conservation of Small Dwelling

Looking at the first findings for 7-hour time occupancy, a large amount of energy is required to condition the dwelling. The second result shows that for 7-hour occupancy with shading design, the impact on energy is insignificant (less than 5% reduction) compared to the previous one. The third result shows that for 7-hour occupancy with only insulation, the impact on energy demand is 15% reduction compared to the 7-hour occupancy reference case. The fourth result shows that for 7-hour occupancy with shading design and insulation, the effect on energy usage is 20% reduction compared to the 7-hour occupancy reference case.

In the 3-hour time occupancy, the use of energy for cooling spaces is understandably much less than the 7-hour occupancy. This is due to halving of the time required for cooling conditions. Impact on energy usage was a 55% reduction compared to the 7-hour occupancy reference case. What is more, by a combination of both 3-hour occupancy and the overhang design on the top of the windows, the need for energy for air conditioning can be reduced further.

Impact upon energy saving was 57% reduction compared to the 7-hour occupancy reference case.

The next result that shows for 3-hour occupancy with insulation, the impact on energy is 59% reduction compared to 7-hour occupancy with similar configuration.

The final finding reveals that for 3-hour occupancy, shading devices and insulation, the impact on energy is up to 62% reduction comparable to 7-hour occupancy.

In relation to overheating as the main problem in warm humid climate (see Chapter Three at section 3.3), these results indicate that the impact of insulation on thermal comfort and energy conservation is a greater than that of shading devices.

Therefore, a conclusion can be drawn from these outcomes of simulation that those strategies have significantly achieved better thermal performance and energy efficiency for a more comfortable dwelling.

7.4.2. Large House Air Conditioning Energy Consumption

7.4.2.1. Ground Floor Air Conditioning Energy Consumption

The ground floor area is approximately 160 m^2, with the space organised as shown in Figure 7.16. Almost all the main rooms on this floor are air-conditioned, such as the living room, family room and dining room.

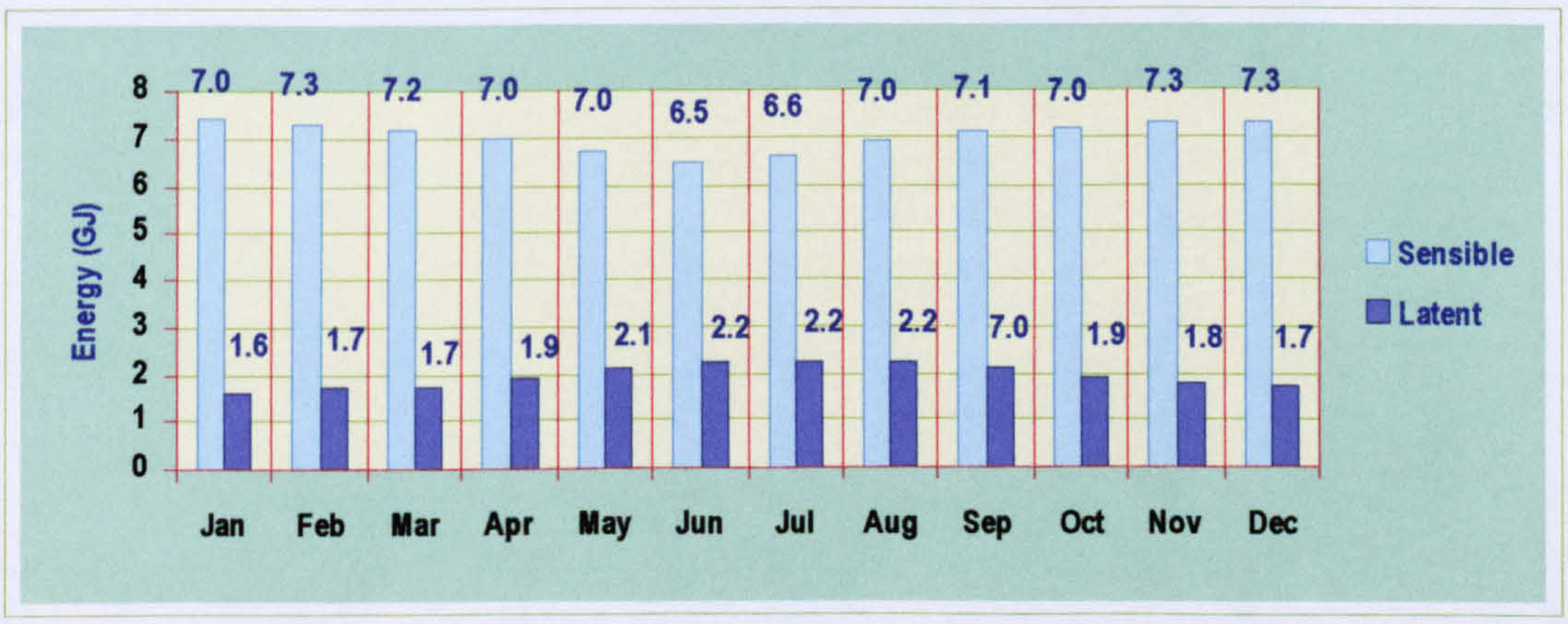


Figure 7.16. Monthly Air Conditioning Energy Consumption of the Ground Floor

According to the simulated results (Figure 7.16), the A/C building energy change between the months over the whole year is less than 5%.

As can be seen in Figure 7.17, the sensible gain is compared with the latent energy gain for the total year. The ratio of sensible energy gain and the latent energy cooling of the dwelling are 80% and 20%. This outcome has a similar pattern to the small dwelling air conditioning energy consumption, but with a higher level of energy consumption.

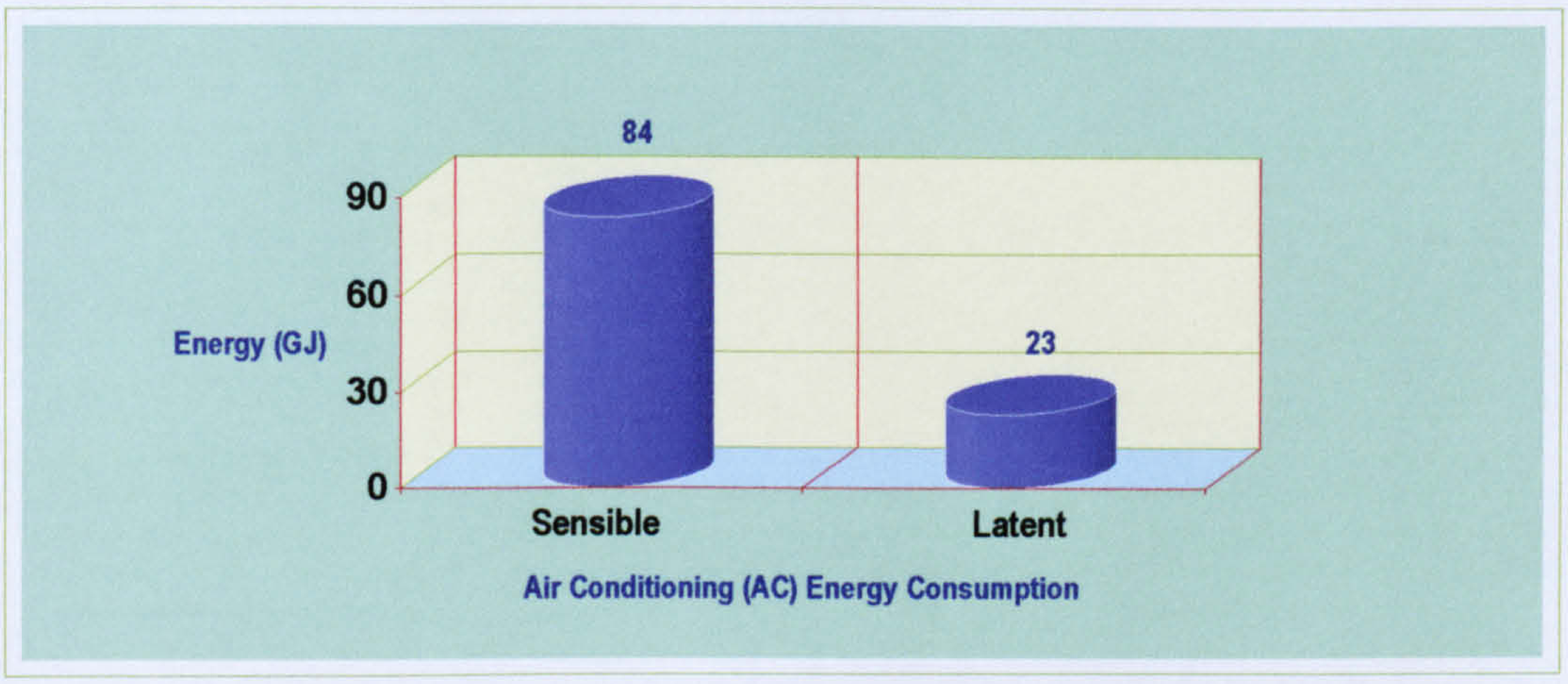


Figure 7.17. Annual Air Conditioning Energy Consumption of the Ground Floor

Figure 7.18 indicates the air conditioning energy consumption between the main rooms. The reasons are that the family room has a larger size and windows than the living room. The room size provides the air volume that needs to be cooled and the window size allows greater overheating radiation, which impacts on the energy load of the air conditioning.

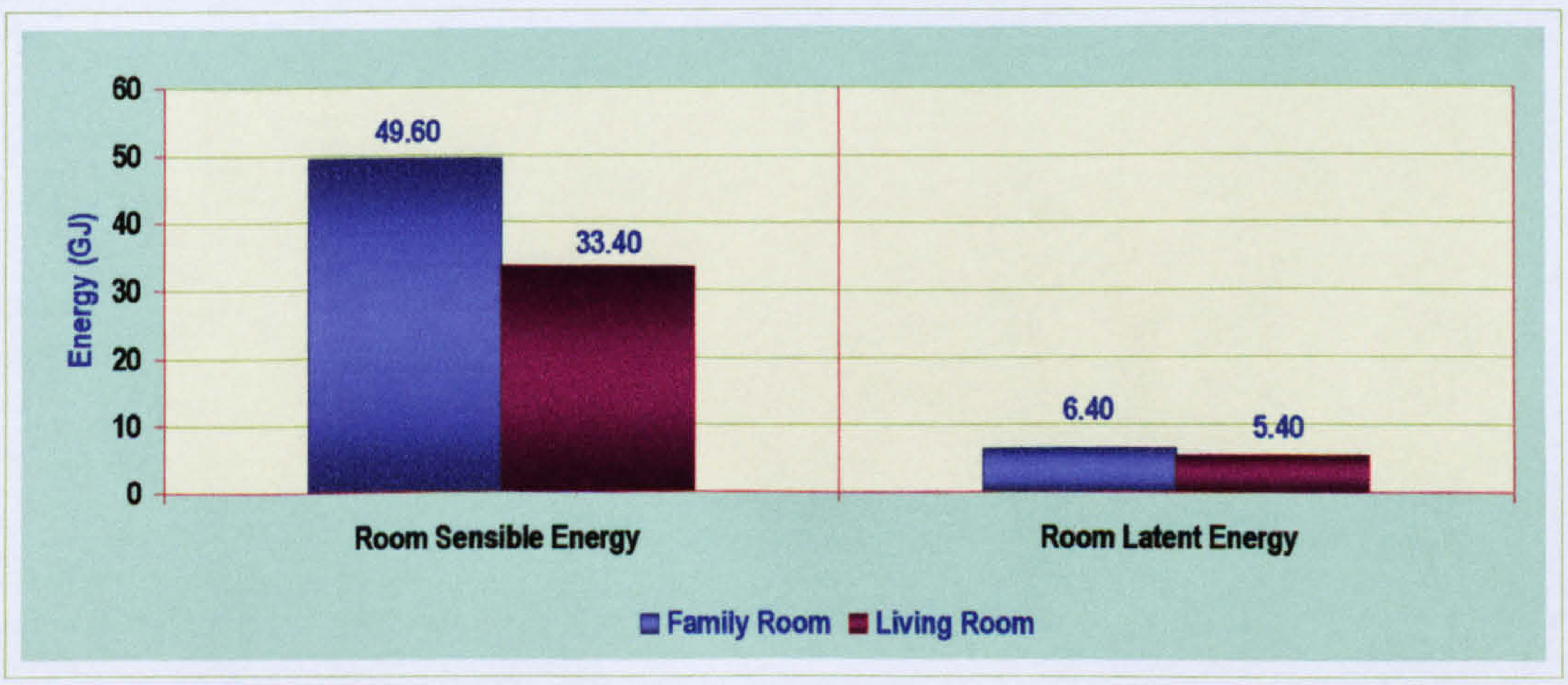


Figure 7.18. Annual Air Conditioning Energy Consumption of the Rooms

In the same way, by undertaking the strategies to reduce energy consumption that have previously been described (see section 7.2) and applied to the small standard dwelling, a considerable reduction of air conditioning energy used in the dwelling can be achieved. This significant achievement is shown in Figure 7.19 below.

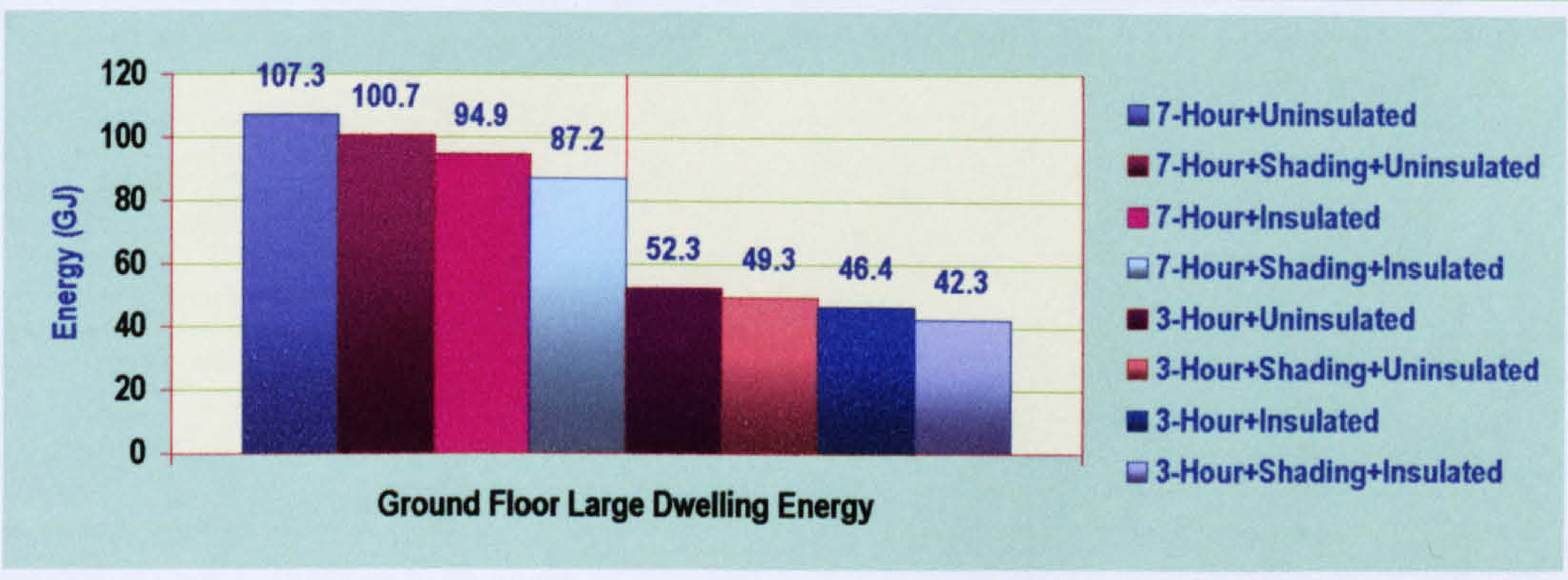


Figure 7.19. Air Conditioning Energy Conservation of Ground Floor, Large Dwelling

Looking at the first findings (Figure 7.19) for 7 hours time occupancy, a large amount of energy is required to condition the dwelling. The second result shows that for 7-hour occupancy with shading design, the impact on energy is 6% reduction compared to the 7-hour occupancy reference case.

The third result, for the same time occupancy comparison with insulation, the impact on energy is 12% reduction. The next result, for 7-hour occupancy, with shading and insulation, the impact on energy use for cooling spaces is 20% reduction comparable to the 7-hour occupancy.

The next strategy compares the 3-hour occupancy and the 7-hour occupancy, where the impact on energy reduction is 50%. By shading window devices for the 3-hour cooling conditions, the result shows 54% energy reduction compared to the 7-hour cooling. For the same occupancy time and insulation, the impact on energy reduction is 57%. For the final result on the same strategy with both shading and insulation, the impact on energy reduction is 61% compared to the 7-hour occupancy. This ground floor energy reduction is similar to the small dwelling energy reduction which achieved 62% energy reduction. Therefore, the energy conservation strategy shows a significant achievement in restoring thermal comfort performance and energy efficient cooling for the dwelling.

7.4.2.2. First Floor Air Conditioning Energy Consumption

The first floor of the large house has the same area as the ground floor, about 160 m^2 (Figure 7.3). This level contains balconies, family room, master bedroom, and bedrooms. All of these rooms are air-conditioned.

It can be seen from Figure 7.20 that in general, looking at the first floor A/C energy pattern, there is an identical trend between sensible and latent gain comparable to the ground floor. For the first floor, there was a slight variation between January and December air conditioning sensible energy gains and latent energy of the entire year.

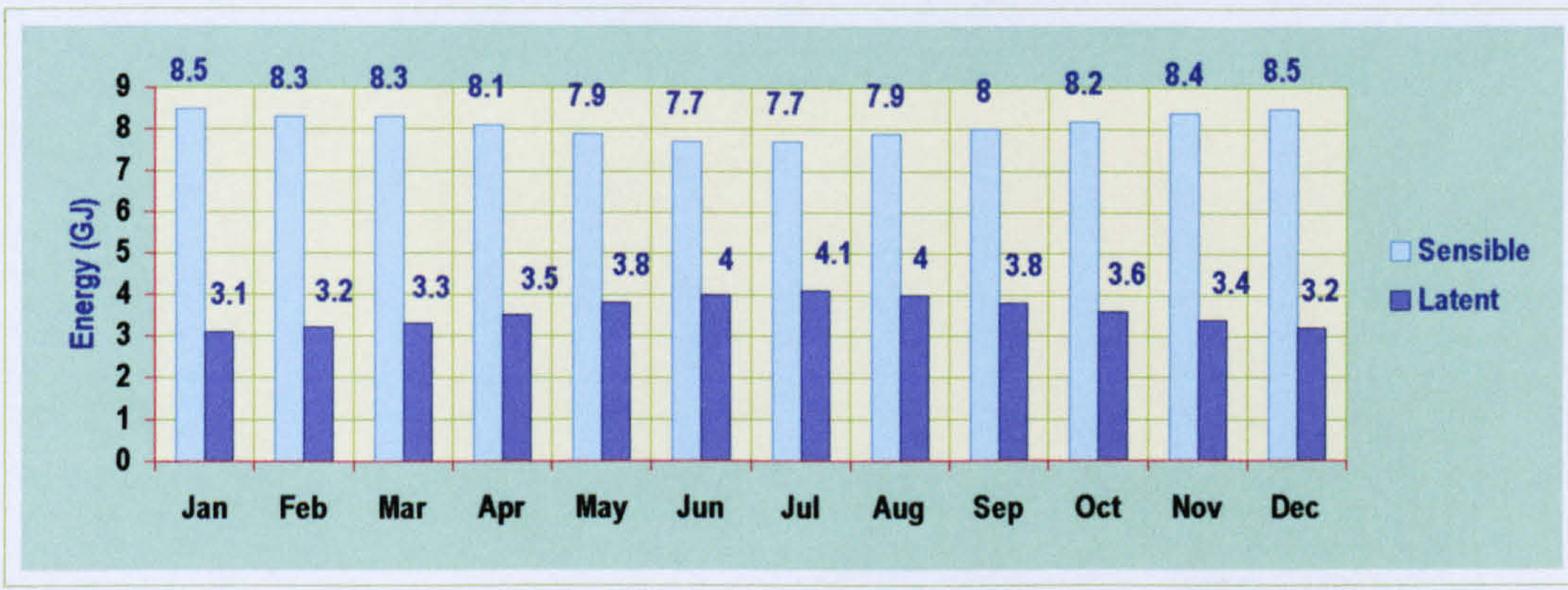


Figure 7.20. Monthly Air Conditioning Energy Consumption of the First Floor

The total air conditioning energy consumption of the whole year is shown in Figure 7.21. As has been described previously, the sensible gain energy use is three times higher than the building energy latent gain.

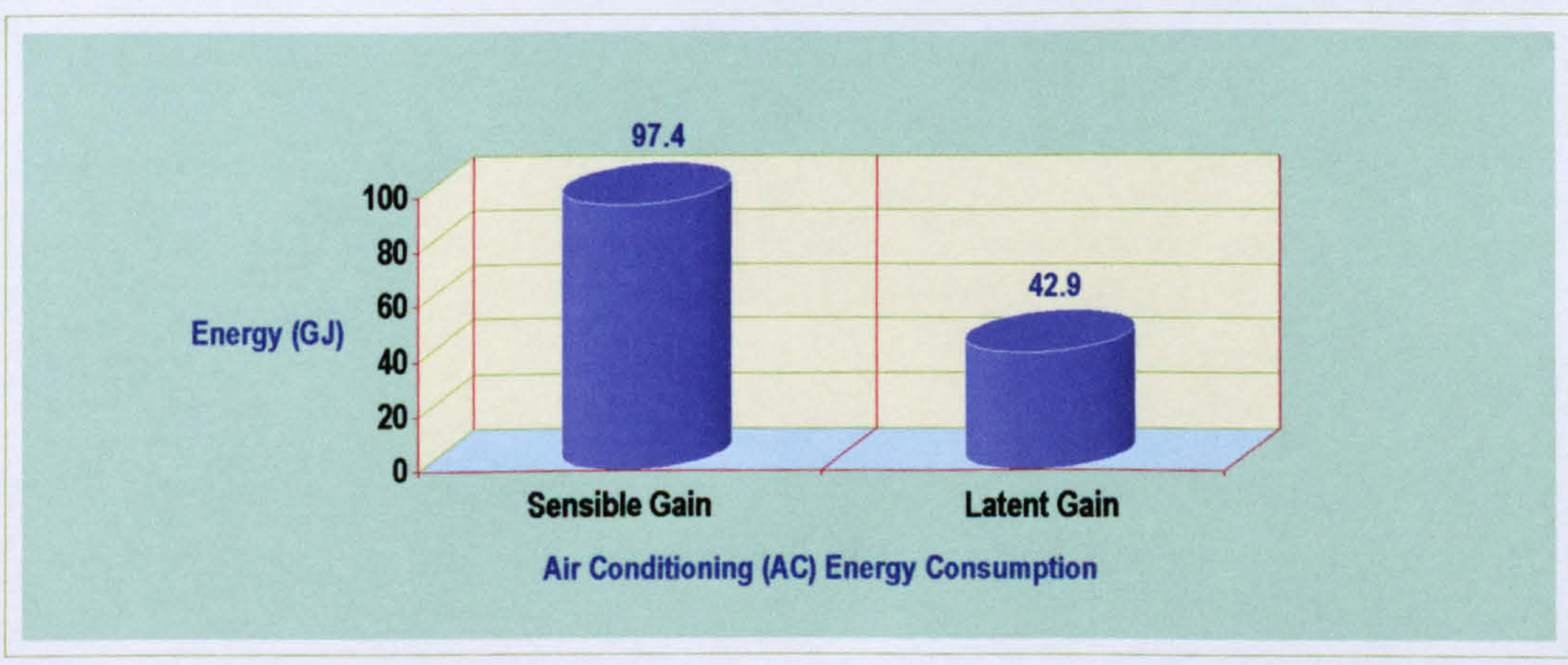


Figure 7.21. Annual Air Conditioning Energy Consumption of the First Floor

In terms of air conditioning energy use for the first floor of the house, the rooms' sensible energy gains show a similar pattern to that of the ground floor.

As can be seen in Figure 7.22, the sensible and latent energy gains have similar values for the bedrooms and the master bedroom. The room with the highest energy gain was the common room, which is the largest room and has the largest window sizes.

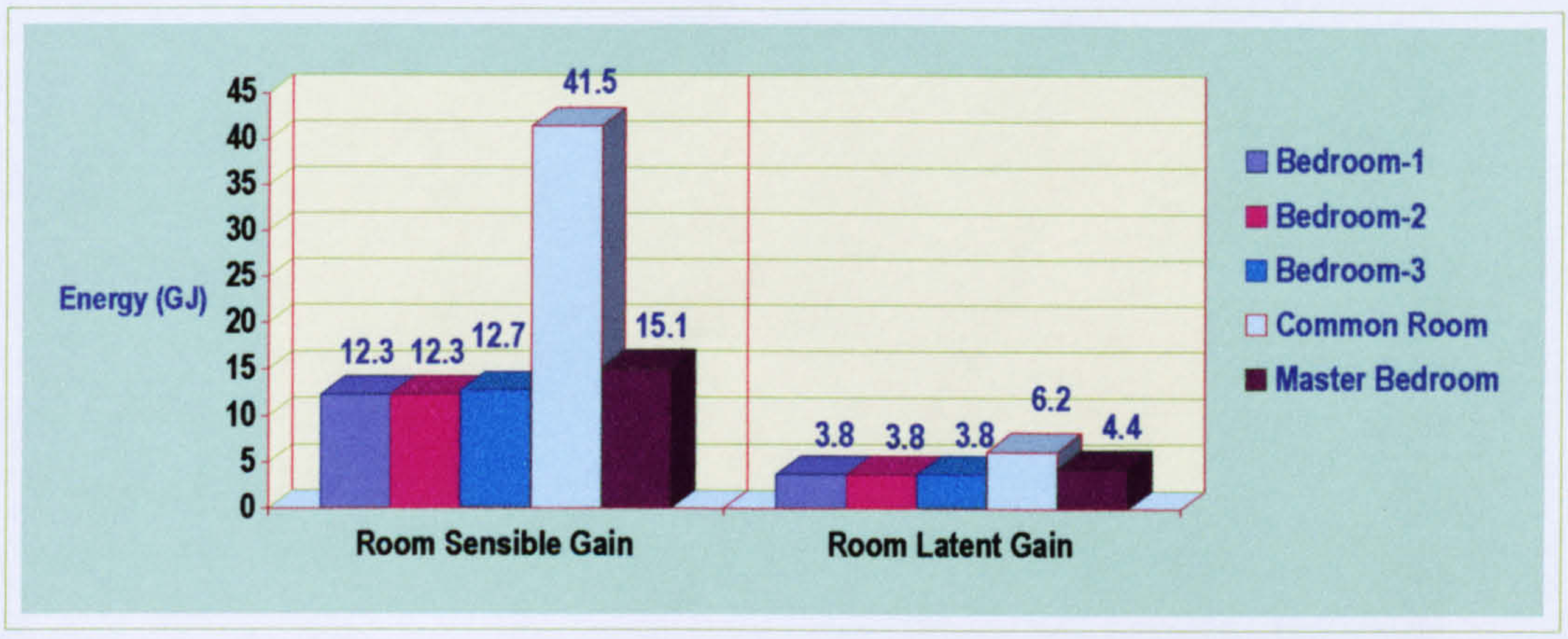


Figure 7.22. Room Air Conditioning Energy Consumption of the First Floor Large Dwelling

By undertaking the same strategies to reduce energy consumption that have previously been applied on the small dwelling and ground floor, the results show a significant reduction of air conditioning energy used in the dwelling (Figure 7.23).

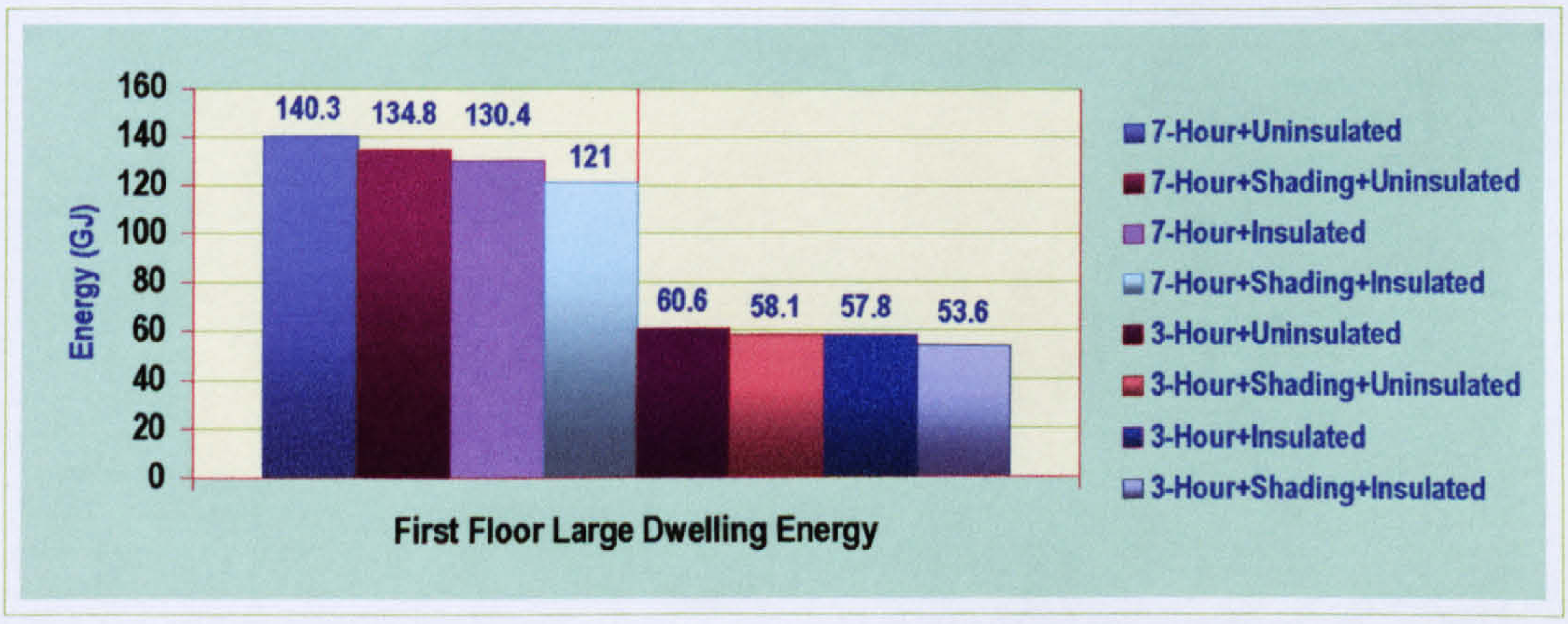


Figure 7.23. First Floor Air Conditioning Energy Conservation of Large Dwelling

Looking at the first findings (Figure 7.23) the first result shows that a large amount of the energy is required to achieve comfort in the first floor. The second result shows the impact of shading to be a 4% energy reduction. In the third result, the insulated case, the impact on energy is a 7% reduction. The combined strategy has an impact on use of energy for cooling spaces of 14% reduction.

Comparing between 3-hour and 7-hour occupancy, impact on energy is almost a 57% reduction. By using the window shading devices the result shows a 58% energy reduction. In the following result with insulation, the impact on energy is still approximately 59% reduction. The final result for the same combined strategy using both shading and insulation, impact on energy is a 62% reduction. This first floor's energy reduction is the same as for the ground floor, at 62%.

These outcomes indicate that the energy conservation strategy shows a significant achievement in restoring thermal comfort performance and energy efficiency for cooling the ground floor and the first floor of the large dwelling.

Figure 7.24 shows all the outcomes of simulation analysis of the dwellings giving the greatest thermal comfort performance and energy efficiency for air-conditioned buildings.

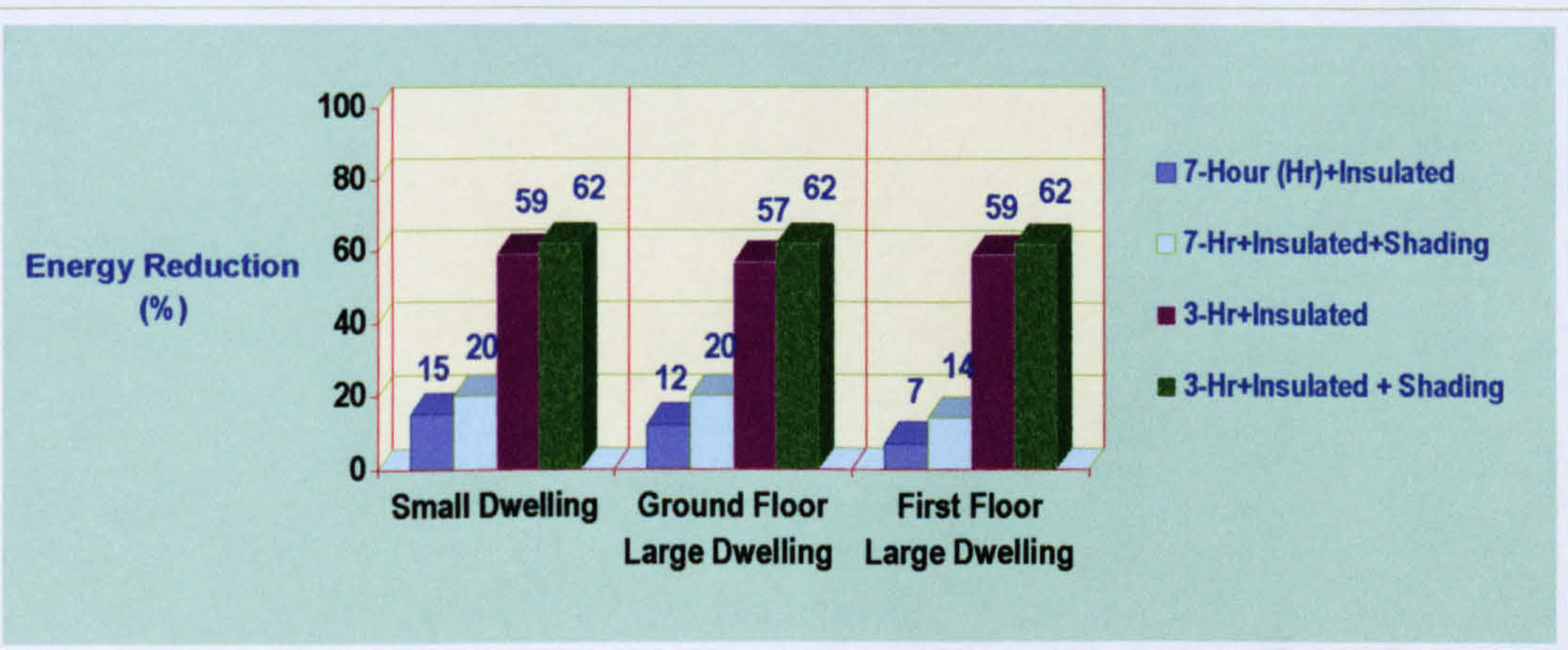


Figure 7.24. Air Conditioning Energy Reduction of Dwellings

The computational simulation shows that energy reduction between small and large dwellings is similar.

In a comparable result between the dwellings, the small dwelling that has room size of 27 m^2, air-conditioning consumed 29.00 GJ energy, equal to 1.10 GJ/m^2, and the ground of the floor large dwelling with room size 70 m^2, air-conditioning consumed 42.30 GJ energy, equal to 0.60 GJ/m^2. On the first floor which has 112 m^2, air-conditioning consumed 53.60 GJ energy, which is equal to 0.50 GJ/ m^2.

From this can be concluded that per square metre energy load for cooling the large dwelling is more efficient than the small dwelling (Figure 7.25).

The reason is that the small dwelling design is more exposed to the sun, so creating a larger overheating than the large dwelling which has less exposure to the radiation resources, when comparing the contained floor area.

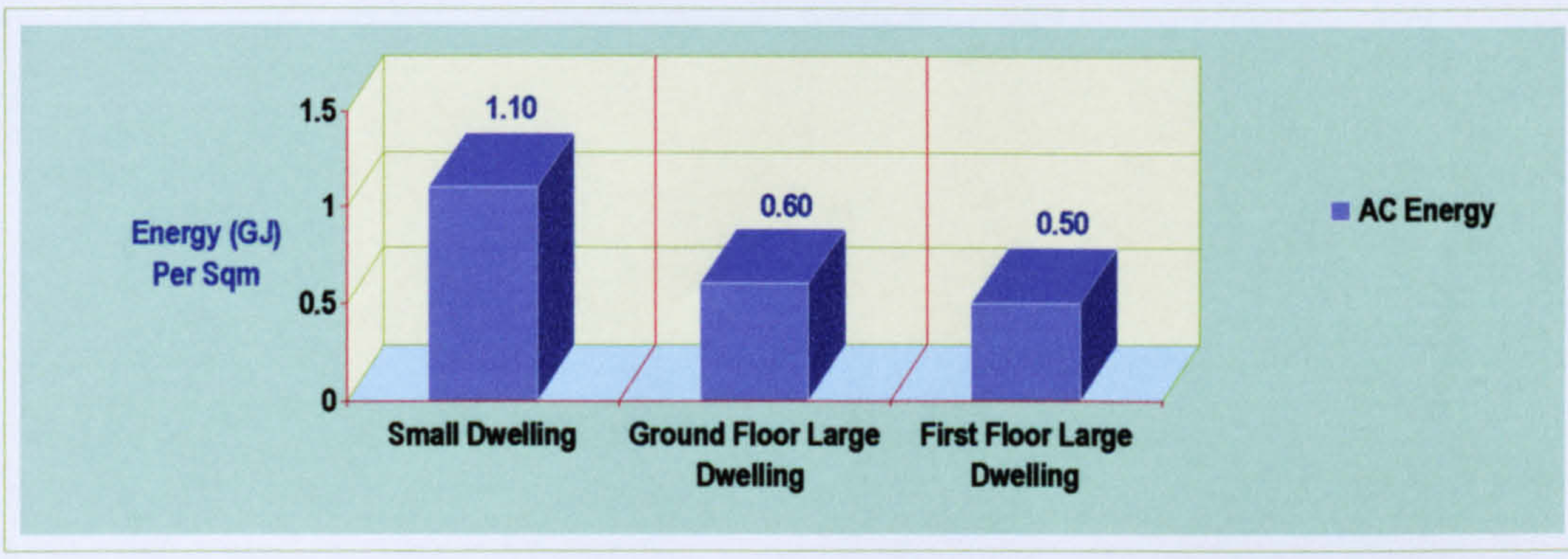


Figure 7.25. Air Conditioning Energy Consumption Per Square Metre of Dwellings

However, this simple per square metre comparison ignores the fact that the large dwelling consumes 95.9 GJ of energy, but the small dwelling only 29 GJ. By opting for the standard small dwelling type, approximately 75% reduction in energy demand can be achieved. Hence, wherever possible the large dwelling which is in any case unaffordable by most people, should be replaced by the standard dwelling.

7.5. ECONOMIC ENERGY

This chapter has discussed the energy reduction potential of various measures. In this respect, the energy saving will be described in terms of cost for the small dwelling (Figure 7.26).

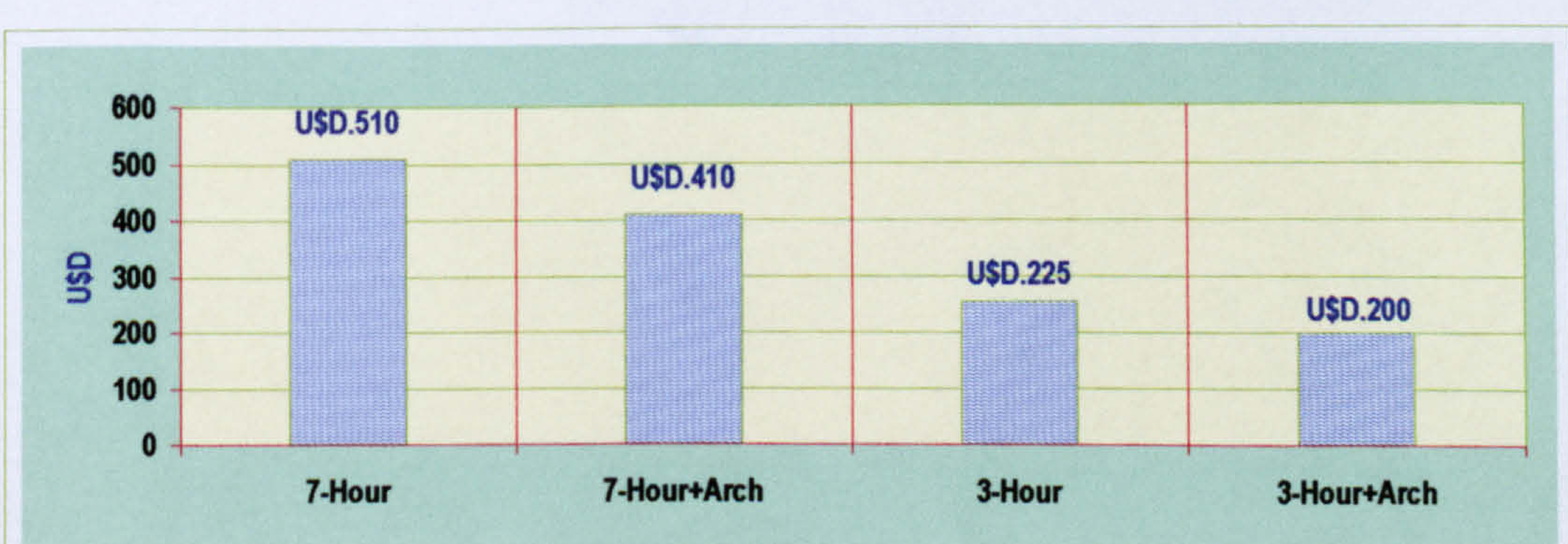


Figure 7.26. Annual Cost of Air Conditioning Energy Consumption

The result for the 7-hour occupancy with shading devices and insulation gives an average energy reduction of 20%, a saving of over US$ 100.

In comparison, the 3-hour occupancy uses less energy for cooling than the previous 7-hour occupancy. An average energy reduction of 50% for air conditioning energy cost, a saving of US$ 255, was achieved.

This result shows that energy consumption can be reduced by combination of 3-hour occupancy, insulation, and the design of solar shading. Through these strategies, the average energy saving was a 60% cost reduction, a saving of $ 310.

From Chapter Five, the research survey case study, the respondent's monthly expenditure on energy is shown in Figure 7.27. The average energy expenditure is US$ 40 monthly, or annually US$ 480.

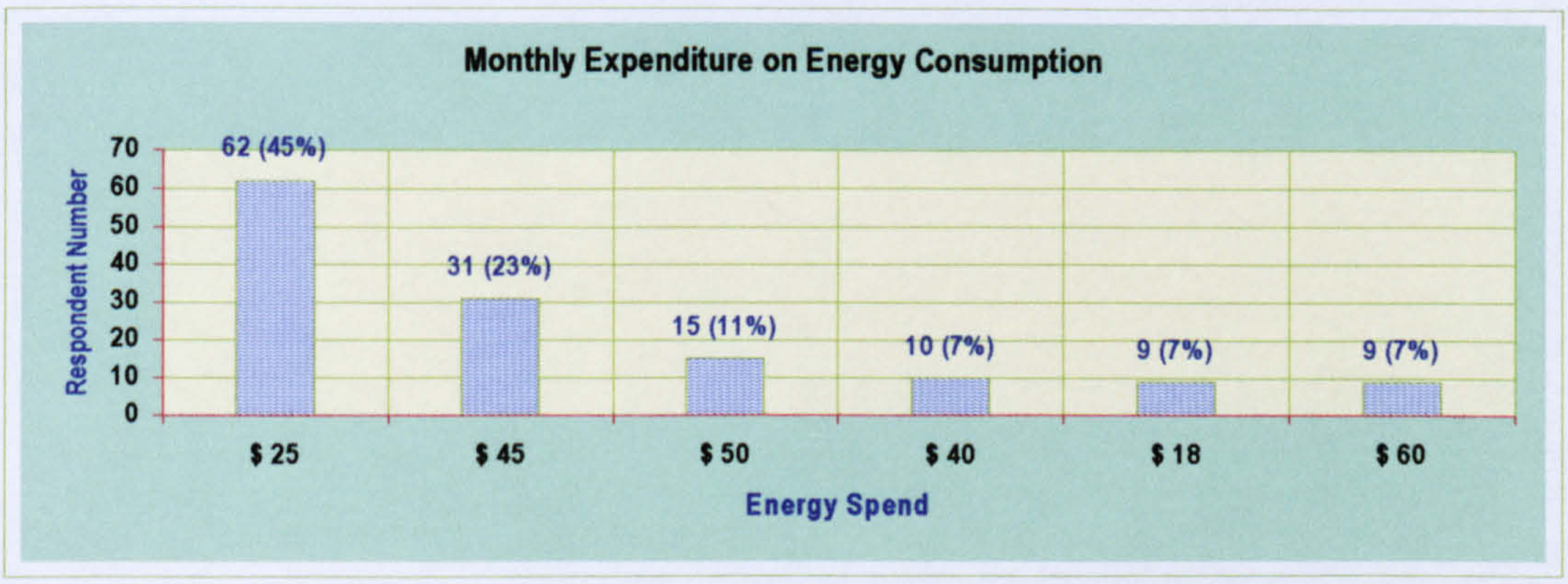


Figure 7.27. Monthly Expenditure on Energy Consumption.

The annual income for the research survey case study is shown in Figure 7.28 below. The average income is US$ 2,350 per year.

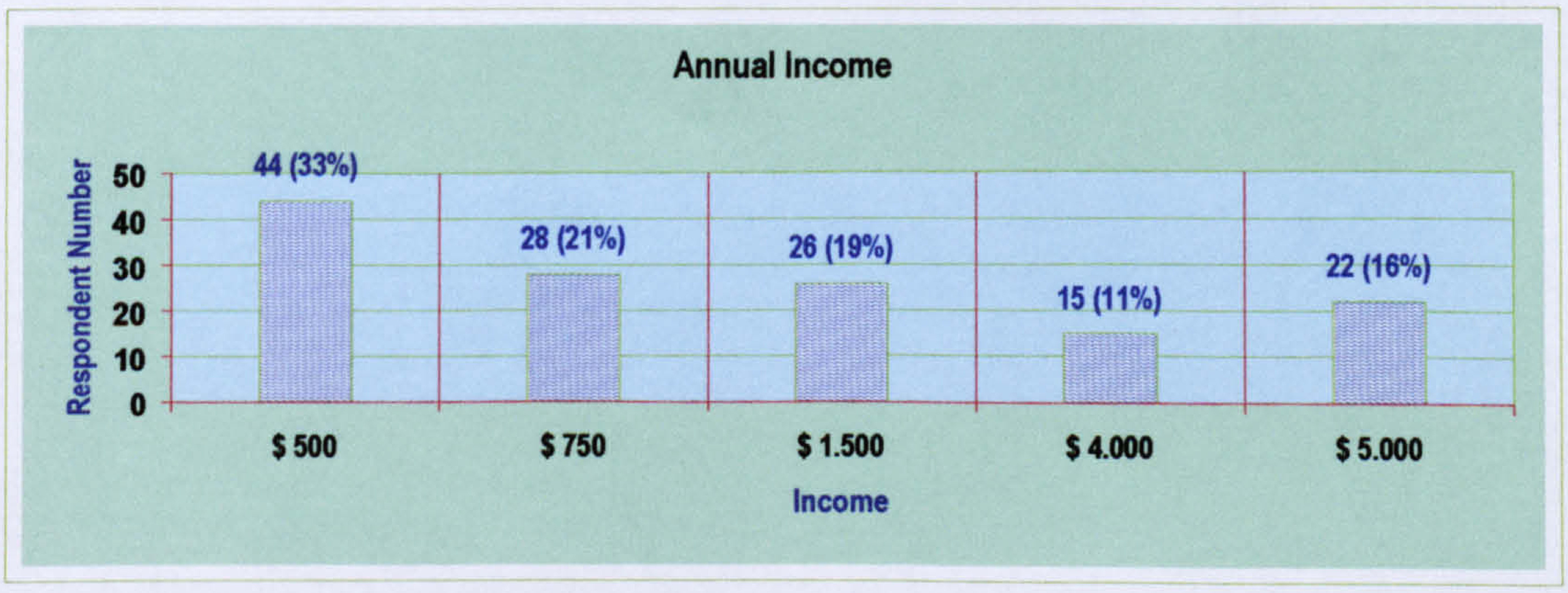


Figure 7.28. Annual Income

Comparing income and energy cost, the average expenditure on energy is about 20% of income (Figure 7.29).

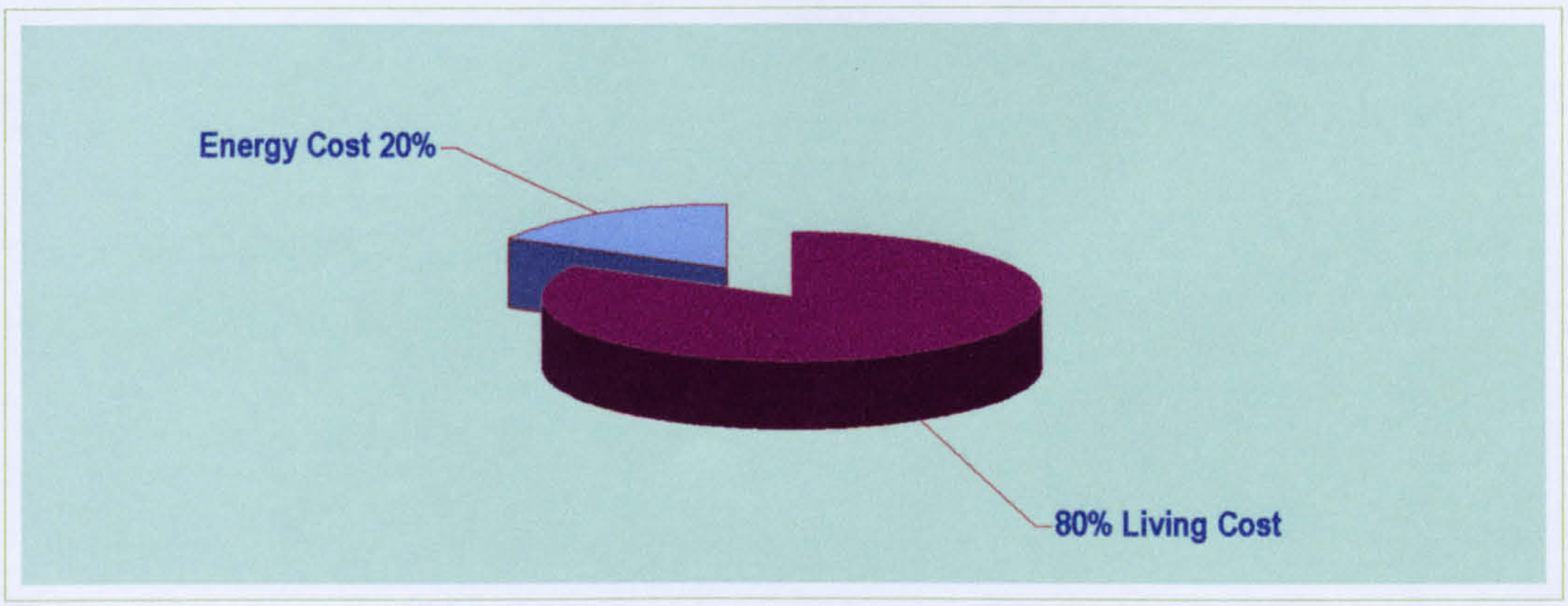


Figure 7.29. Living Cost and Energy Cost Ratio

In the outcome of the simulation, the average expenditure on energy is only 8.50% of income (Figure 7.30), a reduction of 11.50% spent on energy, and an annual saving of US $ 270.

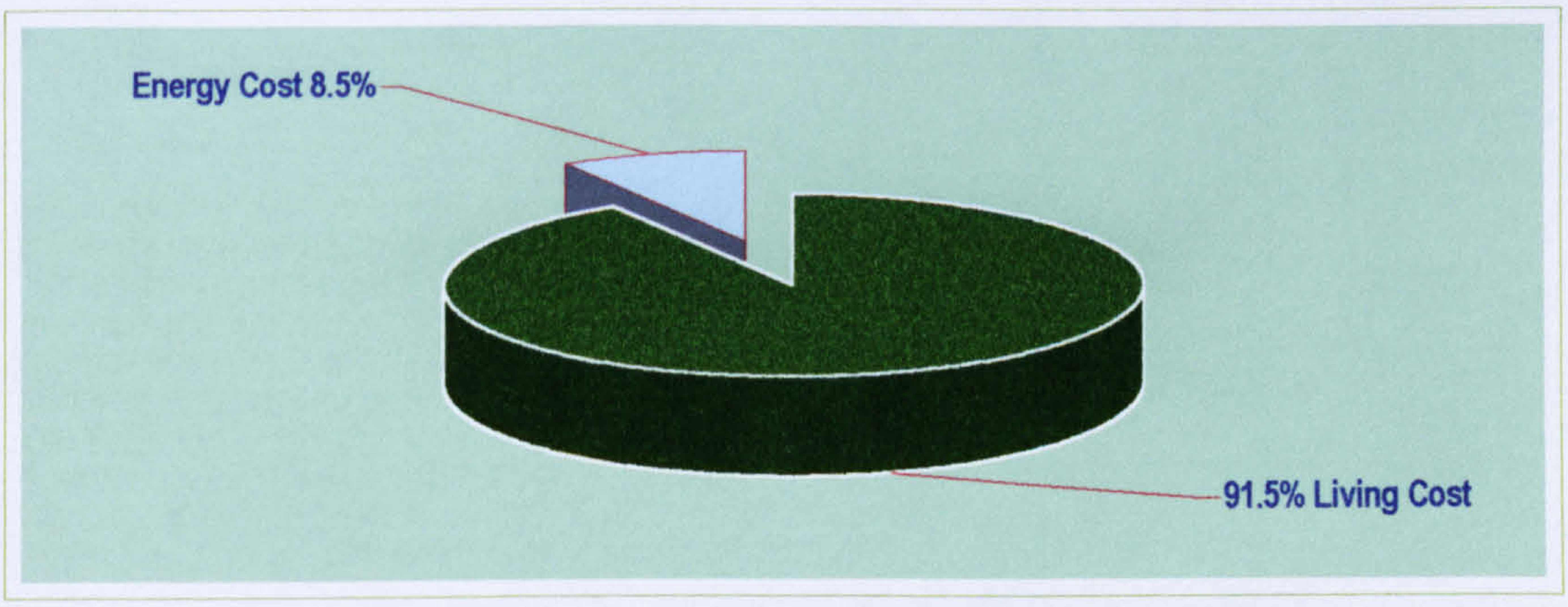


Figure 7.30. Result of the Living Cost and Energy Cost Ratio of the Research

7.6. CONCLUSION

From the viewpoint of energy conservation, the study reveals that without any design strategy applied to the dwellings, greater air conditioning energy consumption is required to achieve better thermal performance.

On the other hand, the outcome of the simulation indicates that time occupancy pattern, shading devices, and insulation have remarkable impact on making dwellings comfortable and at the same time reducing cooling energy demand.

This significant increase in thermal comfort could be achieved by including the following factors in dwelling design.

Firstly, from the economic point of view, particularly for the middle class dwelling standard type, when the dwelling needs to be air-conditioned, it is recommended that only the living room be cooled during the peak overheating period, between 18:00-and 21:00 p.m. During these hours, the occupier is usually occupying their dwelling after work. The bedrooms could be conditioned later, between 21:00 p.m. and 00:00 a.m.

Secondly, concerning thermal comfort, especially for the middle class and above, the cost savings can be converted to longer periods of thermal comfort by running the air conditioning for longer. The living room could be cooled between 17:00 and 22:00 p.m., with air conditioning in the bedrooms afterwards, perhaps between 22:00 p.m. and early morning.

In technical terms, it is always important to consider the walls, ceiling insulation, improved floor conditions and shading devices.

Therefore, for the larger dwelling, the same approaches are recommended especially when considering the demand for economic and thermal comfort. This is mainly to deal with the high energy use that has to be reduced, and to avoid thermal discomfort in the dwelling when a power cut occurs.

Clearly, these recommendations are only applicable to new dwellings, but could be applied to any improvements a house owner may be planning in the future.

However, the success of the traditional compound dwelling in terms of thermal comfort has been established previously in the thesis. Whilst accepting the site size of new urban developments, an element of the compound dwelling could be introduced. The next chapter explores the option of a hybrid design, which has elements of both the traditional compound house, and the compact, insulated dwelling.

Chapter Eight

COMBINED DWELLING DESIGN: INSULATION AIR CONDITIONING AND NATURAL VENTILATION STRATEGY

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Chapter Eight

COMBINED DWELLING DESIGN: INSULATION, AIR CONDITIONING AND NATURAL VENTILATION STRATEGY

8.1. INTRODUCTION

This section will offer initial ideas related to combined dwelling design, that come from the research outcomes; the computer simulation, the research survey and the previous-works reviewed. The literature reviewed is also included.

It has been clearly discussed in the overall previous chapters, that in a summary, the design of a dwelling in a warm humid region taking advantage of breezes and using air conditioning for indoor thermal comfort, has significant implications for the shape of the dwelling. What is more from the scientifically architectural features and computer simulation studies, adding insulation to the dwelling design modifies the energy efficiency and comfort within the dwelling.

In a design perspective, this will be done by combining insulation, natural ventilation and air conditioning as strategies within a dwelling to provide acceptable indoor climate conditions, and what consequence they have in terms of energy efficiency and environmental comfort.

This means that the decision on whether or not to use insulation, natural ventilation and/or air conditioning has to be decided upon during the very early stages of the design, when significant alteration to the house pattern is still possible (Antaryama, 2000; Karyono, 2000; Funo and Silas, 2000; Yeang, 1987).

In this research, the combined dwelling is designed as a combination of both naturally-ventilated and air-conditioned dwelling in which natural ventilation is used predominately whilst air conditioning will only be used when necessary.

Focus on natural cooling as the main point applied to the combined dwelling, the previous study on wind effect around dwellings clearly indicated that;

> *"Thermal discomforts during the night were more common than during daylight hours with a ratio of 3:1. In the former, airflow was sufficient for thermal comfort on only 60% of occasions due to an increased occurrence of calms. On most occasions, the latter, 80% was sufficient wind to restore indoors thermal comfort in a well-designed and oriented dwelling."*
>
> Aynsley, 1972.

On the other hand, the sun, the sky, radiant heat from the earth's surface, and the surroundings are primary sources of radiation, both direct and diffuse which effects dwelling. All of those elements will contribute to the heat gained by the building envelope, and thus the increase in indoor temperature, which creates discomfort, internal temperatures to be higher than the outdoor air.

In order to minimise the heat load from all surfaces of dwelling,

> *"solar radiation that reaches the dwelling should be controlled, and the dwelling's materials should be chosen that are able to insulate the dwelling."*
>
> Antaryama, 2000.

Antaryama (2000) further recommended, thus to lower the heat gains, the surface area exposed to solar radiation has to be minimised. This can be achieved either by manipulating the form and orientation of a combined dwelling, or by providing insulation and shade over the structure. Shading is also required to protect indoors from direct radiation, particularly through transparent surfaces. Similarly in order to alleviate the negative impact of heat indoors (i.e. temperature elevation of internal air and surfaces), dwelling materials should be specified according to their ability to prevent heat from being transferred from outdoors to indoors.

> *"A distinction is usually drawn between radiation through opaque and transparent surfaces. In the case of opaque surfaces, the effect is indirect, i.e. by heating the surfaces. This is usually manifested in the form of the 'sol-air' temperature concept: the combined thermal effect of solar radiation incident on the dwelling and ambient air temperature. On transparent surfaces, on the other hand, the effect is direct, i.e. by penetration."*
>
> Antaryama, 2000.

The impact of solar radiation, particularly direct solar radiation is dependent on orientation. Air temperature affects all surfaces of a dwelling in the same way. What is more, increases in indoor air temperature coupled with relatively high humidity, make thermal discomfort in the dwelling very difficult to accept.

To obviate these crucial problems in a warm humid climate, the combination of insulation, natural ventilation, and air conditioning is the best solution to achieve significantly efficient thermal performance, and a comfortable dwelling.

This statement is supported by the summary of the studies for Bali from the previous chapters which will be discussed at section 8.5 of this chapter.

In principle, the brief guidelines of combined dwelling design are based on the following conclusion;

- Natural ventilation is the most efficient way to reduce energy cost.
- Insulation is the best technique to remove heat stress.
- Air conditioning is the most comfortable way to eliminate high humidity.

The first and second parts above are paramount, however the third is used only when it is absolutely necessary.

8.2. INSULATION

The most common way to evaluate the benefit of additional insulation to the house is based on economical, energy efficiency and ecological considerations.

> *"Almost every insulating material in a house is rated in one of two ways. U-value measures heat flow through the material. The lower the U-value the more slowly the material transfers heat into and out of the house. R-value measures the resistance of a material to transferring heat. The higher the R-value, the more effective the insulation."*
>
> Time Mirror Magazine, 1999.

These values have an important relationship to the common dwelling elements within the house such as insulation on the floor, the ceilings, attics, roofs, windows, doors and walls.

To insulate the dwelling, the three ways of dispersing heat into the house must be highlighted:

- Conduction through the floors, walls, ceilings, roofs, windows and doors.
- Radiation through the room from any warm surface.
- Convection from hot surfaces which expands through indoor air.

In terms of insulation, Darwin (1993) emphasised, *"to reduce heat gains, impose energy barriers between living spaces and the outside, i.e. insulate. To keep a level humidity balance, isolation is needed."*

The insulation alternative that has the lowest cost is the favoured alternative from the economic point of view. As Erlandsson et.al. (1995) approved:

> *"In energy environmental perspective, the use of additional insulation is a well-considered decision."*
>
> Erlandsson et.al. 1995.

In terms of comfort and energy efficiency, the search for substitute materials for insulating the dwelling is an area of some interest in dwelling design.

8.2.1 Insulating Walls

In a warm humid region, heat energy radiates through the walls and is conducted through the solid framework of the house. The air between walls will develop convection currents that transfer heat from outer to inner walls. *"The orientation of the exposed walls also affects thermal discomfort house, due to solar heat through walls."* (Consumer's Research Magazine, 1998).

Massive walls exposed without special protection show dynamic equilibrium governed by the alternating events of warm humid climate, and further reduces the rather low insulation level of such walls.

Therefore, thermal insulation quality has to be taken into account in order to improve the indoor comfort conditions, and the thermal performance of the dwelling. The influence of interior and exterior insulation on the thermal behaviour of such walls can be determined with the aid of a recently developed computer program, which has been experimentally validated by comparison with field studies (see Chapter One at section 1.4.2. and Chapter Seven at section 7.1).

The results show that exterior insulation leads to drying the wall, with the drying rate depending on the permeability of the insulation. Interior insulation, however, results in rising humidity of the wall due to the decreasing masonry temperature. This effect is dependent on permeability of the insulation.

While exterior insulation also improves the thermal resistance of the dwelling, interior insulation has the opposite effect and increases the humidity risk. With regard to the latter, Kunzel (1998) concluded:

> *"Therefore, the interior insulation of exposed walls should be combined with humid climate protection completion."*
>
> Kunzel, 1998.

Both sides of the exterior insulation need to be faced by insulation reflectors, e.g. aluminium foil, on the outside surface to exclude the heat, the inside surface to keep cool and to eliminate humidity.

In Bali, Indonesia, coconut fibre is less costly, thermally friendly and environmentally applicable. In the previous experimental study by Funo and Silas (2000), this fibre has been proven to have good heat insulating properties. As they found:

> *"The heat stresses can be avoided by filling the wall with a non-conductive air-movement inhibitor-insulation i.e. coconut fibre which have $U=0.5 W/m^2K$, and face it with an aluminium foil radiation reflector. Wooden finishing walls can be constructed to exclude heat absorption."*
>
> Funo and Silas, 2000.

Infiltration and insulation are important parts of the design for thermal comfort in a dwelling; the air infiltration rate is reduced for the insulated alternatives due to insulated walls typically being more airtight. The vapour barrier is also an important element for comfort related to insulation. Erlandsson et.al. (1995) further recommended; *"to be effective, the barrier should be faced by roll reflective foil-paper insulation with a vapour barrier used for insulating the house on the interior walls. The insulated house can act as both a vapour barrier and insulator."*

8.2.2 Roof and Ceiling Insulations

In order to cut direct sun and effectively shut out heat radiation through the dwelling, the roof has to be designed as a double layer with heat insulation and air layers (Figure 8.1). The insulation material may be a locally available product such as coconut fibre. The air layer is placed on the outer side of the heat insulator, intended for spontaneous discharge of solar radiation. In this respect, *"the effect of the ventilating layer, and insulation material is remarkable in achieving comfort"* (Funo and Silas, 2000). In addition, Foarde et.al. (1996) suggested:

> *"However, this fibre thermal insulation material used in residential ventilation and air-conditioning (Hybrid) systems need to be controlled."*
>
> Foarde et.al. 1996.

Facing with aluminium foil on both sides of any fibre insulation can do much to reflect the heat and maintain cooling within the dwelling. To be more effective, *"in the warm humid type of climate, despite this insulation, the overhangs of the pitch roof design itself can reduce the direct solar heat through the external walls, and windows."* (Consumer's Research Magazine, 1998).

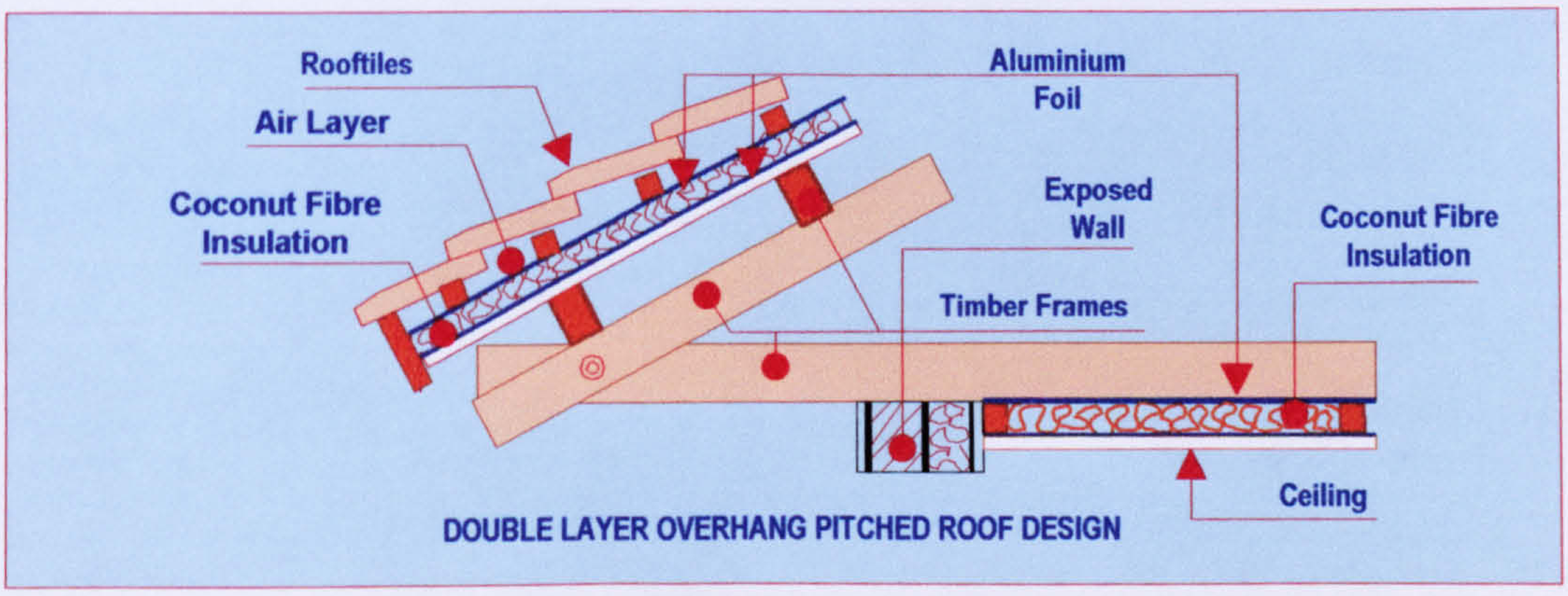


Figure 8.1. Roof Insulation

The attic space is designed for natural airflow and to be an air insulation barrier between the pitched roof and the ceiling. To keep the indoor living space cool and to minimise energy cooling for the air volume ratio to energy balance, the flat ceiling (only for air-conditioned rooms) has also be insulated.

This forgoing design is particularly useful to keep the upper part of dwelling cool, e.g. attic space, while at the same time the wind flow discharges solar radiation through roof space. This creates significantly better comfort either when employing natural ventilation or when air conditioning is required; the cooling energy demand is reduced since the flat insulated ceiling is protecting the living air-conditioned spaces of the dwelling (Figure 8.1 and Figure 8.2).

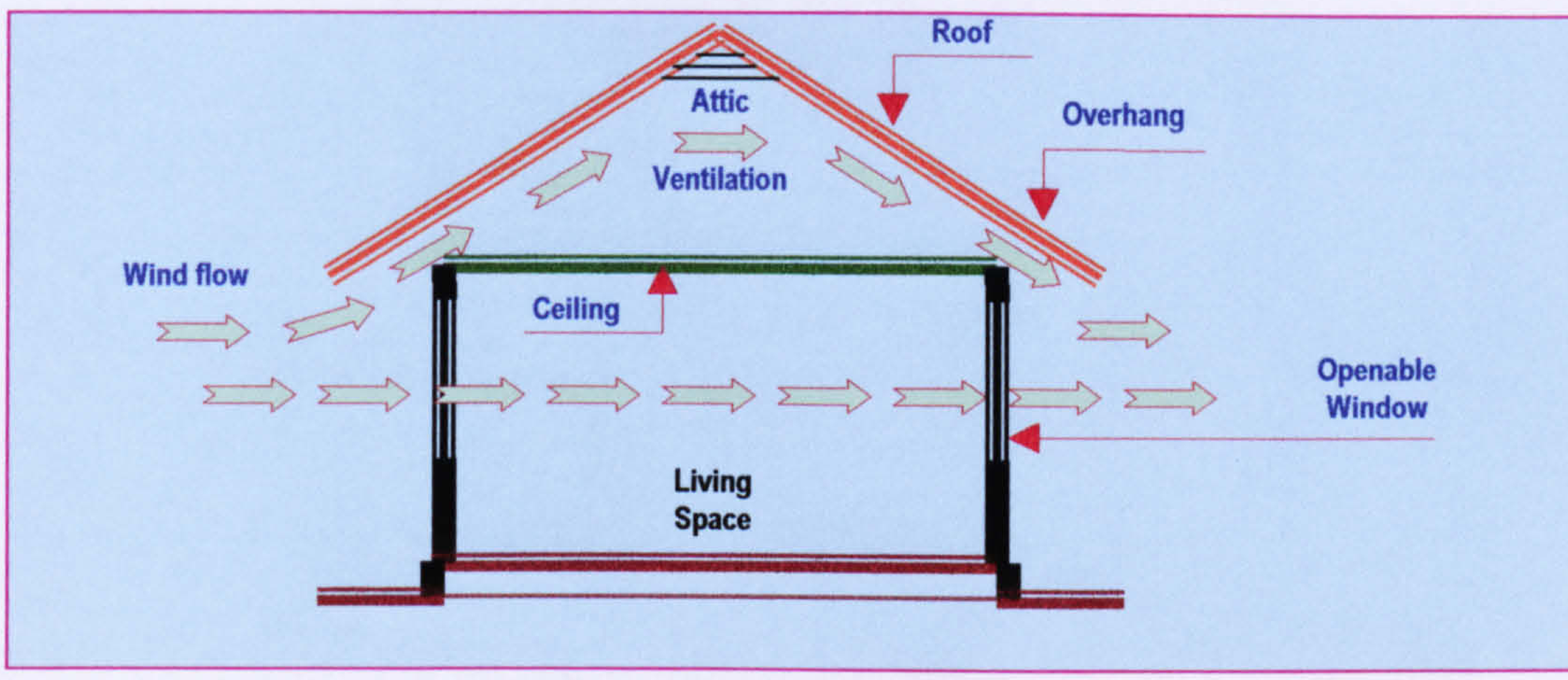


Figure 8.2. Attic Ventilation

8.2.3 Floor

The concrete floor slab with large thermal capacity may be utilised as a cooling storage system and insulation. The previous experimental study by Funo and Silas (2000) indicated:

> *"The floor slab surface has promising cooling radiation, cooling the rooms at night. It stores the cold, and provides coolant about 2°C lower for the next day."*
>
> Funo and Silas, 2000.

This kind of floor, with its damp proof membrane prevents humidity accumulation from the ground that may come through the floor into the dwelling, hence prevent more energy loss through the floor; also an insulated concrete floor can reflect 'coolant' back into the room. Thus, the concrete floor of the dwelling can function during the night as a thermal regulator to keep the floor cool.

8.2.4 Shading and Windows

In warm humid tropical climates, an integrated window design has to accommodate many functions such as to permitting day lighting, import sunshine into a room to reduce moisture, achieve comfortable ventilation to minimise humidity and provide a visual panoramic view for the occupants.

Shading devices and their impact on ventilation and occupant comfort are also very significant. Their role is the prevention of solar gains on the dwelling and the protection of the rooms from heat radiation.

Effective design of solar control systems aims to balance cooling and to exclude heat from the dwelling.

The use of appropriate solar controls may be either by the overhang of the pitched roof or veranda design. These shading strategies protect both the exterior and interior to control heat gain. *"Uncontrolled direct sunlight in this region is a source of very high heat, equivalent to a 1000W electric bar radiator for every square metre of exposed window area"* (Marsh, 1999). Exterior shades are more effective than interior shades because they block sunlight before it enters the veranda, the window, the wall and therefore the space of dwelling.

The extent of shading is given by Marsh (1999) below;

> *"An east and west orientation of the window needs a shade of at least 65% to 75% of the window height, a north facing window needs 45% to 60% for the amount of shade."*
>
> Marsh, 1999.

In a modern energy saving double glazing, interaction pane spaces are filled with inert gas heavy molecules, this being less conductive than still air. The latest development is a window with low-emission coatings on a thin plastic film, suspended in argon gas between dual glazings.

Economically, however, these glazing types may only be applicable for future development and impossible to set in the current dwelling design. In a warm humid environment, there is always the danger of a failure of the glazing system due to ingress of moisture between the panes of glass.

Using costly high-tech methods is not necessarily the only answer. Jalousies, sunshades, lattice blinds and awnings also help insulate doors and windows. This is recommended by Lisinski (1998):

> *"When air-conditioning is installed in a dwelling, air tightness has to be taken into account in a window design."*
>
> Lisinski, 1998.

When necessary, an openable louver-window may be applied.

"Concerning sunlight, windows can be as part of the wall oriented to fully take advantage of sunlight or they may need to be protected." (Mansfield and Saxon, 1997). In terms of thermal comfort, the later is paramount in a warm humid region. It was argued, *"through exposed windows, and walls in this respect, the orientation of the dwelling may also affect thermal comfort performance"* (Consumer's Research Magazine, 1998).

> *"However, from the point of view of solar heat gain, dwelling orientation, as observed from both field and simulation study, has little affect on the overall thermal performance of the house."*
>
> Antaryama, 2000.

Indeed, in this warm humid region, *"there are innovative shadow doors, and windows in the dwelling design, and interesting facets of energy use"* (BIAT, 1998), particularly to keep out heat, and save energy for cooling and *"the well designed windows should be made to have U values less than 1 W/m^2K"* (Roos, 1998) (see also Appendix - III).

8.2.5 Economic Insulation Material

To control a warm humid climate, insulation is useful to achieve comfort in a combined dwelling design. It insulates the heat from the sun that comes in through any exposed element of the building envelope, and it isolates cooling inside that may come out through any surfaces of the dwellings. In this design, the whole building is insulated, particularly the living room and bedrooms where the hybrid cooling system is applied.

A previous study in a warm humid climate similar to Bali, by Barkazi and Parker, (1995) indicated that 90% of home insulation came from traditional fibre, and a simulation model indicated energy savings were from 9% to 14% (3 to 5 kW/Day) of air conditioning use in the dwelling. Peak air-conditioning reductions in the afternoon, between 04:00 and 05:00 p.m. were less approximately 7% (154 Wh) (see Chapter Three 3.4.3.3). He further reached a conclusion:

> *"The insulation placed on exterior wall reduced the heat flux by approximately 80%, mid-wall insulation reduced the heat flow by 70%, and interior insulation out-performed both by decreasing heat flow by 60%."*
>
> Barkazi and Parker, 1995.

Conclusions from this previous study can be drawn that wall thermal performance can be significantly improved through fibre insulation in a hot humid climate, and have impact achievement on thermal comfort performance and energy efficiency of the dwellings.

In order to keep the dwelling comfortable, especially in air-conditioned homes airtight floors, doors and windows will eliminate unnecessary thermal energy loses. Insulation can reduce annual energy costs by between 20% and 70%, a saving between US $ 100 and US $ 366 (see also Chapter Seven at section 7.5).

8.3. AIR CONDITIONING

In a warm humid region, air conditioning design strategies conflict with natural ventilation design strategies; the former requires a sealed external envelope, whilst the latter requires the opposite.

Therefore as Eisert 1999 stated, *"keeping cool in the air-conditioned dwelling is seem to be a major concern, and the priorities appeared to be exclusion of heat and elimination of excessive humidity."*

In such a climate (e.g. Bali, Indonesia), *"the latter is a crucial problem in this area"* (Arnold, 1999), and *"one of the primary causes of discomfort"* (Givoni, 1981). *"To prevent warm discomfort, nevertheless, the relative humidity level should not exceed 60%"* (Nevins, 1975).

In warm humid climates, the peak cooling loads in air-conditioned dwellings tend to occur for a few hours in the afternoon (see Chapter Three at section 3.4.3.3).

The use of air conditioning offers great opportunities to transform dwelling design, without the constraints of passive measures required to provide a comfortable internal environment.

In designing a good air-conditioned dwelling, one is faced with the challenge of selecting a system that provides acceptable thermal comfort in the dwelling, while requiring minimum energy consumption.

In addition as Kennett (1998) suggested, *"it should look further, and consider the environment for the future, use it to their full potential, and protect the internal condition of the dwelling from the undesirable external environment."*

> *"By incorporating energy saving features and improved design of air conditioning, can be achieve a high standard of comfort in a warm humid climate dwelling. For these designs, providing a suitable thermal comfort indoor environment whilst addressing the cost and energy efficient is fundamental."*
>
> Trimarianto and Dudek, 1999, 2000.

As the simulation outcomes of air conditioning energy consumption strategies reveal, air conditioning energy consumption of the dwelling over the whole year is quite significant (see Chapter Seven at section 7.4).

8.3.1. Energy Efficient Air-Conditioned Dwelling

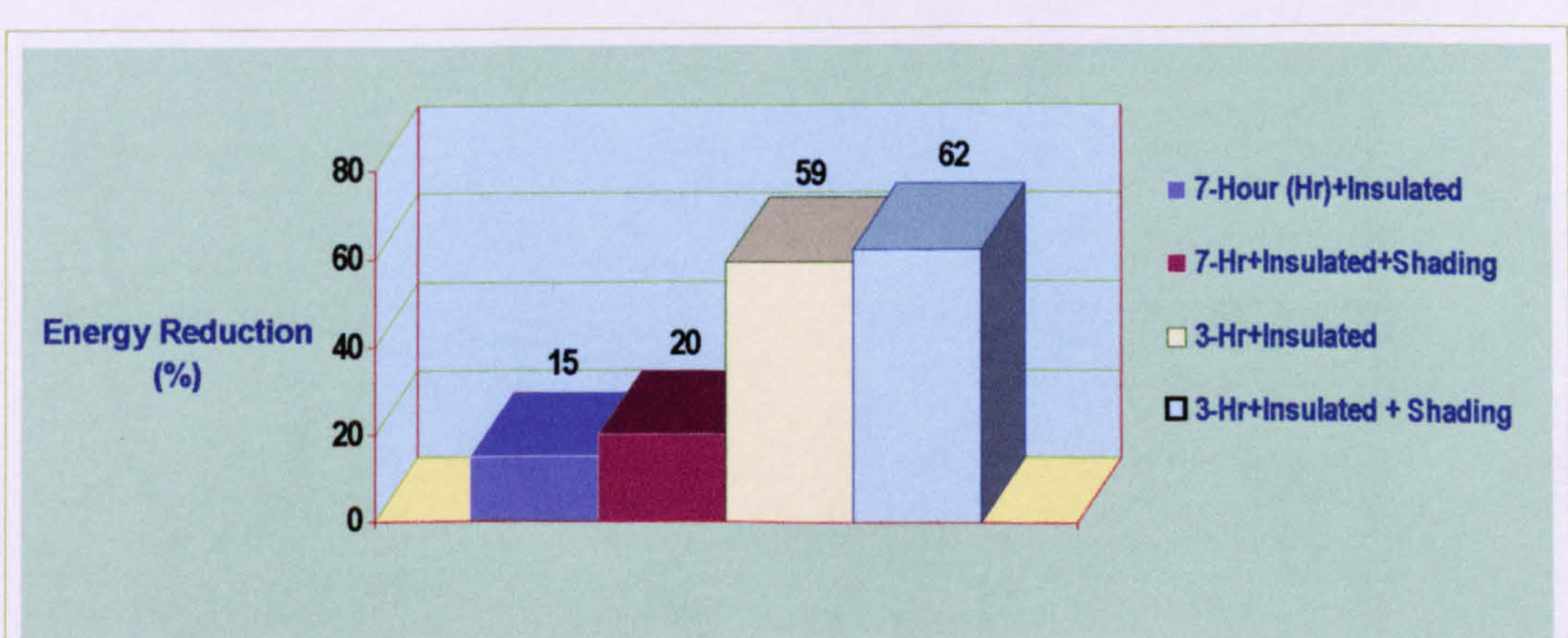


Figure 8.3. Dwelling Air Conditioning Energy Reduction.

Based on the time occupancy, the combined insulation, natural ventilation, and air conditioning strategy, the simulation outcomes show a significant range of energy efficient cooling for the dwelling (Figure 8.3).

The combined insulation, natural ventilation and air conditioning strategy has significant impact on energy reduction.

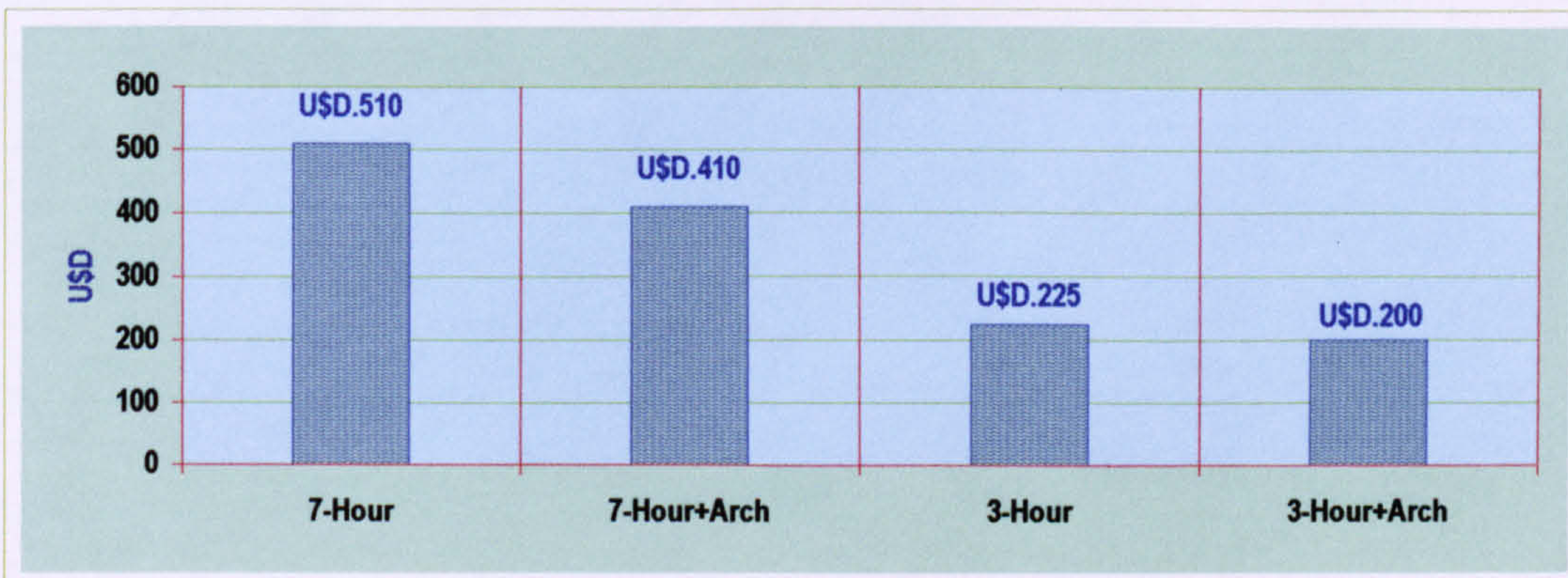


Figure 8.4. Annual Cost Reduction on Air Conditioning Energy Consumption

The greatest finding for energy efficiency shows energy saving of 62%, with US $310 saving in energy cooling costs (Figure 8.4).

8.3.2. Environmental Impact of Air Conditioning

> *"The air-conditioned ideal dwelling has a thermal envelope that completely isolates the inside conditioned space from the outside environment to eliminate space conditioning loads."*
>
> William, 1995.

However, ASHRAE standards require that even a perfectly sealed dwelling must be able to introduce fresh air to occupied spaces, and make provision to exhaust the stale air when necessary.

Therefore, it is important to be diligent in maintaining the integrity of the dwelling envelope, so that indoor comfort can be maintained with minimal energy use. More importantly as indicated from the computer simulation, *"demand-controlled ventilation strategies based on actual occupancy can become more commonplace and effective in reducing energy"* (David, 1995).

The dwelling has adjustable louver windows, which should be fully closed when the air conditioning is to be switched on, or open for natural ventilation.

Although ASHRAE provides widely followed standards (OHSA, 1998), however, the result of most previous dwelling investigations concerned with occupant discomfort in the dwelling attributes this to inadequate ventilation (Gorman, 1998; NIOSH, 1998; Stephen, 1998; Laliberte, 1996). Another previous research confirmed:

> *"The four-year study found that for subjects living in air conditioned dwellings, and living in natural ventilation dwellings, the occurrence of uncomfortable conditions was higher in the air conditioned dwellings."*
>
> WRAIR, 1998.

Indeed, when air conditioning is switched off, high humidity coupled with poor ventilation encourages growth of biological agents and accumulation of dust.

Taking all the above together as significant points, a cooling and natural ventilation strategy becomes more important for the combined dwelling design.

8.4. NATURAL VENTILATION

8.4.1. Natural Ventilation In A Warm Humid Climate

> *"Having considered all of the following aspects, the general principles related to natural ventilation to achieve thermal comfort of a dwelling in the warm humid regions is to provide effective ventilation to remove overheating, and to promote greater evaporation to eliminate high humidity."*
>
> Antaryama, 2000.

In warm humid climates, overheating coupled with high humidity is the most factors causing most discomfort in the indoor environment of dwelling.

Continuous airflow through ventilation adjustable louver-windows is constrained by outdoor climate conditions. When the louver-windows are open day and night and the diurnal temperature range is small, little reduction in internal temperature is possible.

If a contemporary dwelling is badly designed, the internal surface temperature may rise considerably above the conditions outdoors, causing discomfort; particularly during the hot months, in the afternoon and at night when the wind speed drops (see also Chapter Three at section 3.4.3.3).

Even with the maximum ventilation, there are limited conditions under which comfort can be achieved in these circumstances.

The continuous natural ventilation contributes to the improvement of thermal comfort conditions within the dwelling, while at the same time it is recognised as a very efficient technique that, when applied properly, leads to a significant reduction of energy consumption for cooling of the dwelling.

The combination of the above characteristics establishes natural ventilation as the best solution, especially during the cool months between July and September for areas where the prevailing climatic conditions favour its implementation (see Chapter Six at section 6.3.1).

Fans can be installed to cater for those hottest periods, particularly during in the afternoon, when breezes cannot restore thermal comfort indoors (Aynsley, 1999) (see also Chapter Three at section 3.4.3.3).

Natural ventilation thermal effect is dependent on the air temperature and airflow velocity in the interior of dwelling.

More specifically, airflow velocity is the most important factor for assessing thermal feeling during ventilation, because it relieves the 'hot' and 'humid' feeling even if air temperature remains constant.

It should be possible to induce indoor airflow distribution into the dwelling by adjusting the size and position of openings and the design of rooms, for given outdoor wind conditions.

On this point, the important philosophy of living outside inside which is common in the traditional compound dwelling becomes more significant (see also Chapter Two at section 2.3.1.2).

However, as Aynsley (1999) noted, *"this indoor thermal comfort in dwelling depends on the diurnal variations of air temperature, humidity, wind speed and direction."*

It is clear from the foregoing analysis that warm humid climates are the most difficult conditions to handle. As far as passive design is concerned, however, there are two important points to observe with respect to thermal stress. The first is heat avoidance and the second is provision of air movement.

To incorporate these into the design, heat exchange processes in the dwelling should be considered first. As discussed elsewhere, heat exchange in a dwelling primarily constitutes heat transferred through the dwelling envelope, either inward or outwards, heat from solar radiation; heat exchange; internal gains; and heat evaporated from the surface of the building.

Thermal balance in a dwelling is obtained when the sum of all of the heat flow elements is zero.

For hot humid climates this should be less than zero, in order to cool down the dwelling as well as to avoid any unnecessary increase in indoor air temperature (Szokolay 1987, 1980; Koenigsberger et.al. 1974).

As noted above, despite its limitations, ventilation can be used to lower the indoor air temperature. If copious and continuous ventilation is induced into the dwelling, it is even possible to reduce air temperature to outdoor levels (Givoni, 1991; Petherbridge, 1974).

Such a condition might, however, be rather difficult, or perhaps impractical, since it will require a very large area of openings.

The certainty that the indoor temperature is not much warmer than that outdoors and does not exceed the skin temperature is particularly important, if air movement to be used to assist evaporation of sweat.

However, since lowering the temperature alone in this situation cannot provide cooling, air velocity is the critical factor for restoring comfort rather than the volume flow rate.

As well as assisting in thermal comfort, ventilation is mandatory for health, and can have a significant impact on structural cooling where there is a wide temperature variation between day and night.

Apart from solar radiation, dwelling form can be exploited to induce ventilation and air movement. Many studies have concluded that the shape of dwellings determines the pattern and pressure of air that flows around them (Aynsley, 1991, 1972; Givoni, 1969; Olgyay, 1963).

Features included in the shape of the dwelling are projections from the dwelling surface (eaves, columns, and beams), and attached elements such as sunscreens, as well as the overall geometry. Equally important are openings in the dwelling. In this respect, the resulting airflow patterns are independent of air velocity.

Lippsmeier (1969) suggested, *"for warm humid regions, it is suggested that small alike dwellings are most suitable."* Providing that openings are available on all facades, such forms will tend to have better cross-ventilation than compact shaped ones, as in the latter rooms are likely to be arranged in more than single file, thus offering greater resistance to the wind.

As reported by Antaryama (2000), quite a long time ago Fry and Drew (1956) eloquently described how dwellings of warm humid regions dealt naturally with their climate:

> *"There is nothing nicer than to sit in a room well shaded by veranda or vine-covered pergola, to sit back from the sun as in the mouth of a cave, and to feel a gentle breeze passing over one from the cool wall in the rear. And to move out in the evening on to the veranda itself, the heat of the sun removed, in contact with night air and the stars."*
>
> Fry and Drew, 1956.

In order to meet the forgoing requirements in a dwelling, *"as a consequence, it is particularly useful to predict the air flow distribution in a dwelling by natural ventilation, and to design the entire dwelling layout in order to utilise the natural cooling resources"* (Papakonstantinou et.al. 2000)

A satisfactory dwelling ensures that the occupants feel comfortable, in an energy-efficient environment. In order to achieve this, an integrated dwelling design and courtyard pattern can be used to avoid heat stress, to cool the dwelling and to reduce energy consumption. The natural ventilation system is designed to ensure that the air entering the dwelling is as comfortable as possible and equally distributed.

8.4.2. Natural Ventilation Design

Because the movement of air in a dwelling accounts for a significant portion of energy consumption, designing energy-efficient dwellings is important.

In this respect, it is essential to control the dwelling ventilation requirements (NIOSH, 1998; Turner, 1998; Shriver, 1988). *"Each room should have two openings: a supply ventilation that blows airflow in, and an exhaust ventilation at an opposite place that moves old airflow out"* (Laliberte, 1996).

Keeping cool and adequate ventilation in the house to be appeared priorities and major concern (Billings, 1993; Billings et.al. 1989).

Proper natural ventilation must provide adequate fresh air, and sufficient natural ventilation provides comfort and energy efficiency within the dwelling based on the pressure differentials and stack effect. In a design perspective, Cook and McEvoy (1996) clarified:

> *"Natural ventilation is mutually reinforcing design strategies because it encourages adjustable windows, compound floor plans, and courtyard schemes that provide access to the outdoors from both sides of interior spaces."*
>
> Cook and McEvoy, 1996.

The courtyard represents the prototypical plan that generates natural ventilation. Wherever possible the dwelling plan has to be on an axis running East-West, which means that the window walls for ventilation face north and south to encourage cross ventilation through the dwelling and keep the dwelling cool. Adjustable louver-windows on both side rooms are identical and may occupy about 30% of the wall.

Windows can be manually adjusted to provide a constantly changing opening that assures stable indoor conditions, allows good ventilation and maintains cooling simultaneously.

When needed, in the hot months, use of a fan in the first instance can give some power assistance to the airflow movement for comfort.

The airflow through a dwelling opening is directly related to pressure difference across the opening (see also Appendix - IV).

Ideally, naturally ventilated dwellings should be located in park-like settings where the airflow is clean and there is no obstruction.

In fact, the opposite is true; the dwellings are small, and on a limited site. Therefore, the best option is to combine the traditional courtyard pattern, and contemporary dwelling design.

Dwelling design should allow natural airflow to achieve comfort, and good thermal performance. To achieve acceptable indoor thermal conditions, there must be a shift in thinking from using natural ventilation design as the only consideration. Comfort and energy management are equally important to achieve a properly comfortable dwelling.

In contrast, air temperature is influenced by various indistinguishable heat and humidity factors that sometimes make it almost impossible to control air temperature without air conditioning devices.

The best answer then is a combined dwelling design strategy.

8.5. COMBINED DWELLING DESIGN

Referring to the former discussion of the overall previous chapters, it is clear that by taking advantages of the compound, and using a tight design, the combined dwelling design strategy becomes an effective way to achieve a better thermal comfort performance and energy efficient dwelling suitable for warm humid climates. Particularly, this combined dwelling design will be applicable for Bali.

Firstly, the background of the study reveals that resolving housing demand can be achieved not only by building affordable houses and reducing construction costs through technological innovations but also by understanding comfort requirements and energy conservation in residential buildings.

In facts, even though clearly shaped according to social and cultural needs, the traditional house is also very well adapted to the physical environment and is more responsive to the local climate than the contemporary dwelling which is much more shaped by modern life-styles and requirements, and problems imposed by rapid urban development, all of which often outweigh climatic considerations.

However, it is not feasible to build typical Balinese traditional houses in the current economical situation, such is the pace of development that the traditional Balinese house may be replaced by a modern contemporary dwelling.

Therefore, a combination of vernacular architecture and modern technology have great potential to produce affordable dwellings, comfortable solution for the housing needs of Bali.

Secondly, the study cultural and architectural backgrounds of Bali indicates that the compound dwelling architecture of Bali is an expression of Balinese culture, in harmony with nature, being highly ventilated and thermally efficient, and this was the proper dwelling design for warm and humid climatic conditions.

However, due to the recent economic and migration pressures, it has become impossible to build the Balinese traditional houses as the common dwelling types. Compact, mass housing has been offered for the people to live in. In order to achieve thermally comfortable conditions in these compact dwellings, they may require air conditioning, and while to achieve energy efficiency, cross ventilation is necessary.

Accordingly, a combined design incorporating both strategies is required, and an understanding of climatic response in both traditional and contemporary Balinese dwellings is necessary as a guide to future building design.

Thirdly, the study environmental setting and thermal comfort of Bali shows that concerning the warm humid climate, over the beautiful island of Bali there are combination of high temperature and high humidity, coupled with high solar radiation, which traditionally leaves high rates of ventilation and air movement as the only practical way of restoring comfort.

However, in the thermal comfort and bioclimatic points of view, there were more individuals in an uncomfortable conditions than those who were feeling comfortable, causing the cooling methods have moved away from natural ventilation, and comfort is now more often achieved by mechanical cooling.

Therefore for that reasons, to achieve thermal comfort in warm humid regions and to exclude potentially at greater risk of suffering from thermal discomfort; the combination of compound dwelling design and air conditioning are providing effective natural ventilation, reducing external and internal heat gains, whilst shading devices, verandas, overhang, pitched roof and landscape are supporting the exclusion of sun heating, glare and admission of daylight and protection from, and disposal of rain.

Fourthly, the preliminary theoretical conclusions of the study basic dwelling design for modern housing development in Bali shows, that in order to achieve thermally comfortable a dwelling design, the goal of energy conservation, and a better dwelling design within a sustainable environment, can be achieved by taking the advantageous elements from the indigenous pattern and the technological approach, coupling it with passive and active cooling designs.

In another perspective, an effective strategy for meeting housing needs in Bali requires a comprehensive approach in satisfying many various design requirements into the one comfortable dwelling design as well as resulting in many more number of houses can be built, respect to the past cultural and appropriate to current conditions.

Fifthly, the survey research indicated that the levels of demand for combined natural ventilation and air conditioning, in both traditional dwellings and modern houses were comparable.

Therefore, traditional and technological cooling methods need to be proportionally applied, for comfortable dwellings.

Sixthly, the previous studies review found that for the thermal comfort performance and energy efficiency points of view, the comfortable conditions was remarkably achieved by integrated building design; using locally produced materials and combining passive-active cooling technology. This was shown by a greater proportion of occupants to be thermally more comfortable in the hybrid dwelling than those in the naturally-ventilated dwelling, and slightly more comfortable than those in air-conditioned dwelling. Despite the most comfortable conditions being found in the hybrid dwelling, that was with 90% of occupants feeling thermally comfortable, the energy consumption in this dwelling was only one-fifth (20%) of the energy consumption of the air-conditioned dwelling.

Finally, the result of computer simulation study reveals that by doing energy conservation strategies (e.g. 3-hour occupancy, insulation, and solar shading design), the average energy saving was 60% cost reduction.

From the forgoing discussions, it is can be concluded that combined dwelling design is a better way to achieve the goal of the research.

In order to meet the need requirements above, a new thermally comfortable combined dwelling for Bali is now designed.

Ideally, the combined dwelling design accommodates both the traditional-courtyard pattern and contemporary compact design. Traditionally adapted, the combined dwelling to be designed on a compound layout to create plenty of natural ventilation. Technologically, to provide energy efficient cooling, it has to be designed more airtight.

Therefore for that reason, the residential unit is designed as a compound-compact dwelling combining advantages of both the traditional dwelling and the contemporary house.

The courtyard pattern is taken from the traditional dwelling, and the performance compact-model is a reflection of contemporary dwelling design. The centre courtyard will allow heat gain and air movement to influence the indoor air quality, and ventilation of the dwelling.

Accordingly, as a basic point of the design for comfort, the idea of a combined dwelling is offered as an alternative to the standard compact dwelling (Figure 8.5).

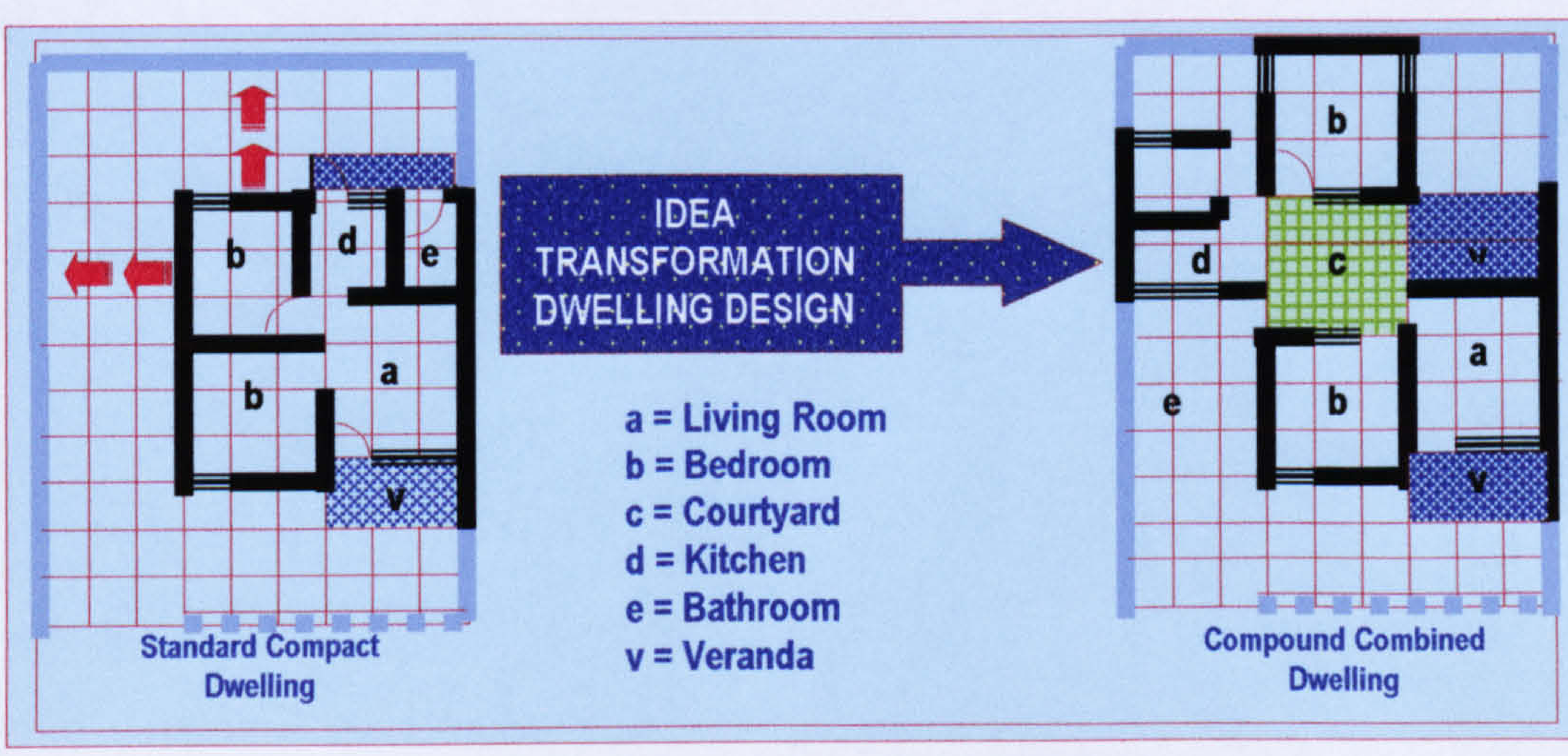


Figure 8.5. Transformation Dwelling Design

In this type of dwelling design, appropriates room volume and window type is necessary in order to optimise airflow ventilation. *"To achieve better solar gain and air movement control, the dwelling has to be built with a ceiling of not less than 3 metre height, and to create greater interior air velocities, the windows have to be higher than they were wide."* (Boutet, 1987).

For natural ventilation, windows that can open consistently are the best way to satisfy the need for comfort. This approach requires adjustable louver-windows and ventilation which occupants can control very easily. At night windows can be locked, while at the top of the windows and doors near ceiling level, louver-ventilation can be opened to maintain airflow.

The previous study on ventilation problem of dwelling indicates that, *"the use of a wing-wall veranda and perimeter can considerably enhance cross ventilation, and promotes average air speed in a room of about 40% of the outside wind speed (15% rooms without wing-walls)"* (Givoni, 1968).

In this respect, dwelling design should allow for rapid cooling of indoor air temperatures at night.

Whenever possible east-west elevation should have few or no windows admitting low sun, and the building envelope should be reflective and well insulated.

North and south walls of the dwelling should include large openings for ventilation and double banking of rooms should be avoided, to aid cross-ventilation and optimise access to breezes.

When necessary however, especially in the afternoon during the hottest months, combined dwelling can be functioned as air-conditioned house, air conditioning is used to cool indoor air, and to eliminate high humidity.

The combined dwelling design that accommodates both the traditional-courtyard pattern and contemporary compact design, and provides natural ventilation and air conditioning cooling systems is illustrated in Figure 8.6.

In an alternative configuration, the open-air centre courtyard can be used as the under-roof dining and family room (Figure 8.7).

The sections of the ideal combined dwelling design (courtyard pattern and dining room pattern) are shown in Figure 8.8.

This combined dwelling is designed as a prototype dwelling for a design solution to answer the problem of accommodation for a middle class income group, based on the family size of a couple with two children that was commonly built by national housing authority in Bali, Indonesia.

Figure 8.6. Ideal Combined Dwelling Design

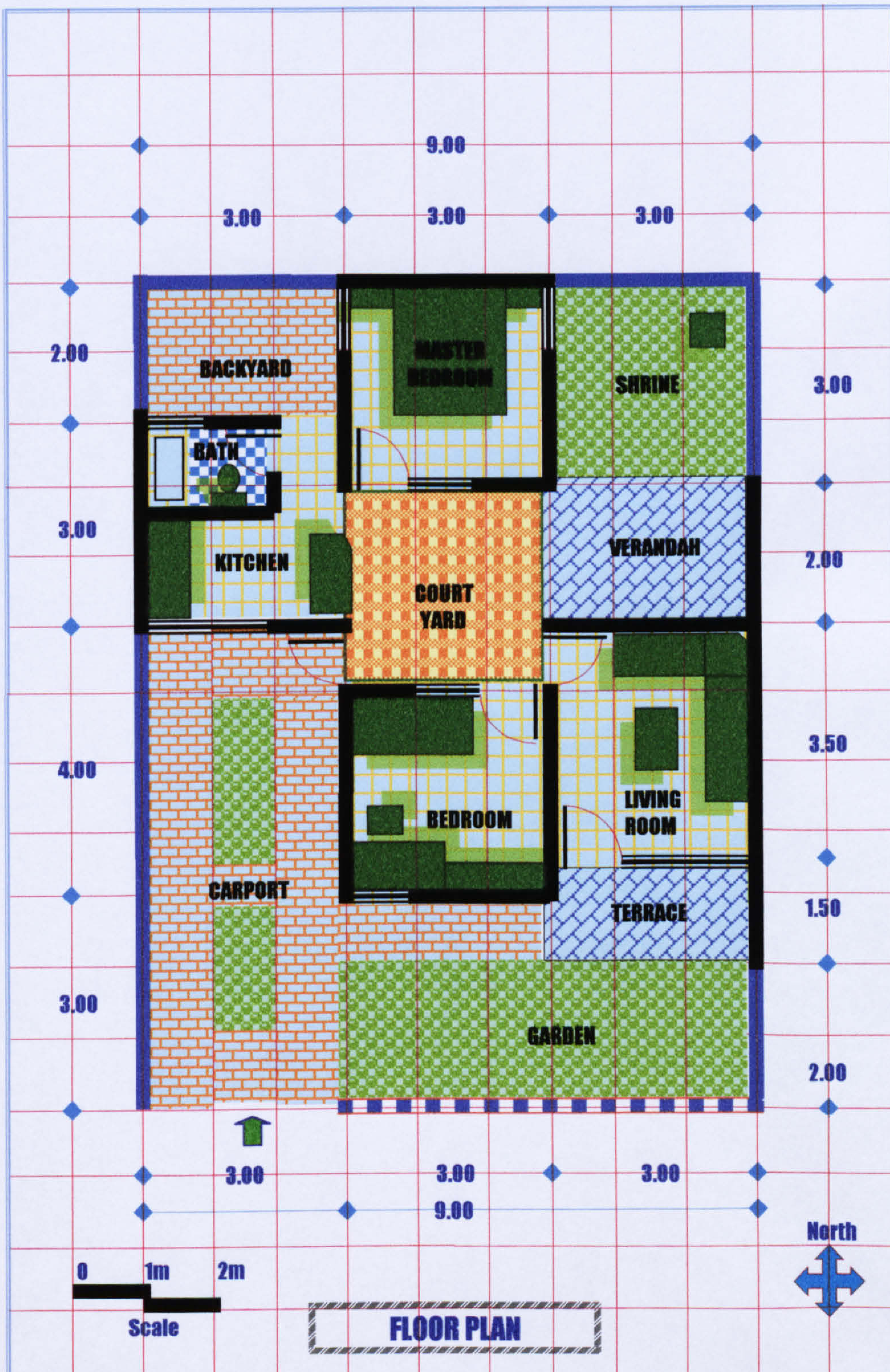


Figure 8.7. **Combined Dwelling Design**

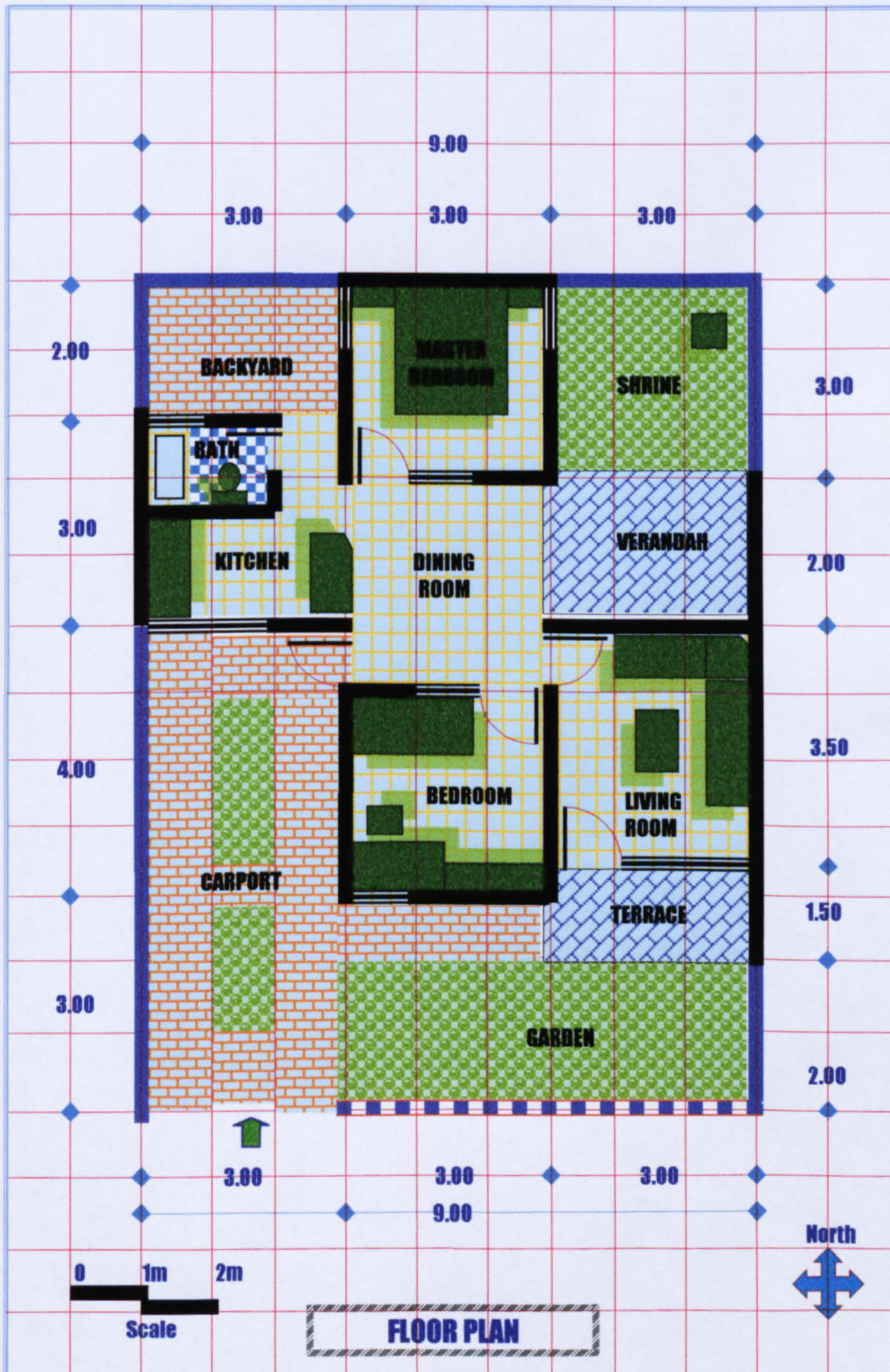
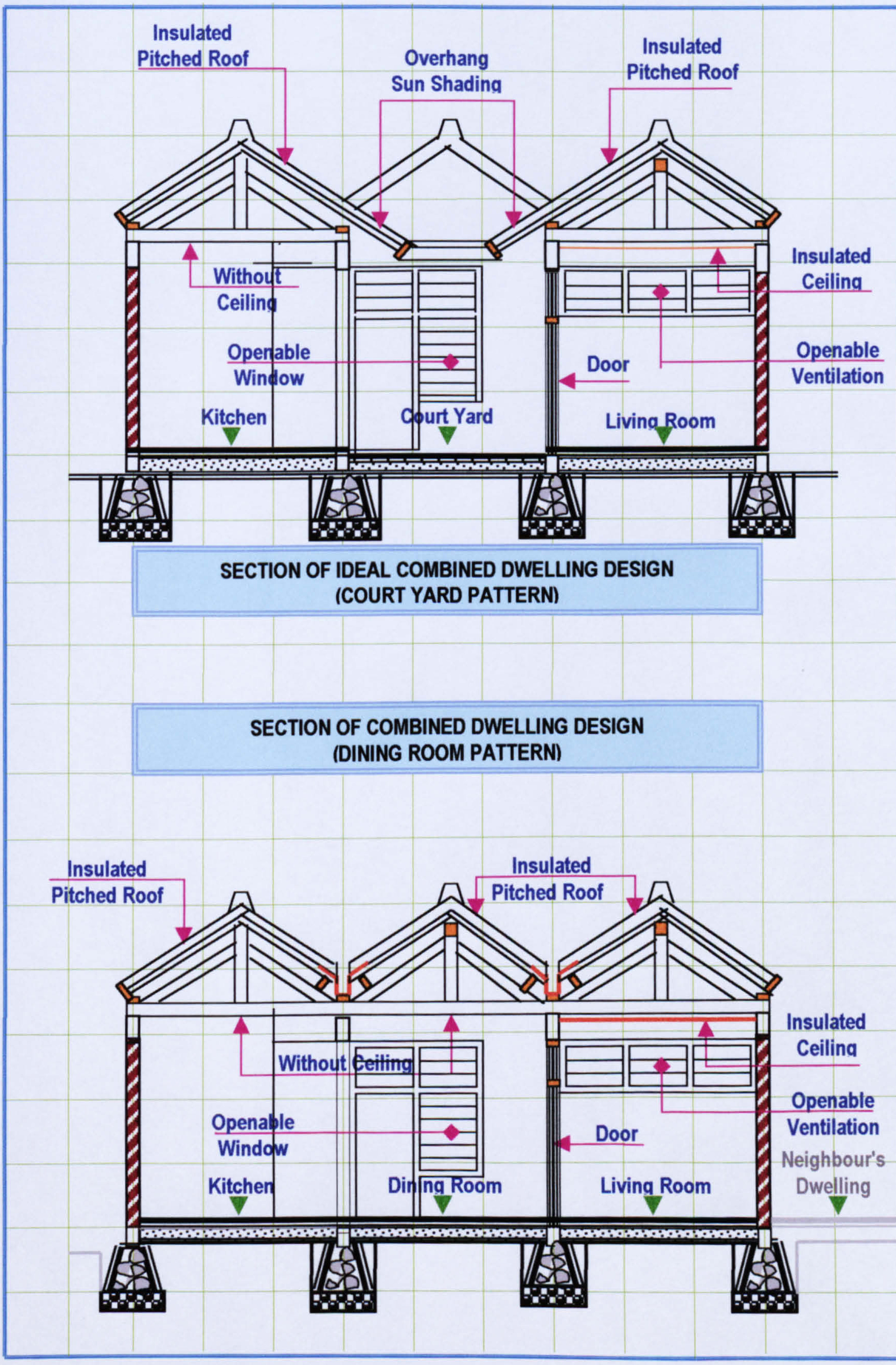


Figure 8.8. **Sections of Combined Dwellings**



Looking at these forgoing sections, flat ceilings are only applied to the rooms of dwelling which require air conditioning.

By using these design considerations, the courtyard dwelling pattern is restored, allowing both comfort by stack effect and cross ventilation (Figure 8.9 and Figure 8.10).

As can be seen in Table 8.1. below, in this combined dwelling strategy, airflow is easily induced and restoring comfort comparable in profile patterns to the traditional dwelling. When natural ventilation is not sufficient to achieve adequate cooling, each element within the dwelling can be isolated and air-conditioned. This minimises unnecessary cooling of spaces not occupied.

In this respect, natural ventilation uses the natural forces of wind and buoyancy to deliver fresh air into the dwelling to increase thermal comfort. Wind causes a positive pressure on the windward side and a negative pressure on the leeward side. The courtyard creates wind driven ventilation and stack effect ventilation.

Better thermal performance of the combined dwelling design is comparable to the contemporary compact dwelling; typically the air changes per hour (ACH) for the combined dwellings is twice of the contemporary compact dwelling (Table 8.1) (see also Appendix - IV).

Dwelling Types ACH Period		**Daily Average of Air Changes per Hour (ACH) MONTH**											
Time		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Traditional Compound Dwelling													
ACH night	19:00-05:00	34	42	30	31	48	51	63	62	51	51	41	34
ACH day	06:00-18:00	34	42	30	31	48	51	63	62	51	51	41	34
Corrected ACH night	19:00-05:00	25	31	22	23	36	38	47	46	37	38	30	25
Corrected ACH day	06:00-18:00	25	31	22	23	36	38	47	46	37	38	30	25
Contemporary Compact Dwelling													
ACH night	19:00-05:00	15	18	13	13	20	21	26	26	21	15	12	15
ACH day	06:00-18:00	23	27	28	28	38	40	50	49	40	30	24	22
Corrected ACH night	19:00-05:00	9	10	8	8	11	12	15	15	12	9	7	8
Corrected ACH day	06:00-18:00	13	15	16	16	22	23	28	28	23	17	14	13

Table 8.1. Daily Average of Air Changes per Hour in Compound and Compact Dwellings
Source: I.G.N. Antaryama (2000)

Protection from heat gains involves design parameters such as the dwelling form, layout (Figure 8.11: Layouts of Combined Dwelling Design with Orientation's Differences) and external finishes, solar control and shading of dwelling surfaces e.g. pitched roof and overhang (Figure 8.12: Roof Layout and Figure 8.13: Elevation), thermal insulation, and control of internal gains. During the cool months, June to September, unwanted heat can usually be passively discharged at night.

Looking specifically at dwelling layouts in difference orientations (i.e. Dwellings facing; North, South, East and West), the most important point to be considered is location of the shrine, a family temple. From this point of view, wherever the street layouts, within the site of dwelling a family temple has to be located at the Northeast area of the plot (Figure 8.11).

With reference to the Balinese Hindu beliefs, such as a dwelling wherever the location and whatever the building designs, the space of highest hierarchy is located at the Northeast corner of the house site. Within the Balinese philosophical culture, with cross section orientations between the highest (North) to the lowest (South) of the Earth, and the highest (East) to the lowest (West) of the Sun can not be changed (see also Chapter Two section 2.3.1.1).

In special cases for the ethnic minorities (e.g. Muslim, Christian and Buddha people) who are living in Bali, the shrine area of combined dwelling will be used as an open space without the necessity to build a family temple.

As has been described previously, this combined dwelling is designed as a prototype dwelling, a standard house type for people on a middle class income, based on the family size of a couple with two children that was commonly built by national housing authority in Bali, Indonesia.

Therefore, it is possible to modify the current compact dwelling, since it is believe that with reference to the combined dwelling design, an improvement can be applied through planning by the home owners in internal spaces to yield maximum comfort.

Figure 8.9. Natural Ventilation Pattern

Horizontal Airflow

Figure 8.10. **Natural Ventilation Pattern**

Vertical Airflow

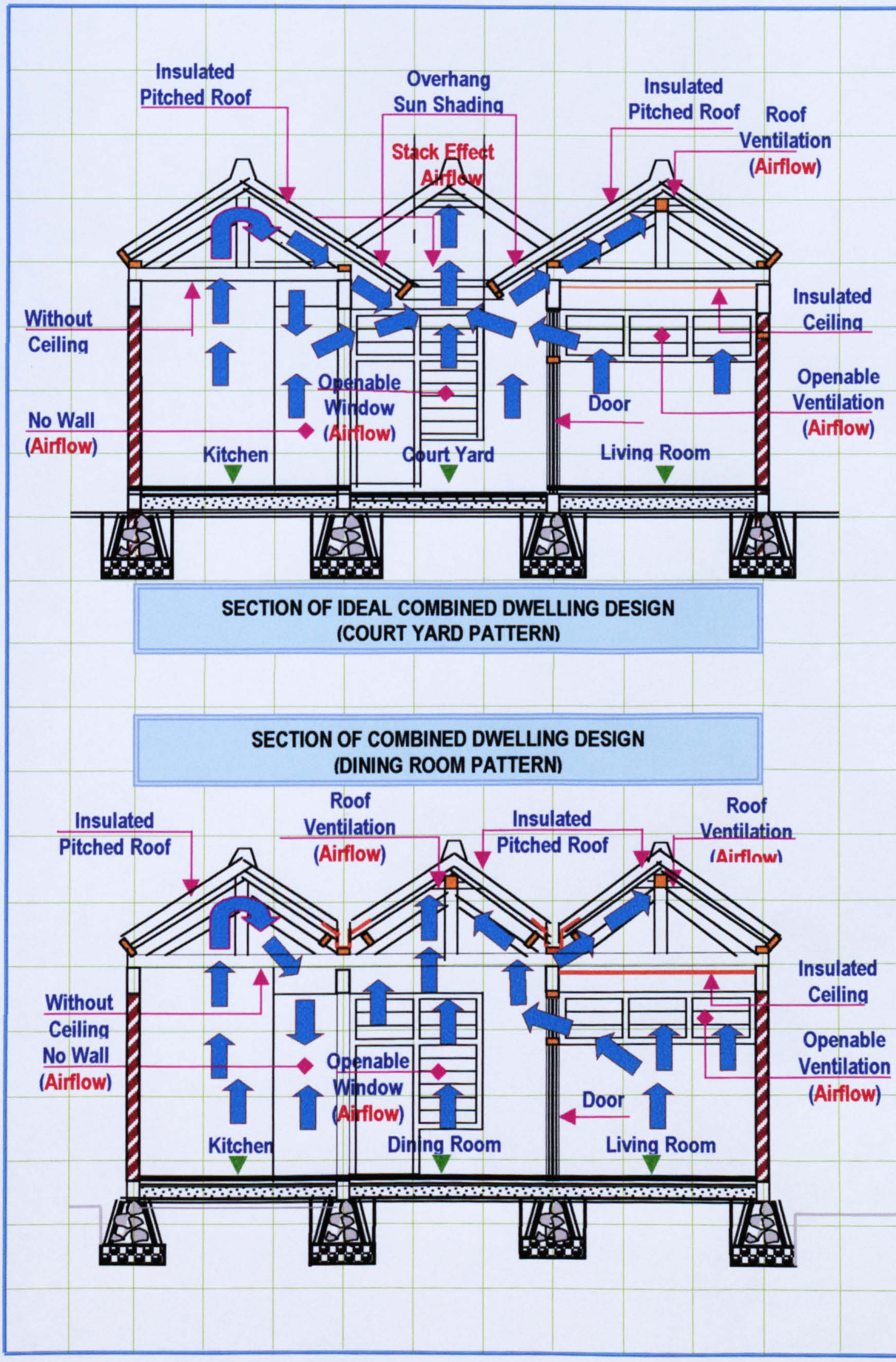


Figure 8.11. Layout of Combined Dwelling Design with Orientation's Differences

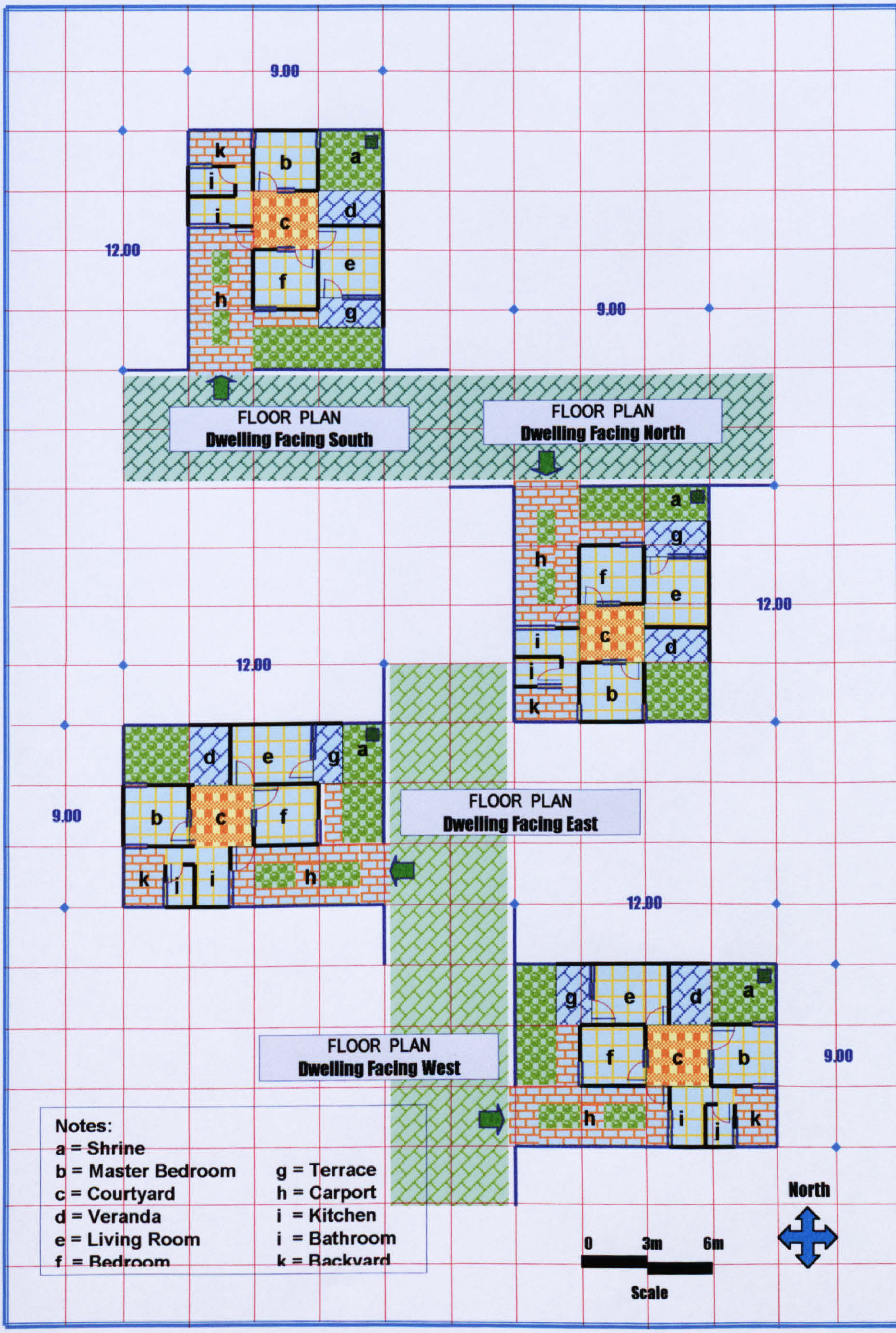
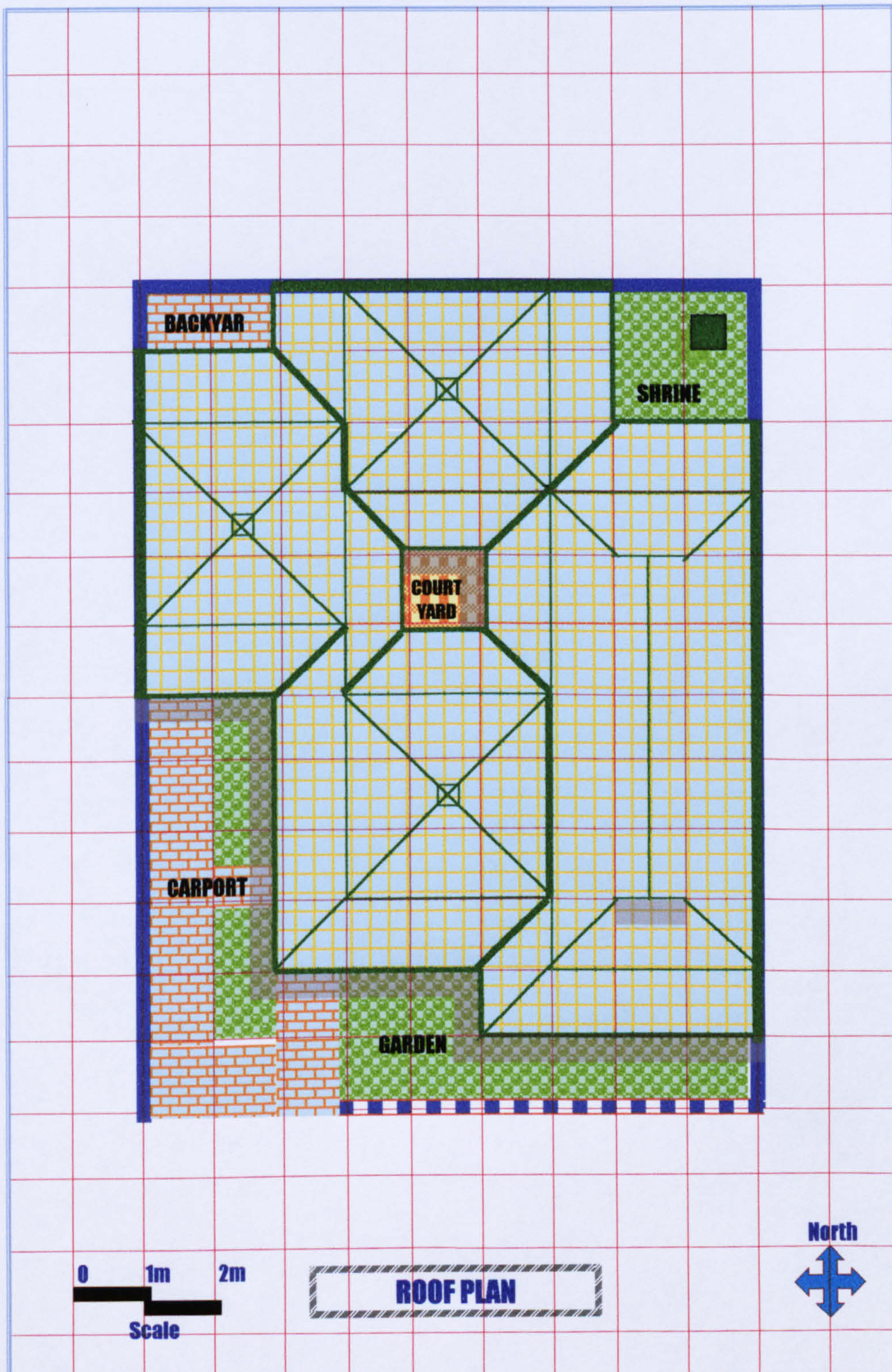


Figure 8.12. Pitched Roof Pattern of the Combined Dwelling



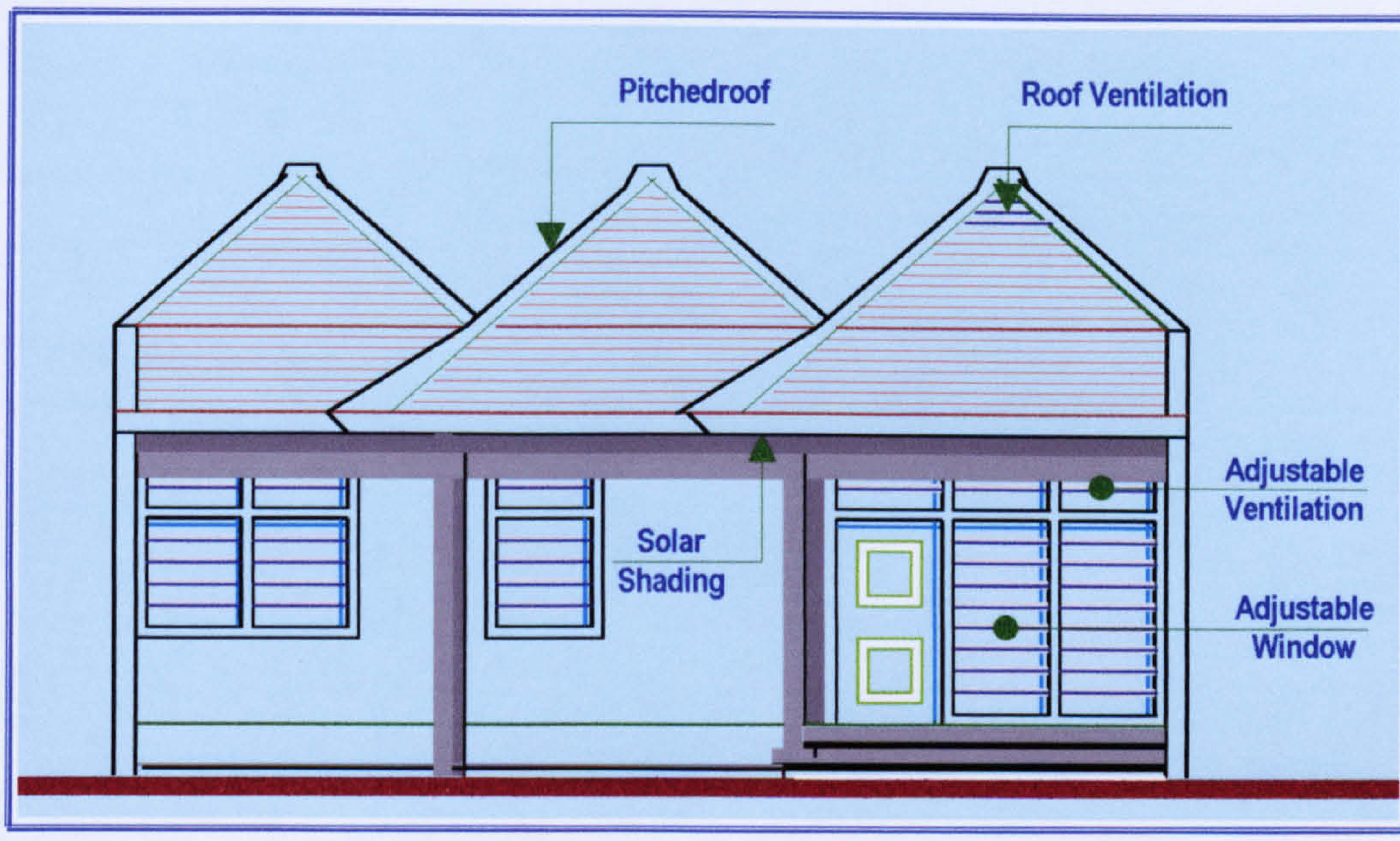


Figure 8.13. Front Elevation Combined Dwelling Design

Figure 8.13 shows the front elevation of the combined dwelling with pitched roof, overhang solar control, adjustable windows and ventilation design (see Figure 8.8 and Figure 8.10).

In respect to the warm humid climate, attic ventilation of this design offers an escape for all the heat that accumulates within attic space.

Air intake vents could be placed in areas of positive pressure and exhaust vents placed in areas of negative pressure, in order to guarantee a steady, cooling airflow in the attic. Attic ventilation is sufficient to keep airflow and air temperature in the attic space, reducing heat sun radiation through the roof and ceiling to the living spaces. This is useful from an energy efficiency point of view especially for both passive and active dwellings (see Figures 8.1, Figure 8.2, and Figure 8.8).

To live in a dwelling with no compromise in comfort or security, a mechanical ventilation system may be a more acceptable solution, because in extremely hot conditions, continuous natural ventilation is not always possible to provide comfort to people who are living in a contemporary, tightly insulated dwelling, in a society with security and privacy concerns.

Using fans to provide internal air movement is the first mechanical point to consider. An efficient fan can expel humidity ten times faster than wind passing through the dwelling. The Home Ventilating Institute (1998) recommends *"that a 10-square-metre house would need a fan rated at 30 l/s.* They further recommended, particularly for warm humid climates:

> *"If it is applied in a warmer and more humid climate, this should be increased by a factor of four."*
>
> Home Ventilation Institute, 1998.

An exhaust system of managed ventilation uses fans to drive warm air away from the dwelling. In the cool months, passive inlets are placed in living areas to keep airflow circulating through the house. In the hot months, however, active inlets have to be installed to achieve significantly thermal comfort. As the Home Ventilating Institute (1998) approved:

> *"These systems are well applicable for the hot humid climate."*
>
> Home Ventilation Institute, 1998.

This requires a balanced system that includes both exhaust and intake air, as the Canada Morgate Housing Centre (C.M.H.C.), (2000) suggested:

> *"All ventilation systems should be balanced, i.e., air in, air out, with intakes sized to allow easy entry of enough air to supply all exhaust devices."*
>
> C.M.H.C. 2000.

When required to match the flow ventilation systems, temporary passive ventilation by means of adjustable windows is necessary.

The hybrid cooling system is a combination of active and passive ventilation approaches. A balanced natural ventilation systems with matched intakes and exhausts is a priority, with active cooling system only used when it is needed.

This is the best way to satisfy occupants, and to achieve a significantly comfortable dwelling in the warm humid climates (Antaryama, 2000; Karyono, 2000; Adamson and Aberg, 1993; Mat, 1993).

In terms of the combined dwelling, Mat (1989, 1993) further approved:

> *"Alternative cooling strategy based on improved thermal performance dwelling and energy efficiency is combined passive and active (hybrid) cooling."*
>
> Mat, 1993,1989.

In order to generate a hybrid-cooling technique within the dwelling, the courtyard environment can play an important role to reduce energy demand by maintaining a suitable surrounding climate.

A field observation by Ca, et.al. (1998) indicated that vegetation could significantly alter the climate.

> *"At noon, the highest temperature surface of the grass area was 15°C lower than that of the concrete surface area and air temperature measured at 1.20 m above the former was 2°C lower than the latter areas. After sunset, the temperature of the ground surface grass area became lower than that of the air, and the grass area became a cool place whereas paved concrete surfaces remained hotter than the overlying air even late at night. This can lead to a significant decrease of in cooling energy in the dwellings."*
>
> Ca, et.al. 1998.

Appropriate siting of a house can provide natural solar protection and help to take advantage of local winds and breezes.

Nearby gardens enhance these effects and during the night may be up to 2°C colder than the surrounding built up area (Upmanis, 2000; Eliason, 1995; Santamouris, et.al. 1992). In addition, Taha et.al. (1988) found the important role of landscaping around the dwelling:

> *"Landscaping can play an important role in microclimate overheated modifications by evapotranspiration to save energy in air-conditioned dwelling."*
>
> Taha, et.al. 1988.

Design of intermediate spaces of this combined dwelling such as verandas, and courtyard may act as tempered microclimates in their own right, as well as having a role in wind channelling and solar protection for adjacent openings and surfaces.

8.6. CONCLUSION

To exclude heat from the combined dwelling, the inside of exterior walls should be insulated by coconut fibre, faced it with aluminium foil to reflect radiation. To keep cool, the interior partitions are insulated on both sides by coconut fibre, also faced on both sides with aluminium foil for thermal comfort dwelling.

In order to cut out direct solar gain, the roof has to be designed as a double layer with heat insulating and air layers. The air layer is placed on the outer side of the heat insulator, intending to quickly discharge solar radiation. The attic space is designed to be ventilated for natural airflow, and have insulation between the pitch roofed and the ceiling. In order to keep the indoor space cool, the flat ceiling has also to be insulated.

Ideally, a floating concrete floor slab should be designed as the cooling storage system, and for thermal insulation.

To eliminate energy cooling lost through doors and windows they must be well insulated, with exposed doors and windows protected by sun shading devices. The windows have to be configured with adjustable louvers.

Unconditionally, coconut fibre is the very best insulation for making a dwelling comfortable and less costly. By adding insulation, the combined naturally-ventilated and air-conditioned dwelling is more efficiently cooled.

The coconut fibre is easy to handle and the most economical insulation product due to being environmentally friendly, and locally available.

An insulated dwelling reduces annual energy costs by 20% to 60%, a saving between US $ 100 and US $ 300. These can be taken as reduced cost or extended use of the air conditioning.

Such a dwelling then can employ passive method, active system, or a combination of both, to modify the indoor climate. Viewing passive methods from the energy perspective has produced dwellings which combine traditional and contemporary designs. The courtyard and open spaces induce ventilation, and hence cooling.

For the control of thermal comfort, the occupants can open and close adjustable window louvers to provide appropriate air movement.

As a rule, the best cooling strategies are continuous natural ventilation, with a fan to cool the dwelling during the hot months, and air conditioning only applied when severe conditions demand.

For energy-efficient cooling at a time when changes in dwelling design are taking place to meet changing requirements, climatic considerations will remain critical in the design, especially if passive and active conditioning systems are to be applied.

The climatic response of the dwelling therefore, remains of great relevance and interest in order to modify indoor comfort by a combined dwelling design.

The goals of hybrid cooling technique for combined dwelling design in a warm humid climate may be briefly stated as follows:

- To use natural cooling means whenever possible.
- To supplement natural cooling when necessary by those simple mechanical means that requires the least energy.
- To employ sophisticated cooling equipment in the most efficient way possible at only those times whenever it is essential.
- To use natural, environmentally friendly local material and insulation to reduce energy cooling and to exclude heat from solar radiation.

In order to achieve the main objectives of the research in a wider perspective, thermal comfort performance of the combined dwelling design will also be testing over a range of energy conservation strategies by a study computer simulation in the next chapter.

Chapter Nine

SIMULATION ANALYSIS COMBINED DWELLING

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Chapter Nine

SIMULATION ANALYSIS COMBINED DWELLING

9.1. INTRODUCTION

Before the final conclusions of the study is drawn in the next chapter, this chapter will discuss the design simulation analysis of air conditioning energy required for a thermally comfortable combined dwelling in the warm humid climate of Bali. Accordingly, the background for this simulation analysis is highlighted below.

> *"Simulation is the process of developing a simplified model of a complex system and using the model to analyse and predict the behaviour of the original system. Why simulate? The essential reasons are that real-life systems are often difficult or impossible to analyse in all their complexity, and it is usually unnecessary to do so anyway. By carefully extracting from the real system the elements relevant to the stated requirements and ignoring the relatively insignificant ones (which is not as easy as it sounds), it is generally possible to develop a model that can be used to predict the behaviour of the real system accurately."*
>
> Aburdene, 1988.

It has also been indicated in previous chapter that hybrid-cooling technique for the combined dwelling is one significant way to achieve a thermally efficient building designed for warm humid climates.

In this respect, natural ventilation should be applied whenever possible, and air conditioning only used when absolutely necessary. In technical terms, Cook and McEvoy (1996) described:

> *"Natural ventilation is mutually reinforcing design strategies because it encourages adjustable windows as well as standard floor plans, and courtyard schemes that provide access to the outdoors from both sides of interior spaces."*
>
> Cook and McEvoy, 1996.

The goal is to produce dwellings with low operating budgets that respond to user needs. Care and investment are essential for a low energy design. As Architecture Today (1992) noted:

> *"The challenge for the designer is to design buildings such that each part works both architecturally and environmentally, and contributes to a fully integrated entity."*
>
> Architecture Today, 1992.

9.2. MODEL AND ASSUMPTIONS

9.2.1. Design Comfort Considerations

In this combined dwelling design, the following factors for comfort in the warm humid climate have been taken into consideration (see Chapter Eight section 8.5).

The compound traditional pattern, which has better thermal performance than the compact, contemporary house, is adopted. About 80% overheating is experienced in the compact dwellings, compared with only 40% in the compound dwellings. In addition, the periods of overheating are considerably shorter in the compound dwelling; generally less than 9 hours, unlike the compact dwelling where it is continuous through the whole day. All compound dwellings experience indoor comfort, but only during the coolest months it is possible for the compact dwelling to achieve comparable comfort levels.

These overall results clearly indicate that acceptable conditions are likely in the compound dwelling. The reason is quite simple; the half-open characteristics of the design, and the fact that the walls are less permeable help to induce a free flow of air through the building, dispersing any excess heat and bringing the indoor temperatures down to that of outdoors.

Comfort of the residential unit is achieved by a courtyard pattern dwelling which is designed as a compound-compact house.

The centre courtyard is quite important to allow heat gain and air movement to influence the indoor air quality, and ventilation of the dwelling. A reflection of compactness dwelling is diminished by performance of the open spaces at the front and each corner of the plot.

The heat gain can help to decrease the humidity content of the indoor air. To avoid overheating, however, direct sun radiation can be reduced to a minimum by the overhang pitched-roof with shading devices on the perimeter of the dwelling.

For these aspects, the dwelling cooling studies undertaken in the warm humid climate (e.g. Bali, Indonesia) have been taken into account.

To give one example, where there is high induced ventilation, the thermal performance of the compact dwelling can sometimes approach that of the compound dwelling.

The influence of dwelling design on thermal performance clearly indicates that the cooling degree hours for the property showing a tendency to increase from compound to compact houses. An increase in cooling degree hours was particularly marked in the compact house. In houses of compound types, the cooling degree hours are typically less. As Antaryama (2000) recognised in his research:

> *"A similar tendency is found with respect to the total overheated, and indoor comfort periods. In the compound dwellings, overheated conditions generally occur for periods of between 160 and 180 hours. In the compact houses, the periods were wider, extending towards higher values, with the majority of houses were experiencing overheated conditions for 220 to 280 hours."*
>
> Antaryama, 2000.

He further noted, since no one of compact houses suffers from a lack heating, the indoor comfort period among dwelling types is more or less that for overheating. An increase in the number of wall attachments will reduce the area of openings, which in turn will reduce the ventilation rate. Since ventilation is one of the primary means of heat dissipation in warm humid climates, any reduction will always result in heat build-up in the dwelling.

Therefore, combined dwelling will experience relatively long periods of comfort. As has been suggested elsewhere, this tendency has something to do with ventilation in the dwelling.

Broadly speaking, the open form adopted in combined dwelling is likely to offer a greater possibility of responding positively to the warm humid climate. The dwelling is staggered; the flow of air and benefits of the wind can be maintained. This is the case for the combined dwelling whose rooms are correctly arranged.

In this respect, Cook and McEvoy (1996) described the principle of supplying fresh air, which is applicable to the combined dwelling:

> *"The concept of natural low energy ventilation in architectural design of a building, is the principle of supplying fresh air to building interiors based on the stack effect, and pressure differentials."*
>
> Cook and McEvoy, 1996.

In the combined dwelling, natural airflow is achieved by providing windows with adjustable glass louvers. Each room of the dwelling is placed between outdoor-open spaces that have similar conditions to the courtyard. Terrace and veranda are included in this combined dwelling. In this respect Fry and Drew (1956) stated:

> *"Terrace and veranda are creating more thermal comfort in the indoor climate of the dwelling."*
>
> Fry and Drew, 1956.

Furthermore, *"it is even possible to achieve thermal comfort, provide effective ventilation to remove excess heat, and promote evaporation loss"* (Antaryama, 2000), with one condition; if plentiful, and continuous ventilation is induced into the combined dwelling (Givoni, 1991; Petherbridge, 1974).

Therefore in the combined dwelling; the stack effect, and internally courtyard drives air movement, and generates the natural ventilation.

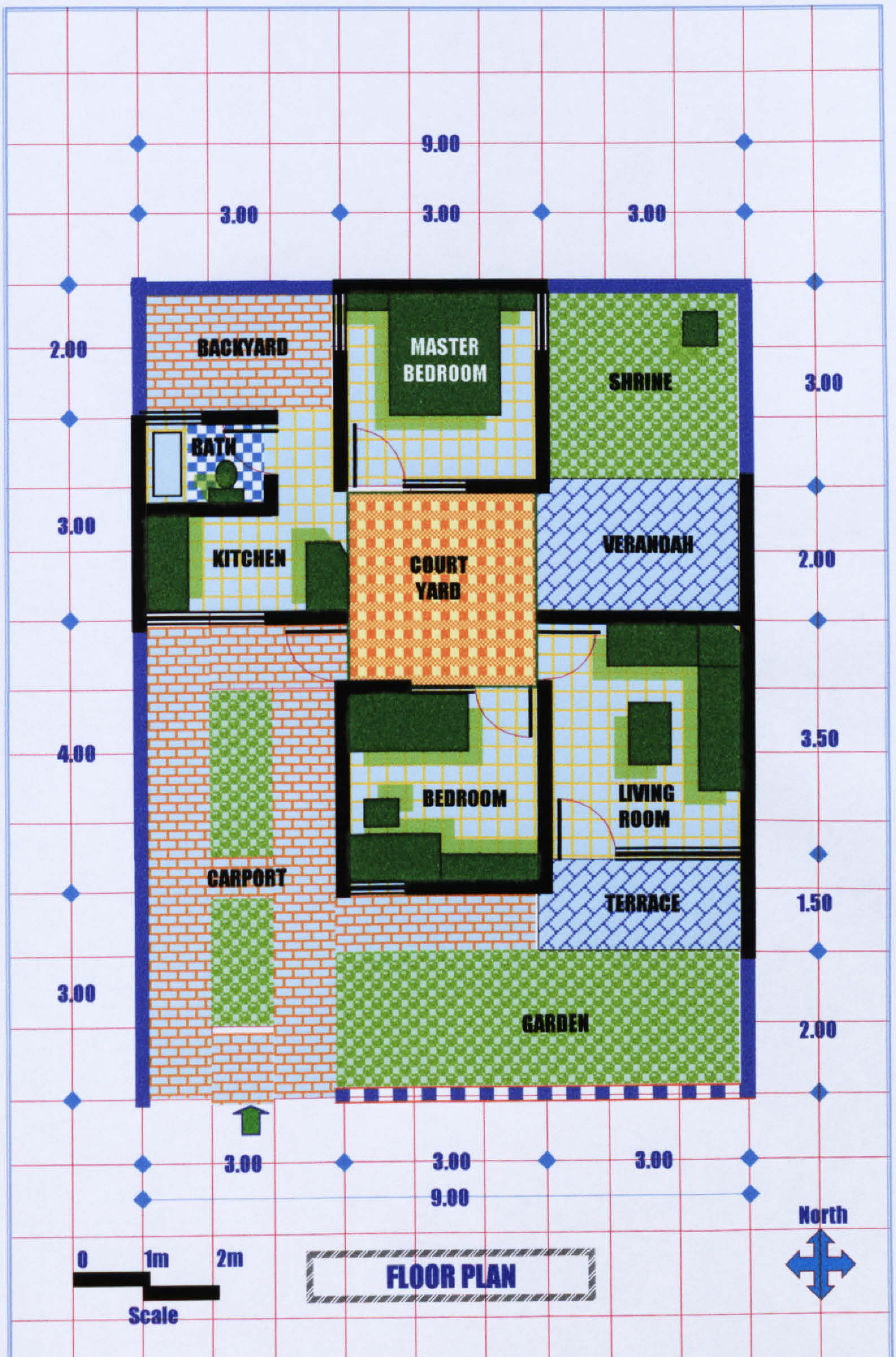
However, combined dwelling is also designed as air-conditioned house. Since comfortable and energy efficient are paramount in the combined dwelling;

> *"For this design, providing a suitable thermally comfortable indoor environment, whilst addressing the cost and energy efficiency, is fundamental."*
>
> Trimarianto and Dudek, 2001, 2002.

9.2.2. Dwelling Design

Figure 9.1. shows the dwelling design of 48 m^2 floor area on a plot of 108 m^2. It has two bedrooms, a living room, (which are possibly air-conditioned when required), kitchen and bathroom. This has floor area ratio of 50% to the plot site, which means the remaining 50% of the plot is outdoor open space that can help to maintain thermal comfort, ventilation and indoor air quality of the dwelling. The basic module of habitable space is 9 m^2 which is similar in size for both the individual traditional dwelling, and standard contemporary house.

Figure 9.1. Combined Dwelling Design



9.2.2.1. Floor

A concrete slab is used, being *" inorganic vapour permeability material which is the best choice of floor structure, and improves thermal mass, while this flooring concrete is both heat and sound insulating, and can be sealed by epoxy resins against capillary action and moisture"* (Adamson and Aberg, 1993). The reason is understandable that:

> *"This floor slab has large thermal capacity, and promising cooling radiation."*
>
> Funo and Silas, 2000.

Floors are finished with ceramic tiling, which has a good thermal performance and is regionally available.

9.2.2.2. Walls

The walls are made of masonry and insulated to combat heat radiation. The inside wall insulation is made of coconut fibre, which is locally available and thermally acceptable (Funo and Silas, 2000).

Both sides of the insulation are faced with aluminium foil, externally to reflect heat, to reduce radiant transfer. Both sides of the wall are plastered. The inside wall, which is also insulated, is covered by wooden material and painted (see Chapter Seven at section 7.3.4.1., Figure 7.5).

> *"Outside is painted a bright colour, with overhanging roof shading devices that are helpful to reduce unnecessary heat radiation."*
>
> Adamson and Aberg, 1993.

9.2.2.3. Windows

Wide, adjustable-louvers windows are installed in each room, one opposite each other, as Boutet (1987) found that *"wide windows create greater interior air velocities than narrow ones."*

In this respect, Adamson and Aberg (1993) discovered:

> *"These flexible louvers are useful for passive ventilation when open, and closed to keep airtight when required for the active house."*
>
> Adamson and Aberg, 1993.

The performance of airflow pattern that depends on air velocity (Aynsley, 1991, 1972; Givoni, 1969; Olgyay, 1963), is generated by the open spaces available in the combined dwelling.

This challenge of window design is to find a strategy which suits these two conflicting approaches, with air conditioning requiring a 'closed' construction and ventilation an 'open' construction (Trimarianto and Dudek, 2000). To be more effective, the reflecting glasses for windows are applied. As Roos (1998) proved:

> *"Sun reflecting glassed is best from the energy view point to be applied, where a 50% reduction of the direct, and diffuse radiation at 30% glassed area of the facade house will reduce by 25%-40% rooms cooling loads, and reduce about 20-30% annually compared with unshaded glass."*
>
> Roos, 1998.

As another way to protect windows in this combined dwelling, however, *"a good overhang roof, projecting 1 metre has to have the same effect as 50% shading of the incident direct, and diffuse radiation"* (Adamson and Aberg, 1993). Features of the windows include attached elements such as sunscreens and fins.

9.2.2.4. Ceiling

The rooms such as, kitchen, bathroom, and verandas that are wholly naturally-ventilated, follow the traditional attic-ceiling pattern. In the living room and bedrooms that use the combined cooling system, flat ceilings are used. These ceiling are designed with 3.00 metre height. As Adamson and Aberg (1993) suggested:

> *"To reduce cooling loads, however, the flat ceiling height should be kept to a minimum, and 3.00 metre height seems to be acceptable for both passive and active cooling systems."*
>
> Adamson and Aberg, 1993.

9.2.2.5. Pitched Roof

Combined ventilation and insulation for the roof, and attic can keep heat gain at a reasonably low level, and the ceiling temperature close to the living space temperature of the dwelling, when the following design and material are applied;

- *"It has been found that in many cases a height of 400mm ventilated air spaces can be required."*

  Adamson and Aberg, 1993.

- *"Coconut fibre insulation material with U=0.5W/m2K is chosen, and a vapour barrier (i.e. sheet aluminium foil) be placed on the upper side of the insulation."*

  Funo and Silas, 2000.

- *"Due to being too difficult to handle, heat gain in the ceiling temperature near the room air temperature, flat roofs, and unventilated air spaces such as dead attics should be avoided."*

  Wang, 1992, 1996.

The shading overhang of the pitched-roof, at 1 metre to 1.20 metres can usefully reduce heat radiating into the indoor environment.

9.2.2.6. Airtightness and Vapour Barrier

Although it is important but difficult to maximise, airtightness is required to keep the cooling load low. In this masonry dwelling design, the insulated walls are vapour barrier and less permeable, and the greatest risk of air leakage is probably through the windows and doors. To minimise energy usage (especially when air conditioning is required), and to avoid discomfort in the dwelling, a relative humidity should be under 80% at air temperature about 20°C.

9.2.2.7. Building Materials

Thermal comfort conditions within the dwelling can also be achieved by taking into account suitable thermally effective building materials available locally, into the design. Yet, the following statement is important to be taken account:

> *"Due to the warm humid climates experiencing such as aggressive solar radiation, humidity, rain, sea spray, strong wind, mould, algae growth and insect damage, however, building materials may tend to deteriorate rapidly and durability may be shorter than expected."*
>
> Adamson and Aberg, 1993.

Considering that statement and related cooling thermal capacity, concrete is the best construction material for the permanent structure of the dwelling.

However, it should be noted that if the concrete is porous, increasing humidity will encourage corrosion of the reinforcement, which deteriorates the concrete with impact on the lifetime of the structure.

Wooden, timber and coconut fibre are locally available and have thermally acceptable characteristics such as being less heat radiant, and offering good insulation.

> *"Coconut fibre (U=0.5W/m2K) is the most efficient material for insulation, and it has been examined as having high thermal capability to reduce energy load for cooling the dwelling."*
>
> Funo and Silas, 2000 .

However, avoiding continuous solar radiation by using shading devices, and placed wood location at above working area height are recommended to avoid humid conditions, mould growth and termite attack.

Therefore for that reason, the qualities of the building materials above are all important, and the concrete slab floor has also important role to solve these latter problems.

9.2.2.8. Cooling Strategy

During the occupied time in the afternoon, when the peak uncomfortable indoor conditions occur, mechanical cooling is switched on and the adjustable louver windows are closed. At night when the outdoor temperature is comparatively low, natural ventilation immediately takes over. As Adamson (1993) indicated:

> *"This regulated cooling strategy can save greater energy."*
>
> Adamson, 1993.

9.2.2.9. Air Conditioning

In this combined dwelling designed which uses both passive and active climate conditioning, the occupants are encouraged to use the former as much as possible, and the latter used only when needed.

An energy-efficient, air-conditioned dwelling can be designed by selecting the most appropriate design requirements for both comfort, and energy consumption.

For cooling load reduction the following techniques should also be considered, in the combined dwelling design.

9.2.2.10. Solar Shading

There are types of sun protectors that can also be used to help in achieving comfortable conditions by minimising overheating. The performance of solar protectors is shown in Table 9.1 and Table 9.2.

1.0	3mm clear float glass
0.9	Standard double glassing
0.5-0.9	Internal Venetian Blinds - Drawn
0.4-0.8	Internal Curtains - Drawn
0.4-0.8	Internal Roller Blinds - Drawn
0.7	Heat Absorbing Glass
0.6	Trees Providing Light Shade
0.5	Internal Blinds - Reflecting Backing
0.4	Solar Control Glass
0.3	1 m Eaves Over North Wall
0.2	2 m Pergola Over North Wall
0.2	External Blinds - Drawn
0.2	External Shutters - Closed

Table 9.1. Comparison of Shading Coefficients for Range of Shading Devices.

Position of Shading and Type of Sun Protection		Solar Gain Factors (*)
Shading	**Type of Sun Protection**	**Types of Single Glazing**
None	Clear glass	0.76
	Lightly heat absorbing glass	0.51
	Densely heat absorbing glass	0.39
	Lacquer coated glass, grey	0.56
	Heat reflecting glass, gold	0.26
Internal	Dark green open weave plastic blind	0.62
	White venetian blind	0.46
	White cotton curtain	0.41
	Cream Holland linen blind	0.30
External	Dark green open weave plastic blind	0.22
	Canvas roller blind	0.14
	White louvered sunbreaker, blades at 45°	0.14
(*) The solar gain factor of a transparent material is the fraction of incident solar energy passing through the material		

Table 9.2. Classification and Performance of Solar Protection (EACEC, 1996)

Direct solar radiation is usually the most significant heat source causing discomfort and cooling loads within the dwelling. Apart from appropriating the glazed design, the most effective method of preventing overheating is to use external shading devices i.e. an overhanging pitched roof (Marsh, 1999; Braham, 1996).

North-south orientation of the dwelling allows easy shading of the glazing. In contrast, an east-west orientation with extensive glazed facade receives maximum solar radiation where the air temperature is highest.

9.2.2.11. Solar Control Glazing

Solar control glass should reflect the radiant of the sun to control internal environment of the dwelling. In order to avoid direct sun into the dwelling, reflective glass coated with a thin layer of highly reflective metal oxide should be considered. Pitched solar shading devices offer still more protection for glazing.

9.2.2.12. Landscaping

Landscaping can assist in modifying the dwelling cooling loads. Gardening in the shrine area, courtyard and landscaping at the front of the dwelling provide both useful solar protection and fresh, cooling air that come from the vegetation as moisture evaporates.

9.2.2.13. Radiant Heat Shields

Radiant barriers can be installed in attics, ceilings and the walls of combined rooms, constructed from an aluminium foil-coated product with an adjacent air gap. This reflects heat and transmits little of the radiant heat falling upon it. The air space prevents heat movement downward by conduction, and allows the attic to remove the heat by convection. Radiant barriers (e.g. aluminium foil) have two potential functions, to eliminate moisture, and decrease roof temperature, as stated below.

> *"Foil is an excellent vapour barrier used to pass water vapour. Increasing air temperature can be sorted out by airflow in the roof, and attic ventilation."*
>
> Braham, 1996.

9.2.2.14. Infiltration Protection

Infiltration through the dwelling fabric wastes energy and can cause discomfort. For energy efficient designs, a reasonably airtight building standard needs to be maintained. Tighter building control implies an improved dwelling, and better attention to detail of the insulation in the building envelope.

9.3. RESULTS OF THE SIMULATION

As has been described in the description of analysis techniques examined previously (Chapter Seven at section 7.2), by imposing three different strategies to the design of an energy efficient house, the effects on energy cost show quite significant results when considering the air conditioning energy used in the combined dwelling design.

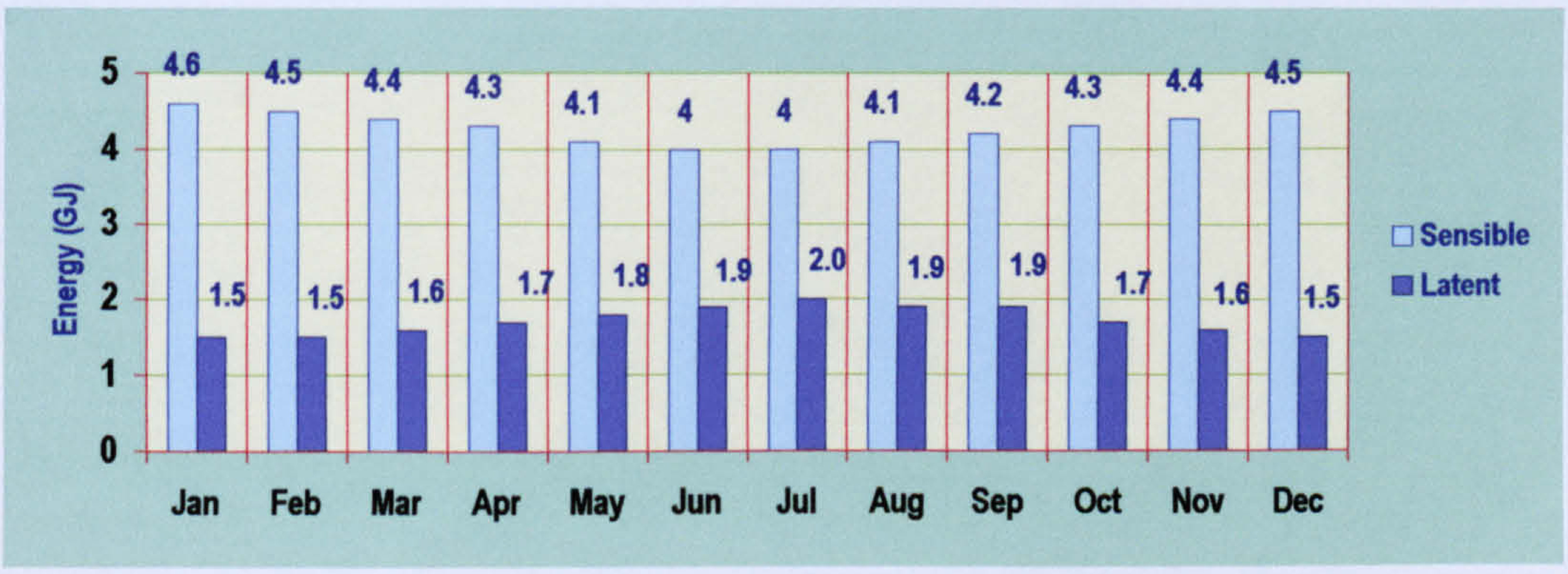


Figure 9.2. Monthly Air Conditioning Energy Consumption

For air conditioning energy consumption, the combined dwelling simulation results are given in Figure 9.2. Overall, as can be seen from the detail results of cooling energy consumption, the monthly energy used is generally quite similar. This indicates that the similar high temperature and humidity conditions experienced all year round consume similar energy for cooling, whether the sensible gain, or the latent gain.

Annually however, the sensible gain is higher than the latent gain, with the ratio for total sensible energy 70% and latent 30% (Figure 9.3). Sensible and latent energy for air conditioning are the dominant states in the warm humid climate.

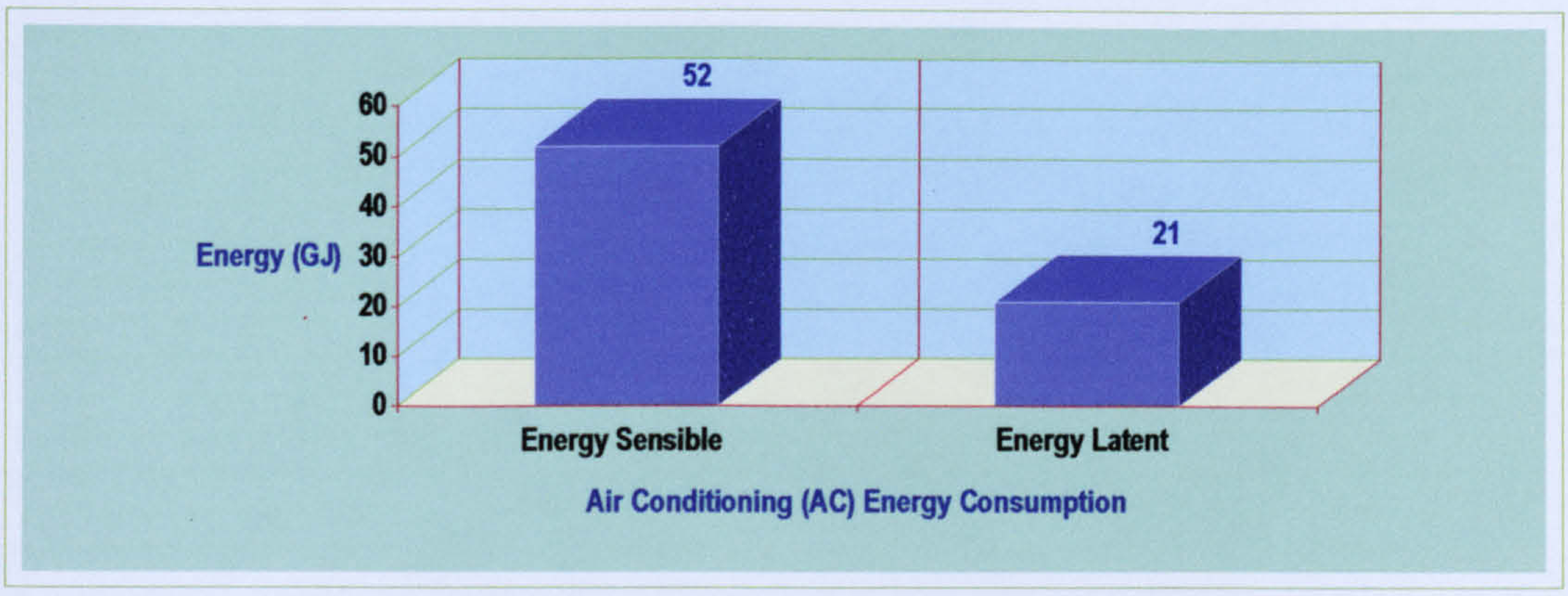


Figure 9.3. **Total Air Conditioning Energy Consumption**

Insulation and shading devices can possibly reduce this energy load to the dwelling.

Looking at an individual room, in descending order for the sensible energy, and latent energy gain are the living room, the master bedroom and then the subsidiary bedroom (Figure 9.4).

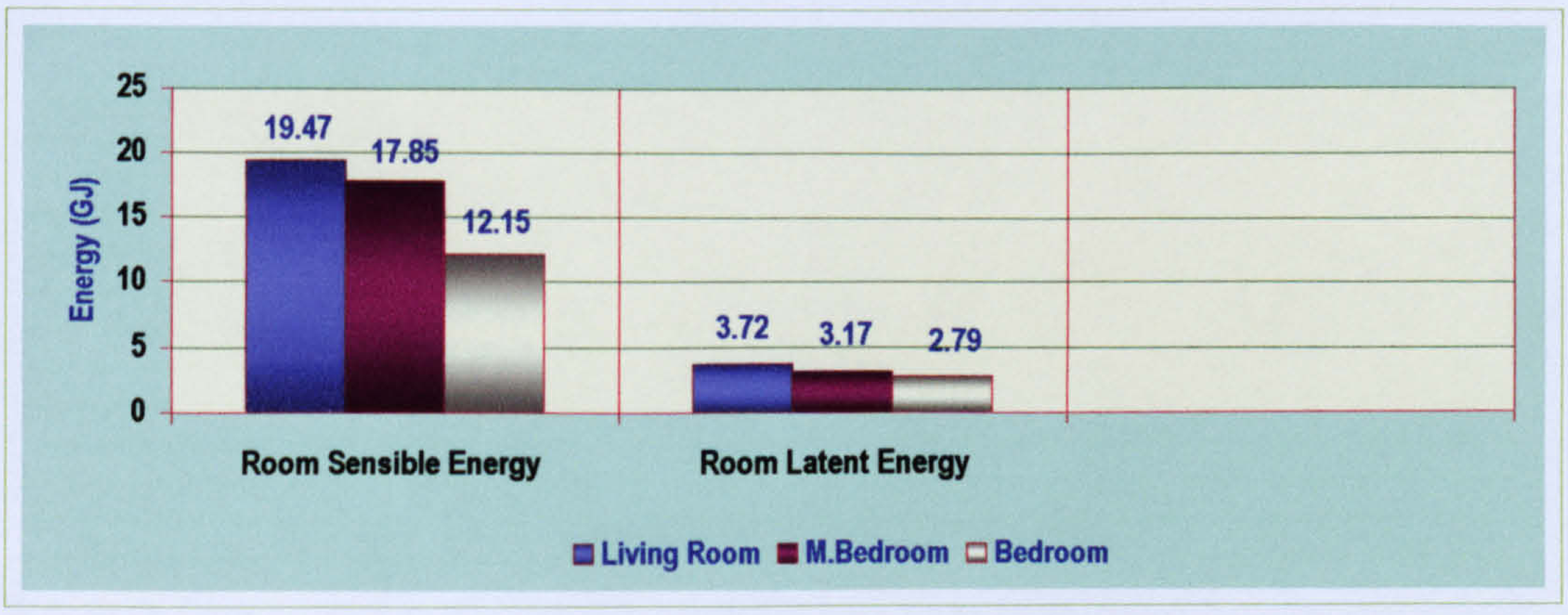


Figure 9.4. **Room Air Conditioning Energy Consumption**

This figure indicates that the larger size of living space needs more energy for cooling, sensible or latent. This is especially true for the living room, it being the largest room and also having the biggest exposed window which allows radiation into the room.

However, in the case of the master bedroom and bedroom of the same size, there is a slight difference for both sensible and latent energy consumption for cooling the rooms.

This is probably due to their different window orientation; the master bedroom having east-west window orientation, while the bedroom has north-south window orientation. This would give a differing amount of thermal load and hence variation in the cooling loads for the rooms.

To reduce energy consumption a series of energy efficiency strategies were adopted as previously described (see Chapter Seven at section 7.2), and the results show significant reduction of the air conditioning energy used in the dwelling.

3-hour time occupancy is adopted, as this was adequate to increase energy reduction on the previous thermal performance simulation. However, when required and affordable for the homeowner, 7-hour occupancy could be used, but naturally with reduced energy savings.

The former time for cooling conditions is most efficient, acceptable to middle income people and the current economic situation. In this strategy, compound dwelling energy consumption for cooling is presented in Figure 9.5 (see also Appendix - VI).

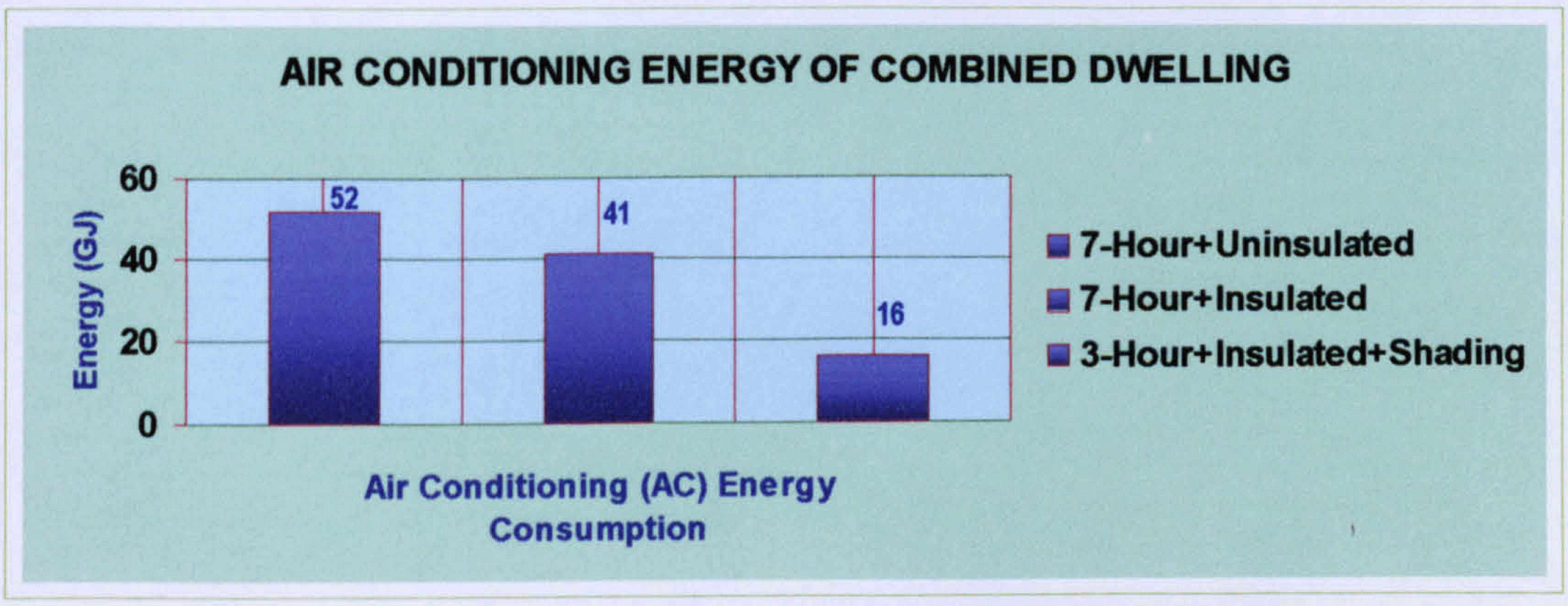


Figure 9.5. Air Conditioning Energy of Combined Dwelling

This finding displays that annually, a large amount of energy is required to cool the standard dwelling. For the insulated dwelling an energy reduction of 20% can be achieved. This is in comparison with the third result, for the dwelling with architectural shading devices and insulation, where the use of energy for cooling rooms is less than the previous. Impact on energy reduction is 70%.

9.4. CONCLUSION

A conclusion can be drawn from the simulation outcomes, that the strategies have significantly achieved better thermal performance and energy efficiency for a thermally comfortable dwelling.

As far as thermal comfort is concerned, as indicated in the low cooling degree-hours, and long periods of comfort, the combined dwelling strategies overall have thermal performance which is more than adequate. When considering the air conditioning energy used in the combined dwelling, as indicated in the results of the simulation, the effects on energy efficiency show quite significant result. The impact on energy reduction was 70%.

Whenever the dwelling is naturally conditioned, the adjustable openings allow a high rate of ventilation, and this promotes indoor air temperatures that are invariably low, which is responsible for delaying further increases of inside air temperature from solar and casual heat gains; hence, continuous comfort inside the dwelling can always be achieved.

Direct access to the outdoor air through three exposed walls of the rooms in this design is unrestricted, due to the wall attachments which result in greater ventilation rates thus lowering the indoor temperature, and the elimination of excessive humidity.

The transformation from compact to compound pattern in the design can do much more to help adequate natural ventilation, and enhances comfort in the dwelling while achieving efficient energy consumption by the air conditioning.

In the combined dwelling design, especially during on the extremely hot months where there is greatest overheating, this is generally confined to the afternoon. For mechanical cooling, an electric fan which should probably be considered first, and then air conditioning could be applied for a short period only.

In order to limit the cooling load, gardens, a shaded courtyard or veranda will act as a pre-cooler for the air entering the dwelling, either for natural ventilation or air conditioning.

A significant reduction of energy consumption in the air-conditioned combined dwelling can further be achieved by setting a higher indoor temperature in the comfort ranges. The air conditioning system can be designed as a split unit, consisting of one compressor and refrigerator unit placed outdoors, and a pipe system distributing the cooling media to several room-cooling coil units. Air-tightness of the dwelling is an obvious necessity, and a good design for the building envelope is needed to keep air infiltration and air exfiltration to a minimum, when using air conditioning.

Another consideration that it is common in the warm humid climate, however, is that the air conditioning system will need frequent service, and may break down.

Therefore, returning to a passive cooling system is a way to sort out the active cooling problems, and the combined dwelling design is remarkably effective in these circumstances.

A well shaded and insulated building envelope influences the cooling value desired, and helps to attain an energy efficient cooling strategy, either on the natural ventilation and/or air conditioning of the combined dwelling.

The dwellings have successfully excluded the heat and humidity stress of warm humid climates by providing solar control and protection, by addressing ventilation, and using insulation to reduce cooling loss through the building envelope.

The environmental conditions of the courtyard pattern of this combined dwelling design is more adaptable to the warm humid climatic conditions, offering adequate indoor thermal performance, generous natural ventilation rates, and acceptable cooling degree hours for comfort inside the dwelling.

In the compound-compact dwelling case, with both passive and active cooling, wind exposure, low density, orientation, shallow room depth, thermally effective building materials, and shadowing are all interrelated in achieving thermal comfort conditions within the dwelling. They have to be considered the main factors promoting improved indoor thermal performance.

If both passive and active dwelling were combined correctly and in harmony to the local climate, there would be the best likelihood for naturally ventilated buildings to provide comfortable indoor temperatures, with a good use of air conditioning to minimise the air-cooling energy consumption.

It can be concluded that the combined dwelling has successfully modified the overheating conditions to provide the most comfortable indoor environment, at a level and cost which is acceptable to the homeowner.

The general principle of the design is then to combine the advantages of a naturally ventilated dwelling with that of an air-conditioned dwelling, and to provide greater comfort with less energy consumption.

The combined dwelling design requires the following:

- The courtyard dwelling pattern.
- Enhanced effective natural ventilation and minimised air conditioning.
- Local natural fibre insulation and aluminium foil reflector insulation.
- Pitched roof with overhanging shading devices and adjustable louver-windows.

This technique attempts to combine the best features of passive and active systems into the combined dwelling design, to maintain a comfortable internal environment. The traditional-contemporary building and natural-mechanical systems are integrated but are intended to operate using natural ways whenever possible, to minimise energy use, with the mechanical mode being used only in peak conditions when extremely high indoor temperatures prevail.

This combined design for comfort cooling in the dwelling is appropriate to the current economic situation in Indonesia, and is affordable to a wide range of income groups.

Indeed, from the economical and psychological standpoint, the combined dwelling design successfully integrates traditional and contemporary features, passive and active cooling, while a thermally efficient dwelling design suitable for warm humid climates has certainly been achieved.

Chapter Ten

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS, LIMITATIONS AND FURTHER RESERACH

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Chapter Ten

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS, LIMITATIONS AND FURTHER RESEARCH

10.1. SUMMARY

The background research for this study has revealed that housing demand is of growing importance to accommodate the increasing urbanisation and development of cities in Bali, Indonesia.

However, lack of land for dwellings in urban areas causes an escalation of land and construction costs. The spread of consumerism, globalisation, the growth of urbanisation and the dramatic increase in the tourist trade in this region are creating new circumstances in which vernacular dwelling may be perceived as losing its relevance.

Indeed, since Bali is experiencing cultural pressures, and sustainability considers culture to be the basic building block for sustainable development in Bali, the regulations related to design dwellings should also in some way reflect Balinese architectural concepts.

Architecture traditional dwelling in Bali is still ecologically sound, environmentally adopted, flexibility adaptive, and able to incorporate international culture to enrich itself without losing its own identity.

Nevertheless excellent dwellings, which draw upon local vernacular patterns, are becoming a trend - one in which the reconfiguration of indigenous design and the creation of hybrid forms rediscover tradition.

Indeed, Bali has been geared to the 'culture-selling' of an image of Bali and this has had significant impact on shaping building design. The dramatic increase of tourist activities has impacted upon Bali with an economic challenge, which is attracting people from other archipelago to migrate to this region. This is causing pressures, principally upon the number of dwellings that need to be provided.

In the urban districts of Bali, their natural pattern has been lost and dwellings are compressed into smaller and ill-suited sites. Moreover, modern dwellings tend to exhibit a sense of exclusion of their surrounding environment.

Urban development is a vital factor, forever demanding dwellings that offer more quality of life. In this respect, a comfortable indoor environment and an appropriate energy conservation strategy are important points.

Energy is the vital power that drives the economy of Indonesia; it has a strong impact on the environment, sustainable development and is essential to keep the country competitive in international trade.

The government has to establish an energy efficiency policy and set performance standards for overall increases in energy efficiency in residential construction, covering renewable energy and conservation under a Building Code.

Economic and environmental factors, however, have to be included when providing a balanced residential environment, particularly reducing costs through technological innovations, use of local materials, understanding the things required for living in comfort; not forgetting energy efficiency in dwelling designed to be thermally acceptable, and suitable for a warm humid climate.

In these circumstances, developing dwelling designs that are environmentally and thermally comfortable for most people, while remaining energy efficient in the warm humid climate of Bali, is required.

This can be done by thermally efficient dwelling design development, using locally available materials, applying reliable standard systems to reduce costs and improving durability of the building.

Development and the economic impact of tourism on this region have contributed to rapid change in Bali, particularly having a significant impact on the transformation of dwelling design.

Indigenous and modern are seen as equivalent to the intercultural process of development between the traditional environment and modern design dwelling.

The Balinese house then has clearly been subject to change. The contemporary house, whatever the undesirable environmental consequences that might result from its design, has offered a solution to changing social and economic needs. Yet, it does not follow that we have fully to accept the new design concepts, nor revert wholly to the principles governing the traditional house.

Today, the dwellings should respect both current cultural and environmental performance which means thermal comfort and climate need receive consideration in the movement to contemporary dwelling types.

For design of these dwellings, providing a suitable thermal comfort environment whilst addressing the economic and energy issues are important.

Since the traditional compound dwelling clearly offers a comfortable adaptation to that warm humid type of climate, from the point of view of thermal comfort, these domains are paramount.

Recently however, because building vernacular dwellings has become unaffordable, to adopt a basic concept of the traditional dwelling applied to a modern dwelling in such a way as to ameliorate the warm humid climate, would be a good solution to provide better thermal comfort performance of the dwelling.

The main aim is to offer an attractive dwelling design that provides a high standard of comfort, using natural ventilation whenever possible and handling the efficiently designed air conditioning.

These have been largely concerned with the indigenous climatic response of dwellings, the materials and construction, and the simplified geometrical models used in the design of modern Balinese dwellings.

With reference to the foregoing summaries of this chapter, such efficiency can be achieved by a combined dwelling design which respects both the comfortable performance conditions of the indigenous dwelling and technological innovation from the more modern design. The former is mainly to do with the compound pattern and natural ventilation, while tight structure and air conditioning mainly affect the latter.

10.2. CONCLUSIONS

10.2.1. Findings

From the thermal comfort point of view, the study reveals that the combined (hybrid) dwelling design, architecturally based on the courtyard pattern, is more responsive to the local climate while at the same time is energy efficient.

In principle due to cultural impact, the design of Balinese house is in a continuous process of change, which was normally based on traditional styles, have been transformed to contemporary patterns, instead of being cooled in the natural way, it now commonly combine employed modern techniques. However, philosophical Balinese beliefs can not be changed.

The level of demand for combined natural ventilation and air conditioning, in both traditional dwellings and modern houses were comparable, these indicates that traditional and technological methods need to be proportionally applied, for comfortable dwellings.

The study in the warm humid climate of Bali shows that the thermal comfort performance with the combined natural ventilation and air conditioning was 90% of the occupants feeling comfortable and 10% feeling uncomfortable. This result is higher than the standard comfort range, "where 80% of people are supposed to be satisfied".

A distinction of the indoors comfortable dwelling in the warm humid climates is where the thermal comfort ranges are in between the lower limit of 24°C and the upper limit of 28°C.

The simulation study reveals in general, that the energy conservation strategy on the combined dwelling achieved on energy reduction of 70% annually. The impact of this on the ratio between annual income and energy expenditure was 92% living cost and 8% energy cost. For the current dwelling types the ratio was 80% living cost, 20% energy cost, this was equal to a 60% reduction in energy cost to the home owner.

In brief, a dwelling design derived from the bioclimatic, cultural, vernacular and modern architectures with natural and advance cooling techniques has achieved comfortable and energy efficient building.

10.2.2. Design Strategies

In the warm humid climate, living in open harmony with nature is the best possible solution, and the best dwellings in this region should provide a sensuous experience of space, design, culture and nature.

For centuries, the dwelling in such regions has been an interface between the built world and the surrounding greenery: open to the sky, with spaces between such as courtyards, gardens, verandas and terraces. Furthermore, as Powell (2000) noted:

> *"Vernacular architectural forms and indigenous materials are adapted and synthesised with modern architecture and technology, to design favourable dwellings which are responsive to warm humid climate ecology, and lifestyles."*
>
> Powell, 2000.

A thermally comfortable environment, in a dwelling design that is acceptable to most people and tailored to the warm humid climate, is required. These parameters would influence the design, the cost and the energy conservation scheme of the dwelling.

Design of houses in this region has to address the problems of heat and humidity, while *"obtain a conscious sensation of harmony with nature"* (Corbusier), *"proclaimed that form follows function"* (Sullivan), *"and are shaped by ecologically interconnected flows of materials and energy"* (Ecological Design Institute).

The design emphasises the development of comfort with appropriate technology, using local materials for reasonable cost and a high quality dwelling.

10.2.2.1. Combined (Hybrid) Dwelling Design

In any warm humid climatic situation, the study reveals that the dwelling which combines in its design natural ventilation, insulation, shading devices and air conditioning will maintain indoor temperatures in the comfortable range, while being energy efficient.

The courtyard dwelling pattern was the best way of maintaining comfortable conditions by maximising airflow, encouraging wind driven ventilation through adjustable windows opening into the rooms. In practice, the courtyard promoted stack effect ventilation.

Verandas provide permanent well-shaded areas in order to reduce heat transfer from the direct sun falling upon the dwelling. They produce continuous natural cooling, and balance indoor air temperatures.

The building envelope insulation in the combined dwelling design obviates high heat transfer, and keeps the inside walls of the dwelling cool, whether during periods of fully natural ventilation or when air conditioning has to be applied. Insulation installed on the inside of the exposed walls is the best barrier to keep the dwelling comfortable, when both sides of the insulation should be faced by aluminium foil. The inside face of this aluminium foil has good reflectance, and its non-permeability aids airtightness, while the outside face reflects the solar heat radiation back out.

The pitched roof and overhanging shading devices are other ways of excluding solar radiation. Attic ventilation, which isolates the roof void from ceiling, further lowers indoor air temperatures in the dwelling.

Adjustable louver-windows are another very flexible facility, either for encouraging natural ventilation or to keep closed when air conditioning is needed. Such adjustable windows, facing the open spaces of the garden and the courtyard, will drive out heat gains from the combined dwelling. Shading and solar control glazing further reduce gains.

Both the building and engineering systems are combined, and employed together to operate the cooling using natural ways whenever possible, to minimise energy use. Mechanical air conditioning may be used in extremist, when the external temperatures reach their peak.

The best performance and thermal efficiency of the combined dwelling design for a warm humid climate takes into account the following considerations:

- Dwelling design to moderate solar and internal heat gains.
- Ventilation and cooling designed for maximum saving in energy efficiency.

The building envelope will influence the cooling services required, and can help to achieve an energy efficient cooling strategy.

In terms of climatic modification, the dwelling has to address the following main functions:

- Minimised solar heat gain, avoiding overheating i.e. by providing solar protection, and maximised use of the building mass to attenuate thermal heat gain.
- Minimised cooling loss through the building fabric, infiltration and ventilation.

Enhanced thermal insulation of this dwelling has the advantages of reduced solar gain and cooling loss, reduced indoor temperatures and humidity, and provides higher comfort standards.

The dwelling is constructed with materials of adequate thermal capacity for energy storage, correctly positioned to act as a thermal regulator, smoothing the temperature, delaying peak temperature, decreasing mean radiant temperature, and providing better year round comfortable conditions indoors.

From the bioclimatic aspect, imposing the courtyard pattern on the combined dwelling design proves the most significant factor governing thermal performance, being much more responsive to the local climatic conditions and having good thermal performance for acceptable indoor air temperatures.

It also has a high level of wind exposure, permeability, and external penetration that are all responsible for the high ventilation rate, and hence the low cooling degree-hours of the combined dwelling.

The building envelope of the combined dwelling has adequate protection from overheating, achieves indoor temperatures in the comfortable range, and remains energy efficient in both active and passive ventilated modes.

When using natural ventilation, the design has to allow for high airflow rates. To use air conditioning most effectively the system has to be designed with the dwelling, not added later.

Effective warm humid climate control has been primarily handled by architectural design rather than mechanically. A lower energy load is better achieved through architectural solutions rather than engineering ones, as the former have a long life span while generally the latter do not.

North-south orientation of the dwelling contributes to the lowest levels of energy consumption required to achieve a comfortable indoor temperature. Shallow square rooms in the dwelling offer better performance in both cases, with reduction in the energy required for mechanical air conditioning.

Moreover, a pitched roof, shading devices, ventilation through the attic, use of reflective insulation material with low emittance, and low absorbance by the building envelope to resist the heat flow, all help to keep things cool inside.

The local landscape helps protected the east- and west-facing parts of the building from solar attack.

Orientation of the openings to the prevailing wind direction generates greatest pressure on the windward side, makes cross ventilation easier, and low energy cooling can be achieved.

All of these internal and external architectural features above have been proved to modify the climate successfully, and have satisfactorily achieved thermal comfort and energy efficiency, as shown in the results of simulation in the combined dwelling (see Chapter Nine at section 9.3).

10.2.2.2. Reducing Heat Gains

In warm humid climates, the extremes of both heating and humidity are the most difficult characteristics to handle whether using natural ventilation or air conditioning.

As far as thermal comfort design is concerned, the combined dwelling design has successfully dealt with these two fundamentals; providing air movement, and excluding heat build-up.

These benefits have been influential in achieving the thermal comfort balance of the combined (hybrid) dwelling design, by avoiding heat transferred either inward or outwards through the building envelope, from solar radiation and heat exchange in either direction of ventilation, internal gains and heat evaporated from the building surfaces.

Thermal comfort in the combined dwelling design has been best achieved by reducing heat gains through the building envelope, minimising internal heat gains by controlling heat production, providing effective ventilation to remove excess heat and promoting further loss through evaporation.

10.2.2.3. Natural Ventilation

Considered to be the primary concern (i.e. thermal discomfort with overheating and high humidity, creating a complicated indoor climate, it being hard to bring the indoor temperature below the outdoor temperature, and uncomfortable conditions within the dwelling) in a thermally efficient dwelling designed for a warm humid climate, while natural ventilation can be used only to an extent to aid cooling indoors, air movement is nevertheless the leading practical method to achieve natural cooling and thermal comfort range in the dwelling (see Chapter Six section 6.4.1.2).

Natural ventilation is required for health, replacing the stale internal air with fresh external air; for thermal comfort, i.e. removing excess heat, and promoting humidity evaporation from the skin of the occupants. It is also required more generally for structural cooling by convection.

In the combined dwelling, copious, and continuous ventilation is introduced into the rooms, and is used to lower the indoor air temperatures to below the outdoor level. In addition, the large area of openings induces cross ventilation, since each room has adjustable-louver windows on two sides.

The courtyard pattern of this combined dwelling design creates natural ventilation pressure differences between the inside and the outside, by means of either thermal force or wind force. The former 'stack effect' relies chiefly on temperature differences, while the latter is mainly governed by the dynamic effect of winds. Either way, it results in high air speed, sufficient to give thermal comfort. The most significant air movement is generated in this dwelling by cross ventilation obtained by adjustable openings positioned opposite one another, the inlet facing out to the garden and outlet facing the courtyard, providing high velocity pressure (see Chapter Eight at section 8.5).

Physiologically, cooling in the rooms of the combined dwelling is ensured by the incoming air being at body height (normally termed the 'living zone'), from openings positioned so the airflow passes through the living zone, and distribution of air velocity is achieved.

10.2.2.4. Air Conditioning

The results of the study and the simulation reveal that despite having achieved better thermal performance than natural ventilation, the combined dwelling strategy shows the greatest reduction in air conditioning energy consumption.

Air conditioning in the hybrid dwelling is used during the short period of thermal discomfort in the late afternoon and in the evening when the room is occupied, while during other periods, natural ventilation is generated continuously to provide cooling.

During the coolest months, between June, and September when low ambient temperatures obtain and indoor conditions are acceptable, (see Appendix-VII), air conditioning of the combined dwelling is unnecessary and hence air conditioning energy consumption is negligible.

10.3. RECOMMENDATIONS

The combined dwelling design, based upon the courtyard pattern is the most applicable way of achieving thermal efficient housing to suit for warm humid climates. It has adequate thermal performance while being energy efficient, and is affordable to most of the people Bali.

Architecturally and psychologically, this image of a hierarchy in the layout of the dwelling is adaptable to the environment, and will maintain the integrity of Balinese culture.

When it is necessary to develop and more spaces needed, vertical extension is recommended. This will provide the same design comfort requirements as the basic concept of the combined dwelling design, while horizontal extension is prohibited.

In general, a two-storey combined dwelling offers better environmental conditions than a single-storey horizontal extension, for the simple reason that external connections can be maximised. In these circumstances, the use of multi-storey construction, but not higher than four-storey, is therefore recommended.

To avoid over-development of sites, regulations need to be tightened particularly with regard to the control of plot size and floor area ratio.

As for energy consumption, architectural features and insulation combined have the greatest potential, and are effective in achieving energy efficient air conditioning of dwelling designed for these climates.

As can be seen in the study, this hybrid dwelling design offers significant reduction of energy consumption for air conditioning.

For these reasons, the combined dwelling design could be promoted as a standard dwelling in the typical housing development. It is vital that housing developments respect the traditional past and use more recent technologies, but make environmentally efficient use of energy resources.

With this development, adequate sustainability of both housing and energy resources in Bali as well as in Indonesia could be achieved.

10.4. LIMITATIONS AND FURTHER RESEARCH

Due to constraints of time and cost, this research has some limitations, either affecting the main research or some other technical area of study, and therefore, for a more comprehensive study, further research is needed.

Focus on the main simulation research, where only a limited number of variable were considered, by using much more variables in the dwelling design would help the generic study analysis.

However, this study refers to the architectural background of prototypes traditional dwellings and contemporary houses that were commonly built in Bali, Indonesia.

Therefore for that reason, this research was focused on the simulation of prototypes dwelling designs, current compact dwelling and combined dwelling finding. In order to presents the work to be widely researched, the design findings for combined dwelling was drawn from a comprehensive analysis of comparative studies (e.g. the crosses analysis of the simulation, survey research, previous works and literatures reviews). The design finding is then also simulated to draw the final conclusions.

Cost of the dwelling is of course escalate annually, creates a crucial problem on a cost limitation elsewhere.

In order to sort out this economic problem, building a core-houses based on the combined dwelling design may help in this respect. In the first instance, not all rooms of the dwelling need to be built straight away, by building step by step, adding rooms when the financial circumstances dictate, would assist the development process.

Therefore, this technique would help the housing supply of Bali, and the rest of Indonesia.

Hence, most people in Bali and in the country can afford to have accommodation, since this system will reduce the loan instalments given from the government Bank and the non-bank financial institutions which are organise funding for housing constructions.

Another limitation to the research is the difficulty experienced in accessing data from the local government of Bali.

The bureaucratic procedures required to obtain such data create long time delays, and even when the data is available, it may produce inappropriate information for the survey because there were inadequacies in the management of data archives, a common problem in a developing country. Traditional management coupled with the computer is only a tool, without extensive networks to access data archives, it impractical to access the data.

However, other sources, books, statistical data about Bali, newspapers, magazines and journals electronics did provide data and helpful to support to the research.

In relation to this research in general, further work might be considered as follows;

Due to land availability being limited in Bali, and vertical development restricted by local government regulations (e.g. a new building shall be built no higher than four storeys), a horizontal extension creates a build-up in area density, with impacts on ventilation. It is important to study two-storey combined dwellings and ascertain how they perform.

The reason is that the two-storey dwelling is becoming a common building type. Contemporary dwellings have been extended from the original to two storeys, without any understanding of how these modifications influence thermal comfort.

However, it should be noted that in terms of thermal comfort, two-storey buildings have more aspects to be studied than do single storey dwellings, because ventilation solutions are more difficult to arrange. On the other hand, the heat gain from sun radiation, particularly to the ground floor of a two-storey dwelling, may be less because of shading. At the same time, heat reflection from the surroundings may build up heat in the dwelling.

In terms of energy conservation strategies, it is necessary to consider the strategies for thermal comfort from the outset of any dwelling design. This is especially true for dwellings of contemporary style, whether in new planning or expanding an existing development.

In other particular technical research, concerning the electronic survey research, there are some points which would need to be taken into account for future research and related development.

As Coomber (1997) described; *"the Internet and electronic mail increasingly offer and clearly provide new horizons for the research community; opportunities that it did not previously have, which present enormous possibilities for the research, currently in its infancy, to reach individuals as research subjects, where the group being researched is normally difficult to reach and to access under normal conditions, spread across geographical borders, and even continents."*

However, nothing is permanent or perfect, and this electronic mail (e-mail) survey research technique also has limitations.

While it does indeed offer new and exciting prospects for research at present, it may be however that any survey research conducted via this technique will have to contend sampling bias (Coomber, 1997; Kehoe and Pitkow, 1996; Nielsen, 1995).

Therefore, while from the growth and development of technology in this field is faster than ever before, Coomber (1997) recognised the following statements:

- *"As use of this technology becomes more general, as is already happening, and methods for collection improve, concerns around sampling bias will come to resemble more closely those which regularly affect conventional surveys.*
- *In the research sample it was argued that while e-mail samples were voluntary, they were also probably a broader sample than would be achieved by other convenient sampling methods.*
- *In the research findings it is recognised that the findings are indicative, and should be read with the necessary caution (accepting the likely relative sample bias), and this would also have been a significant indicator demonstrating how the Internet was a valuable resource for finding out such things.*

- *Moreover, when the researcher first considered the results of the survey, it was concluded that the results could not have been excessively biased. On further reflection, it became clear that there are actually two 'unknowns' here: neither the amount of bias, nor whether the results are 'true', are (or can be) known. All that can be deduced from this kind of research is that either the results are true and there is no significant bias, or the results are false and there is bias."*

Therefore, experience shows that Internet cafés are widely spread out in Bali, with computer ownership increasing, providing more affordable, convenient and exciting tools for the majority of people around the country.

As many researchers expected; importantly, while Internet users still tend to be of a higher social status, their overall characteristics are coming more in line with the average of the general population, and Internet access and e-mail use are becoming increasingly mainstream (Boncheck et.al. 1996; Fisher et.al. 1996; Kehoe and Pitkow, 1996; Nielsen, 1996).

Coomber (1997) further noted, this may be good news for the future perhaps, but a range of difficulties remain in the meantime. Furthermore, doing research via the Internet also presents its own specific issues regarding sampling, which go beyond the representativeness or otherwise of the aggregate user population. Nevertheless, once going beyond this to where such attempts have been made, there is some useful discussion of the pros and cons of using the Internet as a medium for accessing research subjects.

Work on Internet demographics has demonstrated that the Internet can be used to sample effectively up to a point, and particularly that it can be used to produce relatively informative and reliable data (Kehoe and Pitkow, 1996; Urken, 1996).

Importantly, it is concluded that despite the problems relating to survey research via the Internet, there is the need to develop more sophisticated techniques (Kehoe and Pitkow, 1996; Urken, 1996) in relation to the collection of data, which can produce information suitable for exploratory analysis. Similarly, a survey should be undertaken of those receiving information from e-mail but who were being partially by-passed.

Doing research on Internet populations can then, provide certain research opportunities, but as Fisher et.al. (1996) stated in relation to sampling problems, *"the Internet is not as open as a site for survey research".*

However, there are other opportunities where the concerns of general surveys are lessened, and where the potential of the Internet remains real. Deviant or rare element sampling where the target population is difficult to access is in fact rarely able to aim for representativeness in any case (Coomber, 1997; Smith, 1975).

As Coomber (1997) concluded, for the time being it remains to prove that the Internet e-mail survey may have constraints, and it may even have advantages over previous survey techniques. Some groups, due to the existence of the Internet and e-mail may well be more easily reached now than ever before. Using the Internet as a tool for survey research offers exciting new possibilities to researchers.

- *"However, whilst it is important that the potential of the Internet is grasped, it is equally important that its limitations on research are understood. Using the Internet as a means of accessing samples in some way representative of general populations is currently prevented by who has access to it, and who is using it.*
- *Moreover, even when the desired sample is of Internet users themselves, significant technical and operational problems remain in terms of how to ensure that the population targeted, is in fact the population which responds.*
- *Given this, doing survey research on the Internet will, for the time being, continue to present a certain amount of unknowns regarding sample bias. Despite these problems, it has been the purpose of this paper to refer the reader to a number of pieces of survey research undertaken via the Internet w here the indicative data was deemed to be useful and the research worthwhile.*
- *For while the Internet poses methodological problems of one kind, it opens up possibilities of others: access too hard to reach populations, for example, across national borders and even continents. Researchers who are aware of the problems presented by doing survey research via the Internet, and who apply themselves appropriately, can increasingly be sure that they will be able to carry out important research via this medium."*

Coomber, 1997.

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APPENDICES

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APPENDIX - I

(Refer to Chapter Three, Section 3.2.2.2., Source: Antaryama, 2000)

Solar Radiation

Solar radiation was estimated from the sunshine period data, which are available from the meteorological office. The estimation is made in the form of the monthly mean of daily total irradiation on a horizontal surface. Koenigsberger et.al. (1974) and Szokolay (1980) suggest the following formula to calculate the daily total radiation, which is originally given by Glover and McCulloch (1958).

$$\mathbf{H = Ho\ (0.29\ cos\ LAT + 0.52\ ^{n}/_{N})}\ (\text{Wh/m2day})$$

For the calculation of Ho, number of day in year (NDY) for each month is taken according to that recommended by Klein (1977) (Table I.1).

Table I.1. Calculations of Daily Total Irradiation for Bali by 'SUNCALC' sub program of ARCHIPAK (Antaryama, 2000)

Month	Bali Daily Total Irradiation						Monthly
	Average day of month	Possible Sunshine Hours (hour)	Sunset Hour Angle (degree)	Sun Declination (degree)	Actual Sunshine Hours (hour)	Extraterr-estial Daily Irradiation (Wh/m2)	Average of Daily Total Irradiation (Wh/m2)
	(NDY)	(N)	(SHA)	(DEC)	(n)	(Ho)	(H)
January	17	12.43	93.25	-20.92	6.10	10747	5824
February	47	12.26	91.96	-12.95	5.91	10744	5775
March	75	12.05	90.36	-2.42	7.38	10410	6302
April	105	11.81	88.59	9.41	7.21	9624	5815
May	135	11.61	87.10	18.79	8.57	8721	5848
June	162	11.52	86.37	23.09	8.14	8226	5383
July	198	11.56	86.70	21.18	7.81	8410	5367
August	228	11.73	87.96	13.45	8.59	9175	6126
September	258	11.96	89.67	2.22	8.25	10035	6479
October	288	12.19	91.44	-9.60	8.92	10566	7051
November	318	12.39	92.92	-18.91	7.33	10696	6359
December	344	12.48	93.62	-23.05	6.80	10680	6089

Location	**: Denpasar Bali**	**Latitude**	**: 08.45 S**
Elevation	**: 3 M**	**Longitude**	**: 115.15 E**

Monthly averages of daily total beam (direct) and diffuse irradiation on horizontal surface are obtained from hourly values of beam and diffuse irradiation. This is related to Chapter three, section 3.2.2.2., which was calculated by Antaryama (2000), using a computer program 'SUNCALC'- one of the independent sub-programs of ARCHIPAK. Szokolay (1980) explains the method of the calculation. By using the same computer program, the daily total global irradiation on the vertical surfaces of four cardinal points different months was also calculated.

APPENDIX - II

(Refer to Chapter Three, Section 3.4.2.3. and Figure III - 11, Source: Antaryama, 2000)

Climate Analysis and Control Potential Zone (CPZ)

For the climate analysis, comfort and climate conditions, and control potential zone are plotted on the psychrometric chart (Antaryama, 2000) (see Chapter 3, section 3.4.2.3). The procedure of plotting climate conditions and constructing comfort and control potential zone is that devised by Szokolay (1991).

Constructing Comfort Zone

- Location: Denpasar Bali
- Latitude: 8.45 S

Thermal comfort index: standard effective temperature (SET), i.e. combination of DBT and humidity, DBT=MRT, with no significant air movement (less than 0.25 m/s).

The procedure:

1. find the annual mean temperature (Tav), i.e. 27.6 °C
2. find the thermal neutrality (Tn), i.e. 26.2 °C
3. find the lower (T1) and the upper (T2) limits of the comfort range, i.e. :

$$T1 = Tn - 2 = 24.2\ °C$$

$$T2 = Tn + 2 = 28.2\ °C$$

Mark values of steps 2 and 3 on the 50% RH curve of the psychometric chart,

Read the humidity ratio values (HR) for T1 and T2 from the chart and find the baseline intercept for the two side boundaries of the comfort zone. (HR is used instead of absolute humidity (AH) and is dimensionless. Both measure the same quantity, but use the same unit of mass in the numerator as in the denominator:

$$HR = \text{ at } (T1) = 24.2\ °\ C \text{ and } 50\%\ RH = 0.0096,$$

$$HR = \text{ at } (T2) = 28.2\ °C \text{ and } 50\%\ RH = 0.0121,$$

Base line intercepts for SET line at temperature T,

$$= T + 23 \times HR_T \times (T - 14)$$

Where, HR_T is humidity ratio at temperature T.

Thus, base line intercepts for:

$$(T1): 24.2 + 23 \times 0.0096 \times (24.2 - 14) = 26.5\ °C$$

$$(T2): 28.2 + 23 \times 0.0121 \times (28.2 - 14) = 32.2\ °C$$

Draw the top and bottom boundaries respectively at the 0.0012 and 0.004 HR levels to complete all the four side boundaries of the comfort zone.

Plotting the Climatic Conditions

To analyse the climate of Bali, 12 monthly lines representing its climatic conditions are plotted on the psychometric chart and then compared with the required comfort as above.

Each line is defined by two points:

- The main minimum temperature with the early morning relative humidity
- The main minimum temperature with the early afternoon relative humidity

The extent of the problem achieving comfort is indicated in this analysis by the distance between the area on the chart occupied by the 12 monthly line and the required comfort as well as by the extent of their overlapping areas. The further the distance and the less these two areas are intersected, the severer the climate.

Constructing Control Potential Zone (CPZ)

Air movement is employed as a climatic design strategy in the warm humid environment of Bali. For persons wearing light clothing and undertaking medium activity, the physiological cooling effect of air movement can be approximated as a function of air velocity, V:

$$dT = 6xV - (V^2)\ (K), \text{ valid up to 3 m/s}$$

Three wind velocities are considered for the control strategy, i.e. 0.5 m/s, 1 m/s and 1.5 m/s. I m/s is taken since warm humid conditions, it is perceived as pleasant. 1.5 m/s is the maximum limit for normal building occupancy, while 0.5 m/s is the minimum speed at which its movement is noticeable (Evans 1980, Szokolay (1991). Higher velocities are not taken into account as they may cause indirect nuisance effects, such as light objects (i.e. paper) being blown away.

The procedure:

Find the physiological cooling effect (dT) for 0.5 m/s, 1 m/s and 1.5 m/s air velocity:

$$dT\ (0.5\ m/s) = 6 \times 0.5 - (0.5)^2 = 2.75\ K,$$

$$dT\ (1\ m/s) = 6 \times 1 - (1)^2 = 5\ K,$$

$$dT\ (1.5\ m/s) = 6 \times 1.5 - (1.5)^2 = 6.75\ K,$$

Shift the upper comfort limit from T2 to T3 for 0.5 m/s to T4 for 1 m/s and to T5 for 1.5 m/s, mark them on the psychometric chart at the 50% relative humidity level:

$$T2 = 28.2\ °C$$

$$T3 = T2 + 2.75 = 28.2 + 2.75 = 30.95\ °C$$

$$T4 = T2 + 5 = 28.2 + 5 = 33.2\ °C$$

$$T5 = T2 + 6.75 = 28.2 + 6.75 = 34.95\ °C$$

Find the base line intercept for boundaries at higher humidity (i.e. upward from the 0.012 HR level, up to the 90% RH curve):

$$T3\ upward = 30.95 + 23 \times 0.0141 \times (30.95 - 14) = 36.5°C$$

$$T4\ upward = 33.2 + 23 \times 0.0141 \times (33.2 - 14) = 40.4°C$$

$$T5\ upward = 34.95 + 23 \times 0.0141 \times (34.95 - 14) = 43.5°C$$

The high humidity boundaries of the CPZ are defined by point (E) – located at the same DBT as point (A) – on the 90% RH curve, by the RH curve itself and by a line from points (G or T3), (J or T4) and (M or T5) upward, following the slope of the corresponding SET line, until they meet the 90% RH curve. The reason for this limitation is that the evaporation potential is negligible at very high humidity (RH > 90%) even with substantial air velocity. Such humidities are themselves also uncomfortable for other than thermal reasons.

Find the base line intercept for boundaries at lower humidity (i.e. between 0.004 and 0.012 HR level):

$$T3\ upward = 30.95 + 0.5\ [23 \times 0.0141 \times (30.95 - 14)] = 33.7°C$$

T4 upward = 33.2 + 0.5 [23 x 0.0141 x (33.2 –14)] = 36.8°C

T5 upward = 34.95 + 0.5 [23 x 0.0141 x (34.95 –14)] = 39.2°C

At very low humidities, the cooling effect is reducing due to the high evaporation potential from the skin, even with still air. The slope of the boundaries at such humidities (below 0.012 HR), therefore, will be steeper than the SET line (i.e. half of the slope of the SET line).

APPENDIX - III

(Refer to Chapter Four, Section 4.4.5.2 and Chapter Eight 8.2.4, Source: Ross, 1998)

Solar Radiation Effects to Glass Windows Configuration Differences

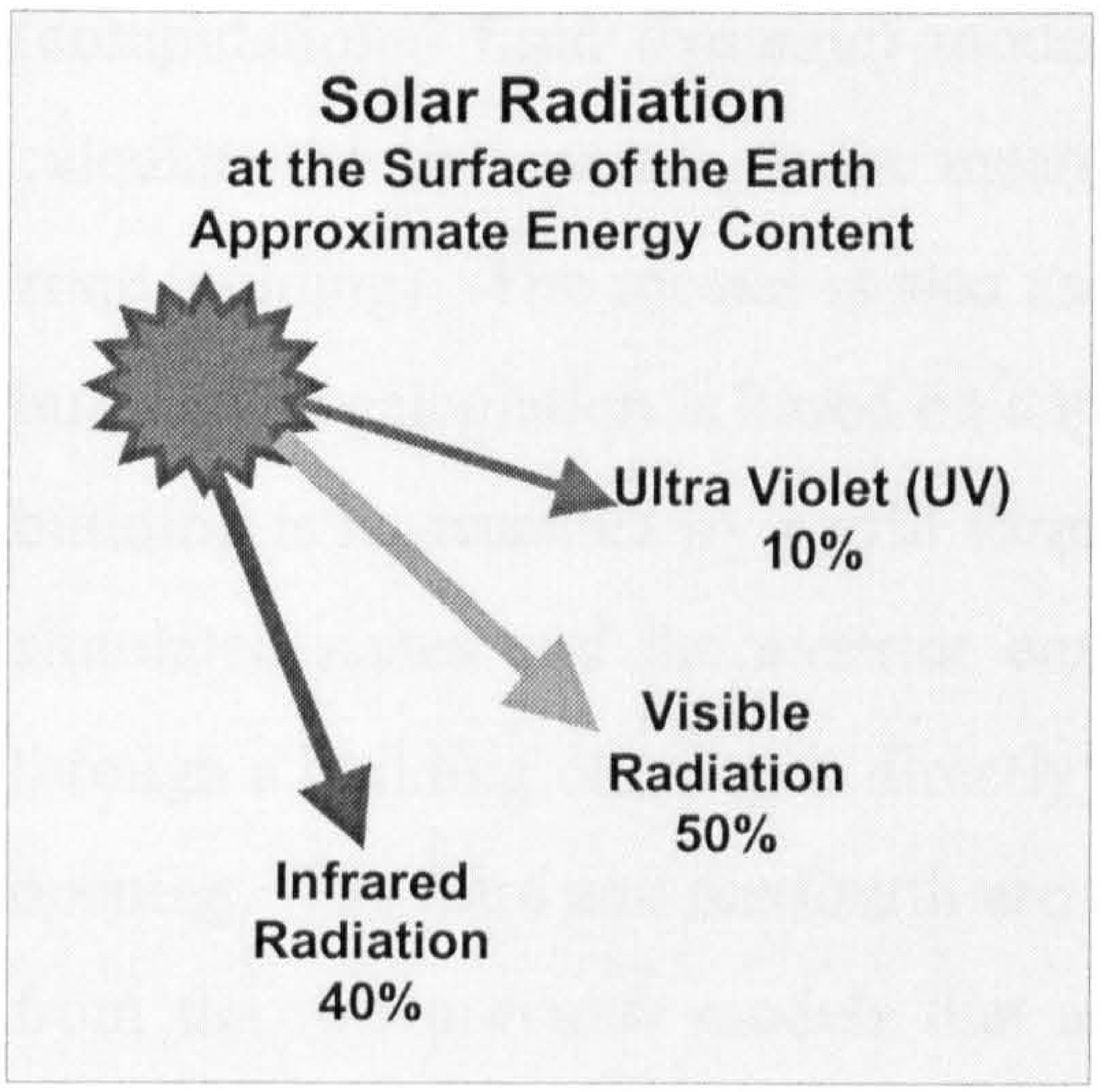


Figure III.1. Solar Radiation

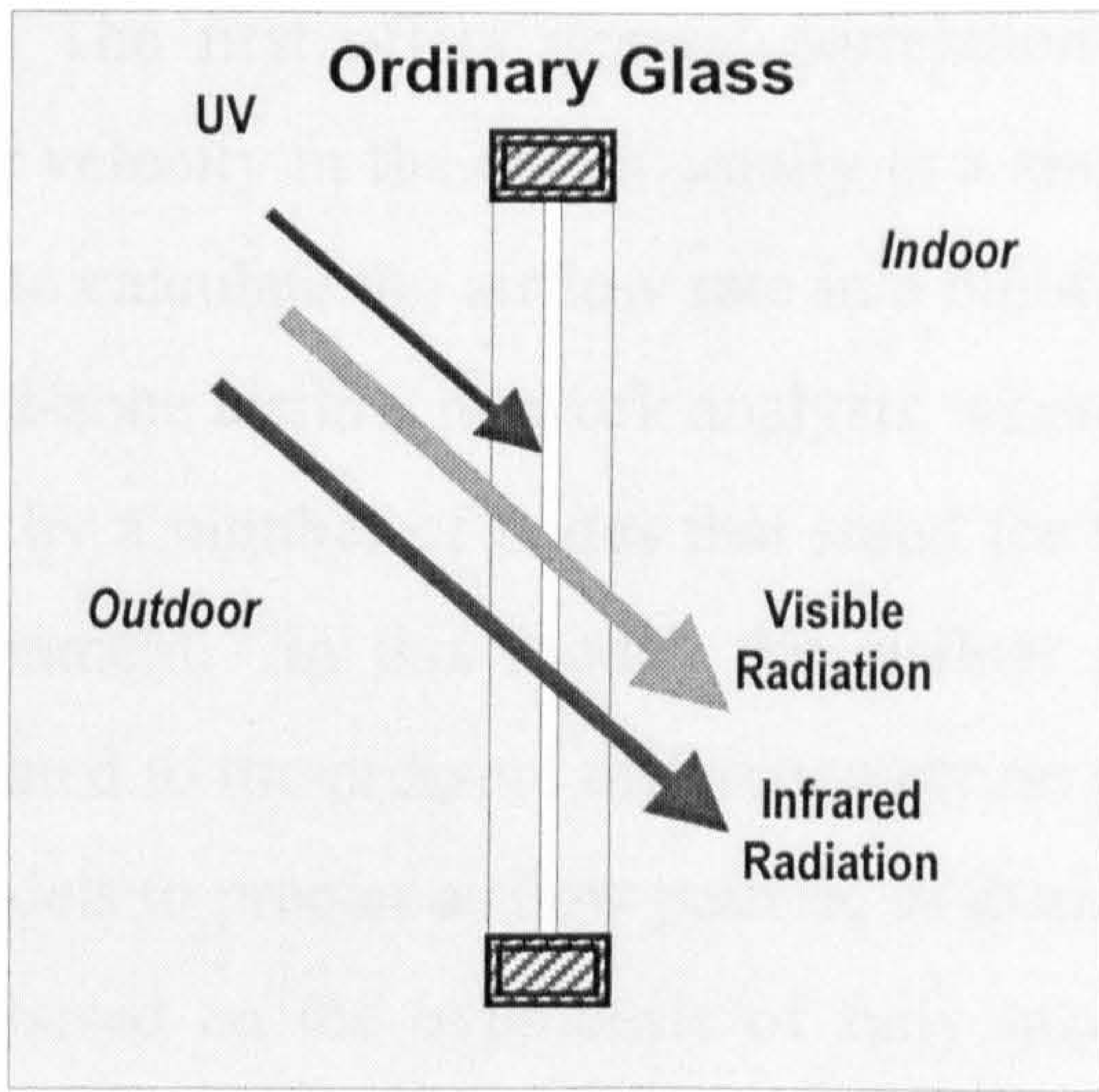


Figure III.2. Ordinary Glass

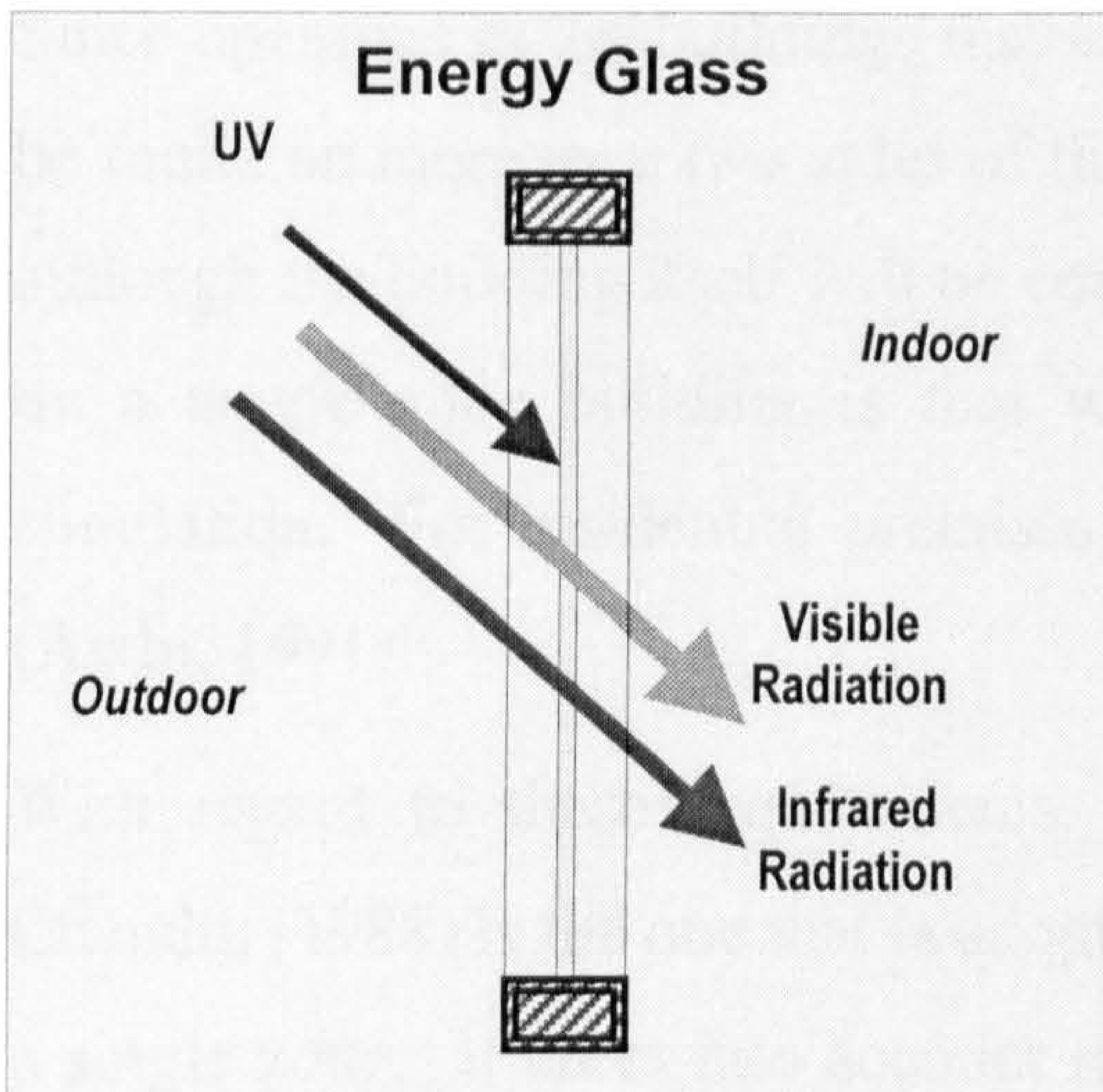


Figure III.3. Energy Glass

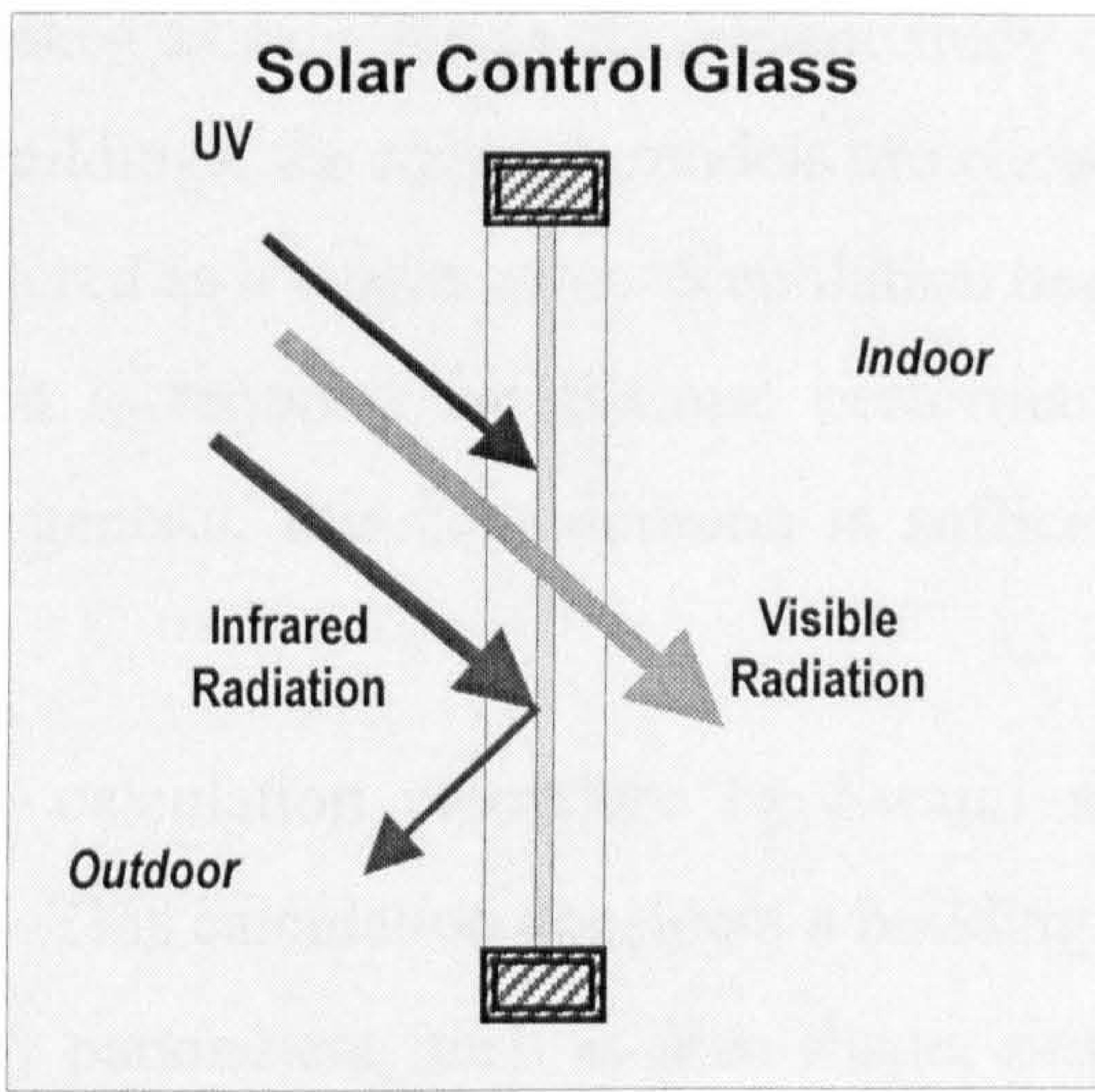


Figure III.4. Solar Control Glass

Figure III.1.:
Solar Radiation at the Surface of the Earth with Approximate Energy Content

Figure III.2.:
Ordinary glass window with U-value of 4-W/m^{2}K

Figure III.3.:
Energy glass window with U-value of 1.5-W/m^{2}K

Figure III.4.:
Ordinary glass window with U-value of 0.9-W/m^{2}K with low emission coatings and infrared radiation's protection

APPENDIX - IV

(Refer to Chapter Eight, Section 8.4., Source: Antaryama, 2000)

Natural Ventilation Flow Rate

Calculations of natural ventilation flow rate are based on four different approaches (Allard, 1998): empirical models, network models, zonal models, CFD (computational fluid dynamic) models. The first offers general correlation to calculate the airflow rate, or the mean air velocity in the zone (usually in a single zone building). The second is also used to calculate the airflow rate in a building but here its calculation is based on a multi-zone airflow network analysis, where a building is represented by a grid formed by a number of nodes that stand for the simulated zones and the exterior environment. In this model, the airflow are through a building opening is directly related to the pressure difference across the opening. The third and the fourth are models to predict airflow pattern, as distinct from the two previous models that are based on the hypothesis of fully mixed zones (Antaryama, 2000).

Since openings in the buildings that are taken as samples in the present study can be found on more than two sides of the buildings, the network models are chosen, although the building itself will be considered as a single zone. Ventilation based on a single zone building is that which is required for thermal performance simulation. For residential premises in general, this consideration is sufficient (Awbi, 1991).

With regard to these requirements, the calculation procedure by Swami and Chandra (1988) is the one that is adopted. This calculation considers a building as a single zone. It takes into account many parameters, such as plan shape, single and multiple openings, openings types, insect screening, and generalised shielding, which represent the surrounding characteristics where a buildings is situated. For this study, however, some steps of the calculation are elaborated to take account of the effects of wind directions on the area of inlet openings, and of more detailed plan shapes. These are compiled from Aynsley et.al. (1977) and Santosa (1988). In the calculation the model will be formed by one node representing the internal zone, and one or more nodes representing exterior environments. The air changes per hour (ACH) calculation for traditional compound and contemporary compact dwellings are presented in the table below.

The Air Changes per Hour (ACH) calculation for Traditional Compound and Contemporary Compact Dwellings.

Dwelling Types and ACH Periods Time		Daily Average of Air Changes per Hour (ACH)											
		MONTH											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Compound Dwelling													
ACH night	19:00-05:00	34	42	30	31	48	51	63	62	51	51	41	34
ACH day	06:00-18:00	34	42	30	31	48	51	63	62	51	51	41	34
Corrected ACH night	19:00-05:00	25	31	22	23	36	38	47	46	37	38	30	25
Corrected ACH day	06:00-18:00	25	31	22	23	36	38	47	46	37	38	30	25
Compact Dwelling													
ACH night	19:00-05:00	15	18	13	13	20	21	26	26	21	15	12	15
ACH day	06:00-18:00	23	27	28	28	38	40	50	49	40	30	24	22
Corrected ACH night	19:00-05:00	9	10	8	8	11	12	15	15	12	9	7	8
Corrected ACH day	06:00-18:00	13	15	16	16	22	23	28	28	23	17	14	13

Table Appendix IV.1. Daily Average of Air Changes per Hour in the Compound and Compact Dwellings (Antaryama, 2000)

APPENDIX - V

(Refer to Chapter Six, Section 6.4.2.1. and Section 6.4.2.2, Source; Antaryama, 2000))

Building Element	Building Material	U-Value (W/m2K)	Admittance (W/m2K)	Time Lag (Hours) Solar Gain Factor	Decrement Factor Alternating Solar Gain Lightweight Building	Absorbtance Alternating Solar Gain Heavyweight Building
	Traditional Dwelling					
Floor	Slab on ground, 4 edges exposed,6x4m	1.09	5.60	0.00	0.00	0.00
Wall	Brick,single,220mm+13mm,plastered both side	1.65	3.60	7.41	0.36	0.50
Door	Solid Timber,20mm	3.10	3.12	0.31	1.00	0.78
Window	Solid Timber,20mm	3.10	3.12	0.31	1.00	0.78
	Clear glass,single,6mm+woodframe 20%	5.00	5.00	0.76	0.64	0.47
Roof	Pitched,40°,thach,no ceiling	0.55	1.30	6.30	0.47	0.70
	Pitched,40°,clay tile, no ceiling	5.29	5.16	0.36	0.97	0.60
	Contemporary House					
Floor	Slab on ground, 4exposed, 6x6m	0.96	5.60	0.00	0.00	0.00
	Slab on ground, 4exposed, 6x10m	0.79	5.60	0.00	0.00	0.00
	Slab on ground, 4exposed, 10x10m	0.65	5.60	0.00	0.00	0.00
	Slab on ground, 4exposed, 20x10m	0.51	5.60	0.00	0.00	0.00
Wall	Hollow concrete block,120mm+13mm, both plastered	1.89	2.79	3.04	0.83	0.40
Door	Metal roller shutter	5.54	5.54	0.00	1.00	0.50
	Plywood,doublesides,4mm	2.39	2.40	0.12	1.00	0.78
Window	Clear glass,single,6mm+woodframe 20%	5.00	5.00	0.76	0.64	0.47
	Clear glass,single,6mm+woodframe 20%	5.00	5.00	0.76	0.64	0.47
	Tinted glass,single,6mm+woodframe 20%	5.00	5.00	0.60	0.53	0.41
Roof	Pitched,30°,terracotta tile+attic+asbes ceiling,5mm	2.34	2.33	0.52	0.98	0.60
	Pitched,30°,terracotta tile+attic+plywood ceiling,6mm	2.21	2.18	0.54	0.98	0.60

Table Appendix V.1. Thermal Properties of Building Materials Used in Traditional Compound and Contemporary Compact Dwellings

APPENDIX - VI

(Refer to Chapter Seven, Section 7.4. and Chapter Nine, Section 9.3.)

The Outcome of Computer Simulation of the Dwelling Combined Design

Calculated using Design Database, Version 15, 1998, Hevacomp Ltd.

Location of Bali - Indonesia

Floor Area of the Dwelling: 28.50 metre square

A. Dwelling Combined Design *without* Energy Conservation Strategies

Month	Air Conditioning Energy (GJ)	
	Sensible	Latent
Jan	4.6	1.6
Feb	4.5	1.5
Mar	4.4	1.6
Apr	4.3	1.7
May	4.1	1.8
Jun	4.0	1.9
Jul	4.0	2.0
Aug	4.1	1.9
Sep	4.2	1.9
Oct	4.3	1.7
Nov	4.4	1.6
Dec	4.6	1.6
Total	**51.50**	**20.80**

B. Dwelling Combined Design *with insulation of* Energy Conservation Strategies

Month	Air Conditioning Energy (GJ)	
	Sensible	Latent
Jan	3.6	1.5
Feb	3.6	1.5
Mar	3.5	1.6
Apr	3.4	1.7
May	3.2	1.9
Jun	3.2	2.0
Jul	3.2	2.0
Aug	3.3	1.8
Sep	3.4	1.9
Oct	3.4	1.8
Nov	3.6	1.6
Dec	3.6	1.5
Total	**41.00**	**20.80**

C. Dwelling Combined Design *with* Energy Conservation Combined Strategies

Month	Air Conditioning Energy (GJ)	
	Sensible	Latent
Jan	1.5	0.7
Feb	1.4	0.7
Mar	1.4	0.7
Apr	1.4	0.8
May	1.4	0.8
Jun	1.2	0.9
Jul	1.2	0.9
Aug	1.2	0.9
Sep	1.4	0.9
Oct	1.4	0.9
Nov	1.4	0.7
Dec	1.5	0.7
Total	**16.40**	**9.60**

Energy Efficient Cooling of the Dwelling Combined Design = 0.86 GJ per metre square

The Outcome of Computer Simulation of the Dwelling Standard Design

Calculated using Design Database, Version 15, 1998, Hevacomp Ltd.

Location of Bali - Indonesia

Floor Area of the Dwelling: 27.00 metre square

D. Dwelling Standard Design *without* Energy Conservation Strategies

Month	Air Conditioning Energy (GJ)	
	Sensible	Latent
Jan	4.8	1.7
Feb	4.7	1.7
Mar	4.7	1.7
Apr	4.5	1.8
May	4.4	2.0
Jun	4.3	2.1
Jul	4.3	2.1
Aug	4.4	2.0
Sep	4.5	1.9
Oct	4.7	1.9
Nov	4.7	1.8
Dec	4.8	1.7
Total	**54.80**	**22.40**

E. Dwelling Standard Design *with insulation of* Energy Conservation Strategies

Month	Air Conditioning Energy (GJ)	
	Sensible	Latent
Jan	3.8	1.6
Feb	3.8	1.7
Mar	3.8	1.7
Apr	3.7	1.8
May	3.6	2.0
Jun	3.6	2.1
Jul	3.6	2.1
Aug	3.6	2.1
Sep	3.7	2.0
Oct	3.8	1.9
Nov	3.8	1.8
Dec	3.8	1.6
Total	**44.60**	**22.40**

F. Dwelling Standard Design *with* Energy Conservation Strategies

Month	Air Conditioning Energy (GJ)	
	Sensible	Latent
Jan	1.7	0.8
Feb	1.6	0.8
Mar	1.5	0.8
Apr	1.5	0.9
May	1.4	0.9
Jun	1.4	0.9
Jul	1.4	0.9
Aug	1.4	0.9
Sep	1.5	0.9
Oct	1.6	0.9
Nov	1.7	0.8
Dec	1.7	0.8
Total	**18.40**	**10.30**

Energy Efficient Cooling of the Dwelling Standard Design = 1.10 GJ per metre square

Detail

The Outcome of Computer Simulation of the Dwelling Combined Design

Calculated using Design Database, Version 15, 1998, Hevacomp Ltd.

Location of Bali - Indonesia

Floor Area of the Dwelling: 28.50 metre square

Month	Dwelling Combined Design Air Conditioning Energy (GJ)			
	Un-Insulated		Shading Devices	
	Sensible	Latent	Sensible	Latent
Jan	4.6	1.6	4.5	1.5
Feb	4.5	1.5	4.4	1.5
Mar	4.4	1.6	4.4	1.6
Apr	4.3	1.7	4.3	1.7
May	4.1	1.8	4.1	1.8
Jun	4.0	1.9	4.0	1.9
Jul	4.0	2.0	4.0	2.0
Aug	4.1	1.9	4.1	1.9
Sep	4.2	1.9	4.2	1.9
Oct	4.3	1.7	4.3	1.7
Nov	4.4	1.6	4.4	1.6
Dec	4.6	1.6	4.5	1.5
Total	**51.50**	**20.80**	**51.20**	**20.60**

Month	Dwelling Combined Design Air Conditioning Energy (GJ)			
	Insulated		Combined Strategies	
	Sensible	Latent	Sensible	Latent
Jan	3.5	1.5	1.9	0.8
Feb	3.5	1.5	1.8	0.8
Mar	3.5	1.6	1.8	0.8
Apr	3.4	1.7	1.7	0.8
May	3.2	1.8	1.7	0.8
Jun	3.2	1.9	1.6	0.9
Jul	3.2	2.0	1.7	0.9
Aug	3.3	2.0	1.7	0.9
Sep	3.4	1.9	1.7	0.9
Oct	3.4	1.7	1.8	0.8
Nov	3.5	1.6	1.8	0.8
Dec	3.5	1.5	1.8	0.8
Total	**40.60**	**20.70**	**21.00**	**10.00**

Detail

The Outcome of Computer Simulation of the Dwelling Standard Design

Calculated using Design Database, Version 15, 1998, Hevacomp Ltd.

7-Hour Occupancy

Location of Bali - Indonesia

Floor Area of the Dwelling: 27.00 metre square

Month	Dwelling Standard Design 7-Hour Occupancy Air Conditioning Energy (GJ)			
	Un-Insulated		Shading Devices	
	Sensible	Latent	Sensible	Latent
Jan	4.8	1.6	4.6	1.6
Feb	4.7	1.7	4.5	1.7
Mar	4.7	1.7	4.5	1.7
Apr	4.5	1.8	4.4	1.8
May	4.4	2.0	4.2	2.0
Jun	4.3	2.1	4.1	2.1
Jul	4.3	2.1	4.2	2.1
Aug	4.4	2.0	4.3	2.0
Sep	4.5	2.0	4.4	2.0
Oct	4.7	1.9	4.5	1.8
Nov	4.7	1.8	4.6	1.8
Dec	4.8	1.7	4.6	1.7
Total	**54.80**	**22.40**	**52.90**	**22.30**

Month	Dwelling Standard Design 7-Hour Occupancy Air Conditioning Energy (GJ)			
	Insulated		Combined Strategies	
	Sensible	Latent	Sensible	Latent
Jan	3.8	1.6	3.6	1.6
Feb	3.8	1.7	3.5	1.7
Mar	3.8	1.7	3.5	1.7
Apr	3.7	1.8	3.4	1.8
May	3.6	2.0	3.4	2.0
Jun	3.6	2.1	3.3	2.1
Jul	3.6	2.1	3.3	2.1
Aug	3.6	2.0	3.4	2.1
Sep	3.7	1.9	3.4	1.9
Oct	3.8	1.9	3.5	1.8
Nov	3.8	1.8	3.5	1.8
Dec	3.8	1.7	3.5	1.7
Total	**44.60**	**22.30**	**41.30**	**22.30**

Detail

The Outcome of Computer Simulation of the Dwelling Standard Design

Calculated using Design Database, Version 15, 1998, Hevacomp Ltd.

3-Hour Occupancy

Location of Bali - Indonesia

Floor Area of the Dwelling: 27.00 metre square

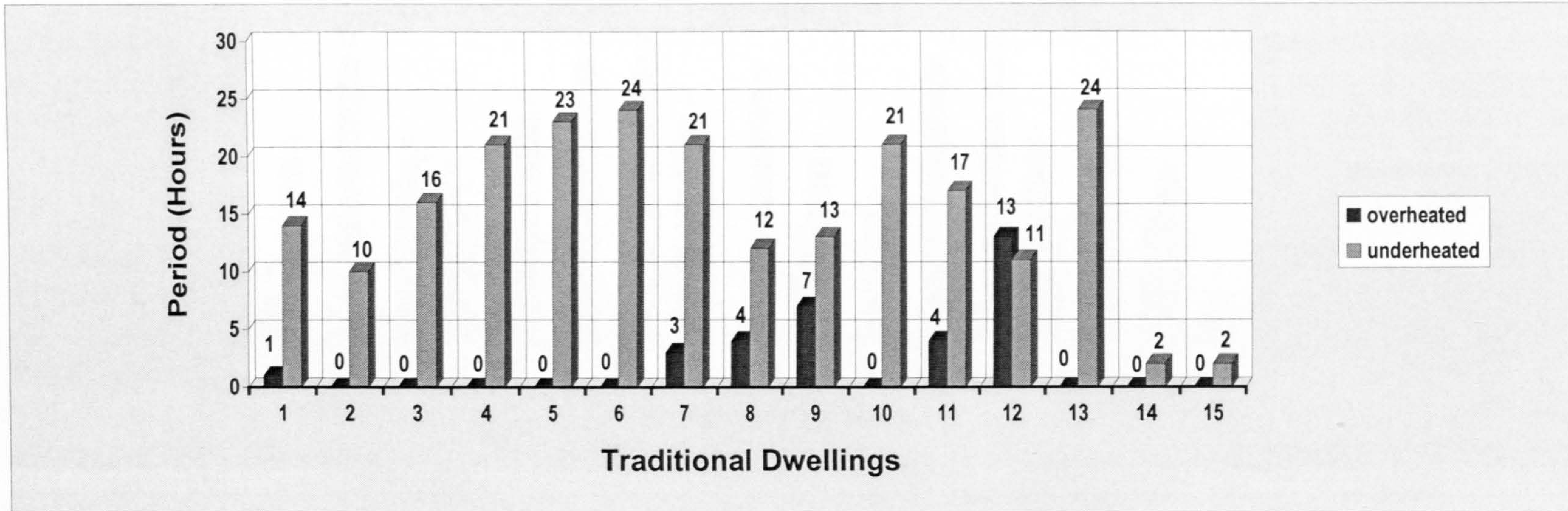
Month	Dwelling Standard Design 3-Hour Occupancy Air Conditioning Energy (GJ)			
	Un-Insulated		Shading Devices	
	Sensible	Latent	Sensible	Latent
Jan	2.2	0.8	1.8	0.8
Feb	2.1	0.8	1.8	0.8
Mar	2.1	0.8	1.9	0.8
Apr	2.1	0.9	1.9	0.9
May	2.0	0.9	1.9	0.9
Jun	1.9	0.9	1.9	0.9
Jul	2.0	0.9	1.9	0.9
Aug	2.0	0.9	1.9	0.9
Sep	2.1	0.9	1.9	0.9
Oct	2.1	0.9	1.8	0.9
Nov	2.1	0.8	1.8	0.8
Dec	2.1	0.8	1.8	0.8
Total	**24.80**	**10.30**	**22.30**	**10.30**

Month	Dwelling Standard Design 3-Hour Occupancy Air Conditioning Energy (GJ)			
	Insulated		Combined Strategies	
	Sensible	Latent	Sensible	Latent
Jan	1.8	0.8	1.7	0.8
Feb	1.8	0.8	1.6	0.8
Mar	1.8	0.8	1.5	0.8
Apr	1.8	0.9	1.5	0.9
May	1.7	0.9	1.4	0.9
Jun	1.7	0.9	1.4	0.9
Jul	1.7	0.9	1.4	0.9
Aug	1.7	0.9	1.4	0.9
Sep	1.8	0.9	1.5	0.9
Oct	1.8	0.9	1.6	0.9
Nov	1.8	0.8	1.7	0.8
Dec	1.8	0.8	1.8	0.8
Total	**21.20**	**10.30**	**18.40**	**10.30**

APPENDIX - VII

(Refer to Chapter Six, Section 6.4.2.2. and Section 6.4.3.1., Sources; Antaryama, 2000)

Thermal Performance of Traditional Dwellings of the Field Research Measurement

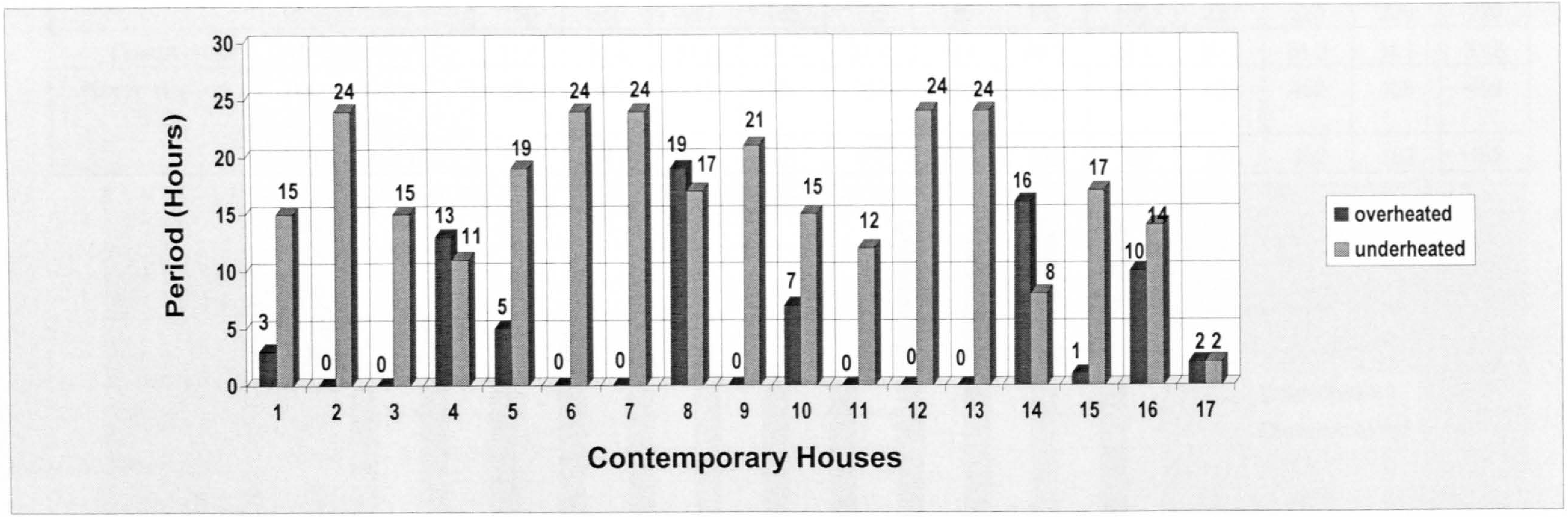


Traditional Dwelling		L	O	C	A	T	I	O	N							
		A			B			C			D			E		
House No		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Orientation		360	360	5	5	5	5	40	40	40	360	345	345	355	5	5
Period* (hour)	Overheated	1	0	0	0	0	0	3	4	7	0	4	13	0	0	0
	Underheated	14	10	16	21	23	24	21	12	13	21	17	11	24	2	2

Figure VII.1. Histogram of Overheated and Indoor Comfort Periods from the Measured DBT in the Traditional Dwellings

(*out of a 24-hour day)

Thermal Performance of Contemporary Dwellings of the Field Research Measurement

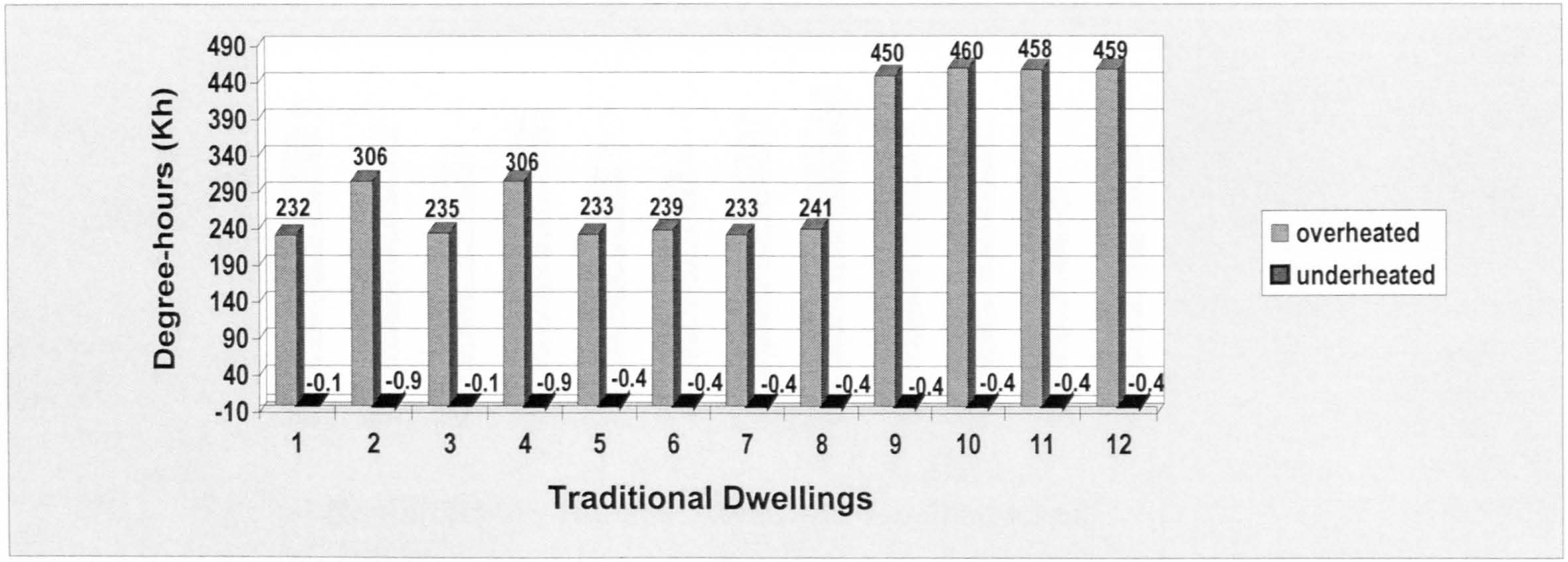


Housing Estate		LOCATION																
		I					II			III						IV		
House No		1	2	3	4	5	6	7	8	4	5	11	12	13	14	15	16	17
Orientation		357	10	252	357	10	180	180	360	180	360	177	357	360	10	357	357	188
Period*	Overheated	3	0	0	13	5	0	0	19	0	7	0	0	0	16	1	10	2
(hour)	Indoor Comfort	15	24	15	11	19	24	24	17	21	15	12	24	24	8	17	14	2

Figure VII.2. Histogram of Overheated and Indoor Comfort Periods from the Measured DBT in the Contemporary Houses
(*out of a 24-hour day)
(I = 0-wall attached type, II = 1-wall attached, III = 2-wall attached type, IV = 3-wall attached type)

Thermal Performance of Traditional Dwellings of the Computer Research Simulation

Houses	Number	1	2	3	4	5	6	7	8	9	10	11	12
	Orientation	180	180	180	185	185	185	185	185	220	220	220	220
Temperature	Maximum (°C)	31.4	31.6	31.7	31.6	31.0	30.4	29.5	29.4	30.3	31.2	31.7	31.8
Over Heated (Kh)	Degreehour	232	306	235	306	233	239	233	241	450	460	458	459
	Period*(hr)	138	141	138	141	137	138	136	136	137	162	163	162

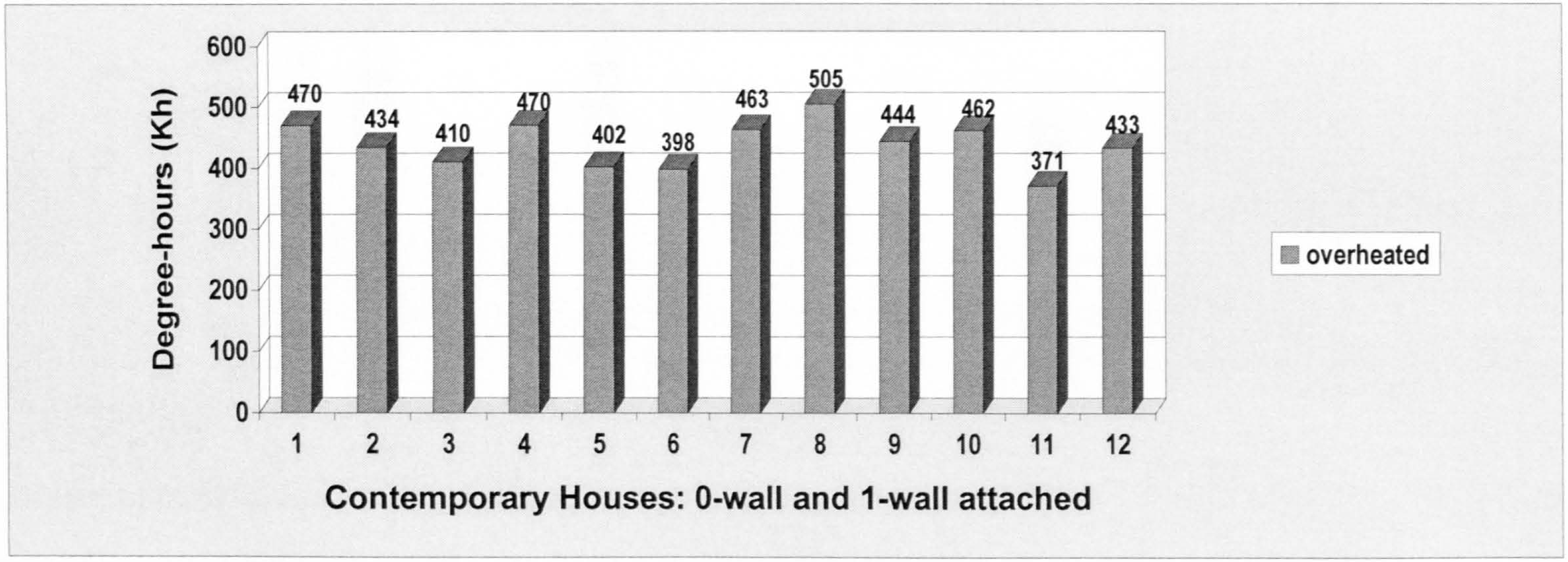


Temperature	Minimum (°C)	24.6	24.8	24.6	24.5	24.1	23.9	23.6	23.5	23.6	24.2	24.9	24.9
Under Heated (Kh)	Degreehour	-0.1	-0.9	-0.1	-0.9	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
	Period*(hr)	0	0	0	0	1	3	4	6	4	0	0	0

Figure VII.3. The Computer Simulation Outcome of Cooling and Heating Degree-hours in the Traditional Dwellings.
(*out of a 288-hour [12monthsx 24 hour] year)

Thermal Performance of the Computer Research Simulation of Contemporary Houses: 0-wall and 1-wall attached

Houses	Number	1	2	3	4	5	6	7	8	9	10	11	12
	Orientation	180	180	180	185	185	185	185	185	220	220	220	220
Temperature	Maximum (°C)	33.5	33.0	33.5	33.7	33.2	33.1	34.5	33.4	33.3	34.2	32.7	33.8
Over Heated (Kh)	Degreehour	470	434	410	470	402	398	463	505	444	462	371	433
	Period*(hr)	171	167	164	171	164	163	173	196	170	180	158	215

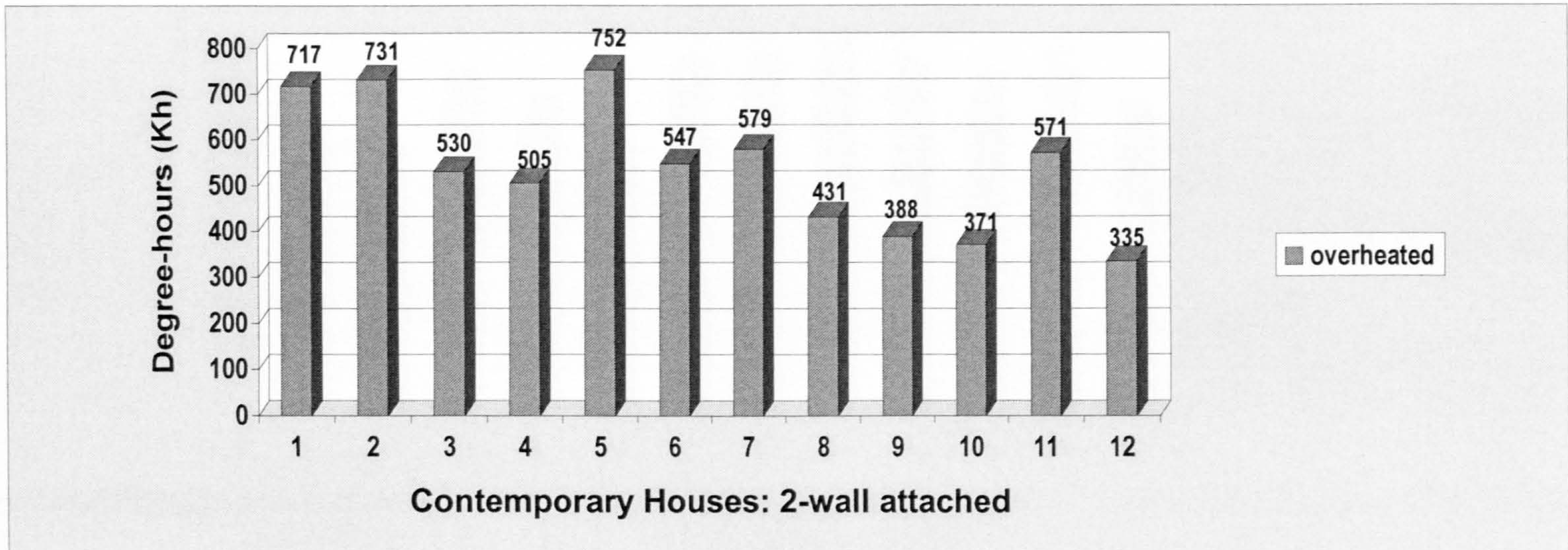


Temperature	Minimum (°C)	24.6	24.8	24.6	24.5	24.1	23.9	23.6	23.5	23.6	24.2	24.9	24.9
Under Heated (Kh)	Degreehour	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Period*(hr)	0	0	0	0	0	0	0	0	0	0	0	0

Figure VII.4. The Computer Simulation Outcome of Cooling and Heating Degree-hours in the Contemporary Houses: 0-wall and 1-wall attached. (*out of a 288-hour [12monthsx 24 hour] year)

Thermal Performance of the Computer Research Simulation of Contemporary Houses: 2-wall attached

Houses	Number	1	2	3	4	5	6	7	8	9	10	11	12
	Orientation	180	180	180	185	185	185	185	185	220	220	220	220
Temperature	Maximum (°C)	34.5	35.0	34.5	34.7	35.2	33.1	34.5	36.4	34.3	34.2	35.7	33.8
Over Heated (Kh)	Degreehour	717	731	530	505	752	547	579	431	388	371	571	335
	Period*(hr)	171	167	164	171	164	163	173	196	170	180	158	215

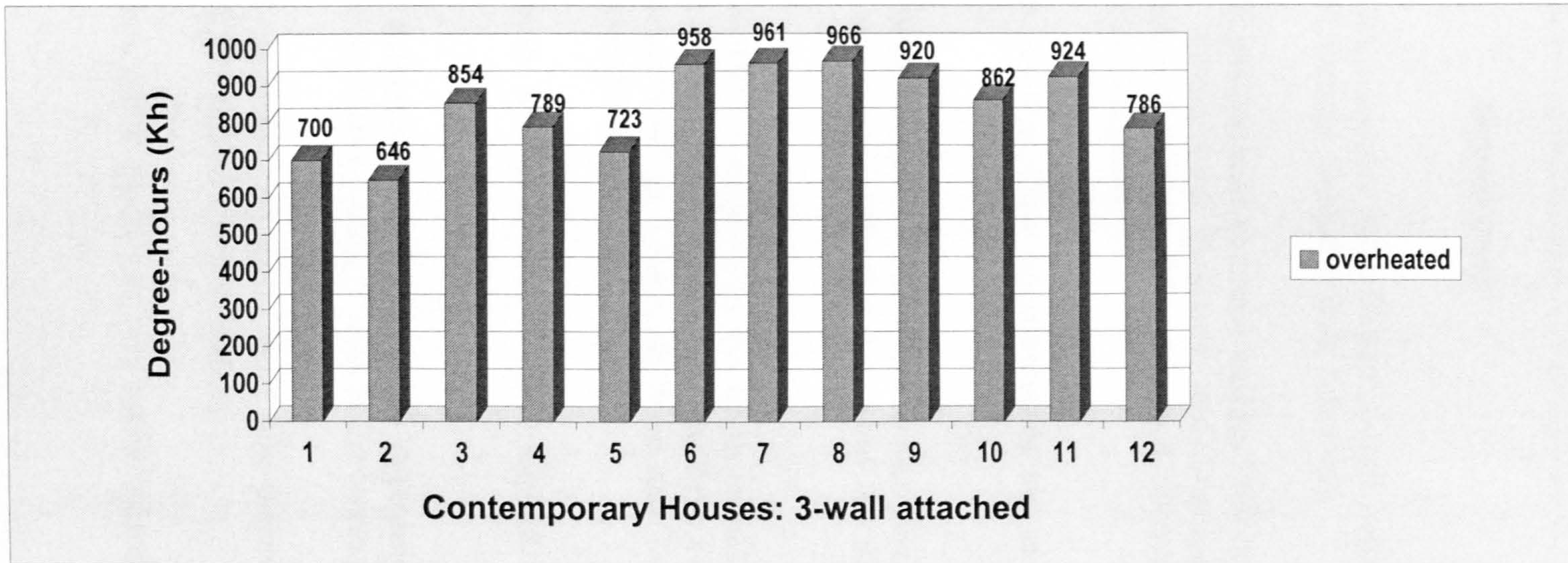


Temperature	Minimum (°C)	24.6	24.8	24.6	24.5	24.1	23.9	23.6	23.5	23.6	24.2	24.9	24.9
Under Heated (Kh)	Degreehour	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Period*(hr)	0	0	0	0	0	0	0	0	0	0	0	0

Figure VII.5. The Computer Simulation Outcome of Cooling and Heating Degree-hours in the Contemporary Houses: 2-wall attached. (*out of a 288-hour [12monthsx 24 hour] year)

Thermal Performance of the Computer Research Simulation of Contemporary Houses: 3-wall attached

Houses	Number	1	2	3	4	5	6	7	8	9	10	11	12
	Orientation	180	180	180	185	185	185	185	185	220	220	220	220
Temperature	Maximum (°C)	34.5	35.0	34.5	34.7	35.2	33.1	34.5	36.4	34.3	34.2	35.7	33.8
Over Heated (Kh)	Degreehour	700	646	854	789	723	958	961	966	920	862	924	786
	Period*(hr)	171	167	164	171	164	163	173	196	170	180	158	215



Temperature	Minimum (°C)	24.6	24.8	24.6	24.5	24.1	23.9	23.6	23.5	23.6	24.2	24.9	24.9
Under Heated (Kh)	Degreehour	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Period*(hr)	0	0	0	0	0	0	0	0	0	0	0	0

Figure VII.6. The Computer Simulation Outcome of Cooling and Heating Degree-hours in the Contemporary Houses: 3-wall attached. (*out of a 288-hour [12monthsx 24 hour] year)

APPENDIX - VIII

(Refer to Chapter Five, Section 5.5.)

Questionnaires

Introductory

Dear Sir/Madam *English*

My name is Ciptadi Trimarianto, a lecturer at the Department of Architecture, Faculty of Engineering, University of Udayana, Denpasar Bali, Indonesia.

Recently, I am registered as a postgraduate research student PhD degree program in Architecture at Centre for Architectural Research and Development Overseas (CARDO), School of Architecture Planning and Landscape, University of Newcastle, Newcastle upon Tyne, the United Kingdom.

I am writing here to inform you that these questionnaires are as apart as of my doctoral study process.

Indonesia is apart an international tourism centres where is the place of meeting the needs between international and local people that they have the difference climate background.

The survey aims to obtain comfort information in the warm humid tropical climate environment such as Indonesia. Your experiences that you have been living in the Tropic and or both in overseas/abroad as Temperate Zone and Tropical Zone are important to give necessarily information.

The information that you provide will be applied to the design of thermal efficient building for tropical climates.

The next two pages of this attachment contain questions regarding your house in Indonesia, please answer these by simply putting a cross in the boxes provided.

Write your name and email addresses and then, could you please send back the answer by e-mail to: Ciptadi.Trimarianto@Newcastle.ac.uk

Finally, I would like appreciates and to thank you very much indeed for your kindly help and attention.

Sincerely,

Ciptadi Trimarianto

Postgraduate Research Student

Pengantar

Yang Terhormat Bapak/Ibu/Saudara *Indonesia*

Nama saya adalah Ciptadi Trimarianto, staf pengajar di Program Studi Arsitektur pada Fakultas Teknik, Universitas Udayana, Denpasar Bali, Indonesia.

Saat ini saya terdaftar sebagai mahasiswa reset pasca sarjana program doctor (S3) dibidang Arsitektur pada Pusat Riset Arsitektur dan Pengembangan Luar Negeri (CARDO), Sekolah Arsitektur, Perencanaan dan Lansekap, Universitas Newcastle, Newcastle upon Tyne, di Inggris.

Saya sampaikan informasi kepada anda bahwa survey ini adalah salah satu bagian dari proses dalam belajar mendapatkan gelar doktor.

Indonesia adalah bagian dari pusat pariwisata internasional dimana merupakan tempat bertemunya kepentingan-kepentingan antara masyarakat internasional and lokal yang mana mereka mempunyai latar belakang kondisi alam yang berbeda.

Survey in bertujuan untuk mendapatkan informasi tentang kondisi nyaman di daerah lingkungan tropik lembab seperti di Indonesia. Pengalaman anda yang tinggal di daerah tropik dan atau pernah tinggal di kedua daerah; tropik dan non tropik di luar negeri adalah sangat penting diperlukan informasinya.

Informasi yang anda berikan akan diterapkan pada disain bangunan bertermal efisien untuk daerah beriklim tropik.

Dua lembar lampiran berikut berisi beberapa pertanyaan tentang rumah anda di Indonesia, silahkan isi jawabannya dengan memberikan tanda silang pada kolom yang tersedia.

Cantumkan nama dan email adres, kemudian, kirim kembali jawaban anda melalui e-mail: Ciptadi.Trimarianto@Newcastle.ac.uk

Akhirnya saya mengucapkan terima kasih dan penghargaan yang sebesar besarnya atas segala perhatian dan bantuan yang anda berikan.

Hormat saya,

Ciptadi Trimarianto

Mahasiswa S3 Program Pasca Sarjana

Name / *Nama*:
E-mail:

QUESTIONNAIRES

CHOOSE AND ANSWER THE QUESTIONS BY CROSS (x) THE BOX

Pilih Jawaban Dengan Memberikan Tanda Silang (x) Pada Kotak Yang Tersedia

No	Questions *Pertanyaan*	Choose Answer *Jawaban*		BOX *Box*
1.	**Settlement Location** ***Lokasi Pemukiman***	Tourism community / *Pariwisata*	1.	
		Inner city / *Pusat Kota*	2.	
		Suburban/Rural / *Pedesaan*	3.	
2.	**Accommodations' Owner** ***Rumah Kepemilikan***	Owner / *Milik sendiri*	1.	
		Family Owner / *Milik Keluarga*	2.	
		Tenant / *Sewa*	3.	
3.	**Household Identifier** ***Identitas Pemilik***	International / *Internasional*	1.	
		Indonesia / *Indonesia*	2.	
		Bali / *Bali*	3.	
4.	**Marital Status** ***Setatus Perkawinan***	Single / *Belum Nikah*	1.	
		Married / *Nikah*	2.	
5.	**Number of Children** ***Jumlah Anak***	No Child / *Tidak punya*	1.	
		1 Child / *1 anak*	2.	
		2 Children / *2 anak*	3.	
		3 Children and more / *3 anak lebih*	4.	
6.	**Education** ***Pendidikan***	High School / *Sekolah Menegah*	1.	
		University / *Universitas*	2.	
		Other / *Lainnya*	3.	
7.	**Main Occupiers' Age** ***Usia Kepala Keluarga***	> 0 - 16 / *0 - 16 tahun*	1.	
		> 16 - 25 / *16 - 25 tahun*	2.	
		> 25 - 35 / *25 - 35 tahun*	3.	
		> 35 - 50 / *35 - 50 tahun*	4.	
		> 50 / *50 tahun keatas*	5.	
8.	**Household Occupation** ***Pekerjaan Kepala Keluarga***	Government / *Pemerintah*	1.	
		Private / *Swasta*	2.	
		Other / *Lainnya*	3.	
9.	**Spouse Occupation** ***Pekerjaan Istri***	Government / *Pemerintah*	1.	
		Private / *Swasta*	2.	
		Other / *Lainnya*	3.	
10.	**Do you think Air Conditioning (AC) in the house is vital? /** ***Pentingkah AC dirumah anda ?***	Not Vital / *Tidak penting*	1.	
		Nearly Vital / *Agak penting*	2.	
		Necessary / *Penting*	3.	
		Most Vital / *Selalu penting*	4.	
		Very Vital / *Sangat penting*	5.	

QUESTIONNAIRES
CHOOSE AND ANSWER THE QUESTIONS BY CROSS (x) THE BOX

No	Questions	Choose Answer		BOX
11.	**Which one would you like for convenience house?** ***Manakah dipilih untuk kenyaman rumah anda ?***	Air Conditioning (AC) / *Penghawaan buatan*	1.	
		Natural Ventilation (NV). / *Penghawaan alam*	2.	
		Both AC & NV / *Penghawaan buatan dan alam*	3.	
12.	**What type of house do you like?** ***Rumah tipe apa yang anda sukai ?***	Single Storey House / *Satu Lantai*	1.	
		Two / Three Storey / *Dua, Tiga Lantai*	2.	
		Multi-storey / *Berlantai banyak*	3.	
13.	**Why do you live in your current accommodation?** ***Kenapa anda tinggal dirumah yang sekarang ?***	Convenient / *Kenyamanan*	1.	
		Environment / *Lingkungan*	2.	
		Affordable Price / *Harga Terjangkau*	3.	
		Security / *Keamanan*	4.	
14.	**How much do you spent on energy monthly?** ***Berapa pengeluaran biaya energi untuk rumah anda per bulan?***	Electricity / *Listrik*: Up to 15 U$	1.	
		> 15–50 U$	2.	
		> 50 U$	3.	
		Gas / *Gas*: Up to 10 U$	1.	
		> 10–25 U$	2.	
		> 25 U$	3.	
15.	**If you do not mind, which is your annual income range, please?** ***Jika tak keberatan, berapa penghasilan pertahun anda?***	Up to 500 U$	1.	
		> 500–1,000 U$	2.	
		> 1,000-2,500 U$	3.	
		> 2,500-5,000 U$	4.	
		> 5,000 U$	5.	

No	Questions	Cross (x) the each boxes yes or no / *Beri tanda (x) pada setiap kotak*		Yes	No
16.	**What do you think is the ideal house?** ***Yang bagaimanakah rumah ideal bagi anda?***	Traditional / *Tradisional*	1.		
		Modern / *Moderen*	2.		
		Comfortable / *Nyaman*	3.		
		Affordable / *Terjangkau*	4.		
		Accessible Location / *Mudah dicapai*	5.		
		Air Conditioned / *AC*	6.		
		Natural Ventilation / *Alamiah*	7.		
		Healthy / *Sehat*	8.		
		Save Energy / *Hemat Enerji*	9.		
		Expensive / *Mahal*	10.		
		Small / *Kecil*	11.		
		Large / *Besar*	12.		

APPENDIX - IX

(Refer to Chapter Five, Section 5.5. and Section 5.7.)

Table IX.1. Results of the Survey Research

Household Number and Dwelling Location	Accommodation Owner	Household ID	Marital Status	Children	Education	Occupiers Age	Household Occupation	Spouse Occupation
1. Inner City	Family	Bali	Married	3	University	40	Government	Private
2. Inner City	Tenant	Bali	Married	2	University	40	Government	Private
3. Inner City	Tenant	Indonesia	Single	0	University	30	Private	Private
4. Inner City	Owner	Indonesia	Married	1	University	40	Government	Private
5. Inner City	Tenant	Indonesia	Single	0	University	20	Other	Other
6. Inner City	Tenant	Indonesia	Married	1	Other	30	Government	Other
7. Inner City	Owner	Indonesia	Married	3	University	50	Private	Government
8. Inner City	Family	Indonesia	Married	1	University	30	Government	Government
9. Inner City	Owner	Indonesia	Married	1	University	30	Private	Private
10. Inner City	Owner	Indonesia	Married	2	University	40	Government	Government
11. Inner City	Family	Indonesia	Married	2	University	40	Government	Government
12. Inner City	Owner	Indonesia	Single	0	University	20	Private	
13. Inner City	Owner	Indonesia	Married	2	University	16	Government	Government
14. Inner City	Family	Indonesia	Single	0	University	30	Other	
15. Inner City	Family	Indonesia	Married	2	University	30	Government	Government
16. Inner City	Tenant	Indonesia	Married	0	University	30	Government	Private
17. Inner City	Owner	Indonesia	Married	3	High School	40	Private	Other
18. Inner City	Tenant	Indonesia	Single	0	University	30	Private	Private
19. Inner City	Owner	Indonesia	Single	0	University	30	Other	Other
20. Inner City	Family	Indonesia	Married	1	University	30	Government	Private
21. Inner City	Owner	Indonesia	Married	1	University	30	Government	Government
22. Inner City	Owner	Indonesia	Married	1	High School	30	Government	Other
23. Inner City	Tenant	Indonesia	Married	2	University	30	Government	Private
24. Inner City	Owner	Indonesia	Married	1	University	30	Government	Government
25. Inner City	Family	Indonesia	Single	0	University	50	Government	Government
26. Inner City	Family	Indonesia	Single	0	University	20	Private	
27. Inner City	Owner	Indonesia	Married	2	University	40	Private	Private
28. Inner City	Tenant	Indonesia	Single	1	Other	16	Private	
29. Inner City	Family	Indonesia	Married	2	University	30	Government	Other
30. Inner City	Tenant	Indonesia	Married	1	University	30	Government	Government
31. Inner City	Tenant	Indonesia	Married	2	University	30	Private	Other

Household Number and Dwelling Location	Accommodation Owner	Household ID	Marital Status	Children	Education	Occupiers Age	Household Occupation	Spouse Occupation
32. Inner City	Owner	Indonesia	Married	1	University	30	Private	Private
33. Inner City	Family	Indonesia	Married	2	University	30	Government	Private
34. Inner City	Family	Indonesia	Single	0	University	30	Government	Other
35. Inner City	Tenant	Indonesia	Single	0	University	30	Government	
36. Inner City	Family	Indonesia	Married	0	University	20	Government	Government
37. Inner City	Tenant	Indonesia	Single	0	University	20	Private	
38. Inner City	Owner	Indonesia	Married	2	University	50	Private	Private
39. Inner City	Family	Indonesia	Single	1	University	40	Government	Government
40. Inner City	Family	Indonesia	Single	0	University	0	Other	
41. Inner City	Family	Indonesia	Single	0	University	20	Other	
42. Inner City	Tenant	Indonesia	Single	0	University	50	Government	Other
43. Inner City	Owner	Indonesia	Married	1	University	40	Government	Private
44. Inner City	Tenant	Indonesia	Married	1	University	40	Government	Other
45. Inner City	Tenant	Indonesia	Married	2	University	30	Government	Private
46. Inner City	Family	Indonesia	Married	3	University	40	Government	Government
47. Inner City	Family	Indonesia	Married	1	University	30	Government	Private
48. Inner City	Family	Indonesia	Married	0	University	30		Government
49. Inner City	Tenant	Indonesia	Married	0	University	30	Other	Government
50. Inner City	Owner	Indonesia	Single	0	University	16	Private	
51. Inner City	Tenant	Indonesia	Married	2	University	30	Government	Other
52. Inner City	Tenant	Indonesia	Single	0	High School	30	Government	
53. Inner City	Tenant	Indonesia	Married	3	High School	40	Private	Private
54. Inner City	Owner	Indonesia	Married	1	University	40	Government	Private
55. Inner City	Family	Indonesia	Single	0	University	30	Private	
56. Inner City	Tenant	Indonesia	Married	3	University	40	Government	Government
57. Inner City	Owner	Indonesia	Married	2	University	40	Government	Government
58. Inner City	Family	Indonesia	Single	0	University	30	Private	Other
59. Inner City	Owner	Indonesia	Married	0	University	30	Private	Private
60. Inner City	Tenant	Indonesia	Single	0	University	20	Other	
61. Inner City	Family	Indonesia	Married	2	University	40	Private	Private
62. Inner City	Family	Indonesia	Single	0	University	30	Other	
63. Inner City	Owner	Indonesia	Married	1	University	30	Government	Government
64. Inner City	Owner	Indonesia	Married	1	University	30	Private	Private
65. Inner City	Tenant	Indonesia	Married	1	University	40	Other	Other
66. Inner City	Tenant	Indonesia	Married	1	University	40	Other	Other
67. Inner City	Family	Indonesia	Married	0	University	30	Private	Private
68. Inner City	Family	Indonesia	Single	0	University	30	Private	Other
69. Inner City	Owner	Indonesia	Married	2	University	40	Private	Private

Household Number and Dwelling Location	Accommodation Owner	Household ID	Marital Status	Children	Education	Occupiers Age	Household Occupation	Spouse Occupation
70. Inner City	Owner	Indonesia	Married	1	University	40	Government	Government
71. Inner City	Tenant	Indonesia	Married	1	University	40	Private	Government
72. Inner City	Family	Indonesia	Married	3	University	16	Government	Private
73. Inner City	Family	Indonesia	Single	0	University	0	Other	
74. Inner City	Family	Indonesia	Single	0	University	40	Government	
75. Inner City	Tenant	Indonesia	Married	3	University	40	Government	Private
76. Inner City	Family	Indonesia	Married	1	University	40	Government	Government
77. Inner City	Owner	Indonesia	Married	1	University	30	Private	Private
78. Inner City	Owner	Indonesia	Married	0	University	30	Private	Private
79. Inner City	Tenant	Indonesia	Married	0	University	16	Private	Private
80. Inner City	Family	International	Married	3	University	50	Private	Other
81. Inner City	Tenant	International	Married	1	University	40	Government	Government
82. Inner City	Tenant	International	Married	2	University	40	Government	Other
83. Suburban	Family	Bali	Single	0	University	30	Private	
84. Suburban	Family	Bali	Single	0	University	30	Private	
85. Suburban	Owner	Indonesia	Married	3	University	16	Government	Government
86. Suburban	Owner	Indonesia	Married	3	University	16	Private	Other
87. Suburban	Owner	Indonesia	Married	3	High School	40	Private	Other
88. Suburban	Family	Indonesia	Married	2	University	40	Government	Private
89. Suburban	Tenant	Indonesia	Married	1	University	50	Government	Other
90. Suburban	Tenant	Indonesia	Married	1	University	30	Private	Private
91. Suburban	Tenant	Indonesia	Married	2	University	30	Government	Other
92. Suburban	Owner	Indonesia	Married	1	University	40	Government	Government
93. Suburban	Owner	Indonesia	Married	2	University	40	Government	Government
94. Suburban	Tenant	Indonesia	Married	0	University	30	Government	Private
95. Suburban	Owner	Indonesia	Married	0	University	40	Government	Other
96. Suburban	Owner	Indonesia	Married	3	University	40	Government	Private
97. Suburban	Family	Indonesia	Single	0	University	30	Private	Other
98. Suburban	Owner	Indonesia	Single	0	University	30	Government	Government
99. Suburban	Owner	Indonesia	Married	1	University	30	Government	Other
100. Suburban	Owner	Indonesia	Single	0	University	40	Government	
101. Suburban	Family	Indonesia	Married	1	University	50	Other	
102. Suburban	Owner	Indonesia	Married	1	University	40	Government	Private
103. Suburban	Tenant	Indonesia	Married	0	University	20	Government	
104. Suburban	Owner	Indonesia	Married	0	University	40	Government	
105. Suburban	Owner	Indonesia	Married	3	University	40	Government	Government
106. Suburban	Family	Indonesia	Married	1	University	16	Private	Private
107. Suburban	Owner	Indonesia	Married	2	University	40	Private	Government

Household Number and Dwelling Location	Accommodation Owner	Household ID	Marital Status	Children	Education	Occupiers Age	Household Occupation	Spouse Occupation
108. Suburban	Family	Indonesia	Married	1	University	30	Government	Private
109. Suburban	Tenant	Indonesia	Single	0	University	30	Other	Other
110. Suburban	Tenant	Indonesia	Married	3	University	40	Government	
111. Suburban	Family	Indonesia	Single	0	University	30	Other	
112. Suburban	Family	Indonesia	Single	0	University	30	Other	
113. Suburban	Owner	Indonesia	Single	0	University	40	Government	
114. Suburban	Owner	Indonesia	Married	1	University	30	Private	Other
115. Suburban	Tenant	Indonesia	Married	0	University	2	Government	Other
116. Suburban	Tenant	Indonesia	Married	0	University	30	Private	
117. Suburban	Family	Indonesia	Married	0	University	16	Government	
118. Suburban	Owner	Indonesia	Married	3	University	40	Other	Other
119. Suburban	Owner	Indonesia	Married	3	University	40	Other	Other
120. Suburban	Tenant	Indonesia	Single	3	University	50	Private	Private
121. Suburban	Family	Indonesia	Married	3	High School	50	Private	Other
122. Suburban	Tenant	Indonesia	Single	0	University	20	Other	
123. Suburban	Owner	Indonesia	Married	3		40	Government	Government
124. Suburban	Family	Indonesia	Single	0	University	50	Other	
125. Suburban	Family	Indonesia	Single	0	University	50	Other	
126. Suburban		Indonesia	Married	3	University	40	Government	
127. Suburban	Family	Indonesia	Married	1		16	Private	
128. Suburban	Owner	Indonesia	Married	1	University	30	Private	
129. Suburban	Family	Indonesia	Married	1	University	30	Government	
130. Suburban	Tenant	Indonesia	Single	0	University	30	Other	
131. Suburban	Tenant	Indonesia	Married	3	University	16	Government	Other
132. Suburban	Tenant	Indonesia	Married	2	University	30	Other	
133. Suburban	Family	Indonesia	Married	1	University	50	Other	Government
134. Suburban	Owner	Indonesia	Married	3	University	40	Government	
135. Suburban	Owner	Indonesia	Married	1	University	30	Government	Other
136. Suburban	Tenant	Indonesia	Married	2	University	30	Other	Private
137. Suburban	Family	Indonesia	Single	0	University	30	Private	Government
138. Suburban	Owner	Indonesia	Married	1	University	40	Government	
139. Suburban	Family	Indonesia	Single	0	University	30		Private
140. Suburban	Family	Indonesia	Single	0	University	30	Private	
141. Suburban	Tenant	Indonesia	Married	2	University	30	Other	Private
142. Suburban	Owner	Indonesia	Married	3	University	50	Other	Other
143. Suburban	Tenant	Indonesia	Married	2	High School	40	Private	Government
144. Suburban	Family	Indonesia	Single	0	University	40	Private	
145. Suburban	Owner	Indonesia	Married	1	University	30	Private	Private

Household Number and Dwelling Location	Accommodation Owner	Household ID	Marital Status	Children	Education	Occupiers Age	Household Occupation	Spouse Occupation
146. Suburban	Owner	Indonesia	Married	0	University	40	Government	Government
147. Suburban	Owner	Indonesia	Married	1	University	30	Private	Private
148. Suburban	Owner	Indonesia	Married	3	University	40	Government	Government
149. Suburban	Tenant	Indonesia	Single	0	University	30	Private	
150. Suburban	Tenant	Indonesia	Married	2	University	30	Government	Other
151. Suburban	Family	Indonesia	Single	0	University	40	Government	
152. Suburban	Family	Indonesia	Married	0	University	50	Other	Other
153. Suburban	Family	Indonesia	Married	0	University	40	Government	Government
154. Suburban	Owner	Indonesia	Married	3	University	40	Government	Government
155. Suburban	Owner	Indonesia	Married	3	University	40	Private	Government
156. Suburban	Tenant	Indonesia	Single	0	University	50	Private	
157. Suburban	Owner	Indonesia	Married	2	University	40	Private	Private
158. Suburban	Family	Indonesia	Married	3	University	30	Private	Private
159. Suburban	Tenant	Indonesia	Married	1	University	30	Private	Private
160. Suburban	Owner	Indonesia	Single	0	University	30	Private	
161. Suburban	Owner	Indonesia	Single	0	University	40	Private	
162. Suburban	Owner	Indonesia	Single	0	University	40	Private	Other
163. Suburban	Family	Indonesia	Single	0	University	30	Government	
164. Suburban	Owner	Indonesia	Married	2	University	40	Government	Government
165. Suburban	Owner	Indonesia	Married	3	University	16	Government	Other
166. Suburban	Tenant	Indonesia	Married	3	University	50	Private	Other
167. Suburban	Owner	Indonesia	Married	3	University	40	Government	Private
168. Suburban	Tenant	Indonesia	Married	1	University	40	Government	Private
169. Suburban	Owner	Indonesia	Married	2	University	40	Private	Other
170. Suburban	Tenant	International	Married	1	University	30	Other	Other
171. Suburban	Tenant	International	Married	0	University	30	Other	Other
172. Suburban	Owner	International	Single	0	University	30	Private	
173. Suburban	Tenant	International	Married	0	University	40	Private	Other
174. Tourism	Owner	Bali	Married	3	University	40	Private	Other
175. Tourism	Owner	Bali	Married	3	University	40	Private	
176. Tourism	Owner	Bali	Married	3	University	16	Private	
177. Tourism	Owner	Bali	Married	3	University	16	Private	Other
178. Tourism	Owner	Indonesia	Married	2	University	30	Private	Private
179. Tourism	Owner	Indonesia	Married	2	University	30	Private	
180. Tourism	Family	Indonesia	Single	0	University	50	Government	Other
181. Tourism	Owner	International	Married	2	University	50	Other	

Table IX.2. Results of the Survey Research

Household Number and Dwelling Location	Is AC Vital	Cooling System	Type of House	Preferred House	Monthly Spend Energy	Annual Income
1. Inner City	Necessary	AC & NV	Two	Affordable	£25.00	£750.00
2. Inner City	Not	NV	Two	Environment	£25.00	£500.00
3. Inner City	Most	AC & NV	Single	Convenient	£25.00	£5,000.00
4. Inner City	Necessary	AC & NV	Single	Environment	£45.00	£5,000.00
5. Inner City	Nearly	NV	Single	Environment	£25.00	£500.00
6. Inner City	Necessary	AC & NV	Two	Affordable	£25.00	£500.00
7. Inner City	Necessary	AC & NV	Two	Convenient	£70.00	£5,000.00
8. Inner City	Nearly	NV	Single	Convenient	£35.00	£1,500.00
9. Inner City	Nearly	NV	Single	Environment	£25.00	£500.00
10. Inner City	Not	NV	Single	Affordable	£25.00	£1,500.00
11. Inner City	Necessary	NV	Single	Environment	£15.00	£500.00
12. Inner City	Most	AC	Two	Environment	£25.00	£500.00
13. Inner City	Necessary	AC & NV	Two	Environment	£25.00	£500.00
14. Inner City	Necessary	NV	Two	Convenient	£50.00	£1,500.00
15. Inner City	Not	NV	Multi	Convenient	£50.00	£0.00
16. Inner City	Not	NV	Two	Affordable	£35.00	£1,500.00
17. Inner City	Nearly	AC & NV	Two	Convenient	£25.00	£750.00
18. Inner City	Not	NV	Multi	Environment	£25.00	£500.00
19. Inner City	Nearly	NV	Multi	Environment	£25.00	£4,000.00
20. Inner City	Not	NV	Two	Environment	£25.00	£4,000.00
21. Inner City	Necessary	AC & NV	Two	Convenient	£45.00	£500.00
22. Inner City	Nearly	NV	Two	Affordable	£0.00	£500.00
23. Inner City	Necessary	AC & NV	Single	Affordable	£50.00	£750.00
24. Inner City	Necessary	AC	Two	Environment	£45.00	£750.00
25. Inner City	Necessary	AC & NV	Single	Convenient	£45.00	£500.00
26. Inner City	Necessary	AC & NV	Two	Convenient	£45.00	£500.00
27. Inner City	Necessary	NV	Two	Affordable	£45.00	£4,000.00
28. Inner City	Not	NV	Single	Convenient	£45.00	£5,000.00
29. Inner City	Not	NV	Two	Affordable	£25.00	£500.00
30. Inner City	Necessary	NV	Two	Affordable	£45.00	£4,000.00
31. Inner City	Necessary	AC & NV	Two	Environment	£25.00	£750.00
32. Inner City	Not	NV	Two	Affordable	£25.00	£750.00
33. Inner City	Nearly	NV	Single	Affordable	£35.00	£500.00
34. Inner City	Not	NV	Single	Convenient	£45.00	£0.00
35. Inner City	Not	NV	Two	Convenient	£25.00	£500.00
36. Inner City	Necessary	AC	Two	Environment	£15.00	£5,000.00

Household Number and Dwelling Location	Is AC Vital	Cooling System	Type of House	Preferred House	Monthly Spend Energy	Annual Income
37. Inner City	Necessary	AC & NV	Two	Convenient	£0.00	£750.00
38. Inner City	Necessary	AC & NV	Single	Environment	£45.00	£0.00
39. Inner City	Very	AC	Single	Convenient	£75.00	£5,000.00
40. Inner City	Nearly	AC & NV	Two	Convenient	£0.00	£0.00
41. Inner City	Not	NV	Two	Environment	£25.00	£0.00
42. Inner City	Not	NV	Two	Affordable	£25.00	£500.00
43. Inner City	Nearly	NV	Single	Affordable	£45.00	£500.00
44. Inner City	Necessary	NV	Single	Affordable	£45.00	£1,500.00
45. Inner City	Not	NV	Multi	Affordable	£25.00	£1,500.00
46. Inner City	Nearly	AC & NV	Single	Affordable	£45.00	£0.00
47. Inner City	Most	AC & NV	Two	Environment	£45.00	£1,500.00
48. Inner City	Not	NV	Single	Convenient	£25.00	£750.00
49. Inner City	Very	AC & NV	Multi	Security	£35.00	£1,500.00
50. Inner City	Not	NV	Multi	Affordable	£35.00	£1,500.00
51. Inner City	Not	NV	Two	Convenient	£35.00	£1,500.00
52. Inner City	Necessary	AC & NV	Multi	Affordable	£25.00	£500.00
53. Inner City	Nearly	NV	Two	Environment	£35.00	£750.00
54. Inner City	Necessary	AC & NV	Two	Environment	£50.00	£0.00
55. Inner City	Nearly	AC & NV	Two	Environment	£25.00	£500.00
56. Inner City	Necessary	AC & NV	Multi	Environment	£45.00	£750.00
57. Inner City	Not	NV	Two	Convenient	£25.00	£5,000.00
58. Inner City	Not	AC & NV	Two	Convenient	£60.00	£0.00
59. Inner City	Nearly	AC & NV	Two	Environment	£25.00	£1,500.00
60. Inner City	Not	NV	Single	Environment	£25.00	£500.00
61. Inner City	Most	AC & NV	Single	Convenient	£50.00	£500.00
62. Inner City	Not	NV	Two	Environment	£50.00	£1,500.00
63. Inner City	Necessary	AC & NV	Multi	Convenient	£45.00	£0.00
64. Inner City	Most	NV	Two	Environment	£15.00	£0.00
65. Inner City	Nearly	AC & NV	Two	Environment	£25.00	£5,000.00
66. Inner City	Nearly	AC & NV	Two	Environment	£25.00	£5,000.00
67. Inner City	Nearly	AC & NV	Single	Affordable	£25.00	£500.00
68. Inner City	Necessary	NV	Two	Environment	£25.00	£500.00
69. Inner City	Not	NV	Single	Environment	£25.00	£750.00
70. Inner City	Necessary	AC & NV	Two	Affordable	£25.00	£500.00
71. Inner City	Not	NV	Single	Affordable	£50.00	£5,000.00
72. Inner City	Necessary	NV	Single	Environment	£45.00	£4,000.00
73. Inner City	Nearly	AC & NV	Two	Convenient	£0.00	£0.00
74. Inner City	Nearly	NV	Two	Convenient	£25.00	£500.00

Household Number and Dwelling Location	Is AC Vital	Cooling System	Type of House	Preferred House	Monthly Spend Energy	Annual Income
75. Inner City	Not	NV	Two	Affordable	£25.00	£500.00
76. Inner City	Nearly	NV		Convenient	£25.00	£500.00
77. Inner City	Necessary	AC & NV	Two	Convenient	£25.00	£5,000.00
78. Inner City	Necessary	AC & NV	Single	Convenient	£25.00	£4,000.00
79. Inner City	Necessary	AC & NV	Two	Convenient	£25.00	£1,500.00
80. Inner City	Necessary	AC & NV	Single	Convenient	£45.00	£4,000.00
81. Inner City	Very	AC	Single	Convenient	£75.00	£5,000.00
82. Inner City	Not	NV	Single	Affordable	£75.00	£1,500.00
83. Suburban	Nearly	NV	Single	Environment	£35.00	£750.00
84. Suburban	Nearly	NV	Single	Environment	£35.00	£750.00
85. Suburban	Nearly	AC & NV	Two	Affordable	£25.00	£1,500.00
86. Suburban	Not	AC & NV	Two	Environment	£25.00	£5,000.00
87. Suburban	Necessary	NV	Single	Environment	£25.00	£4,000.00
88. Suburban	Necessary	AC & NV	Two	Affordable	£25.00	£4,000.00
89. Suburban	Not	NV	Single	Environment	£25.00	£750.00
90. Suburban	Nearly	AC & NV	Single	Convenient	£45.00	£4,000.00
91. Suburban	Not	NV	Two	Affordable	£25.00	£750.00
92. Suburban	Necessary	AC & NV	Single	Environment	£25.00	£1,500.00
93. Suburban	Necessary	AC & NV	Two	Convenient	£45.00	£500.00
94. Suburban	Not	AC & NV	Single	Convenient	£15.00	£500.00
95. Suburban	Not	NV	Single	Environment	£25.00	£500.00
96. Suburban	Nearly	NV	Single	Affordable	£25.00	£750.00
97. Suburban	Not	NV	Two	Affordable	£50.00	£500.00
98. Suburban	Most	AC & NV	Single	Environment	£45.00	£750.00
99. Suburban	Not	NV	Multi	Affordable	£25.00	£1,500.00
100. Suburban	Not	NV	Two	Environment	£25.00	£4,000.00
101. Suburban	Not	NV	Two		£20.00	£500.00
102. Suburban	Necessary	NV	Single	Environment	£25.00	£1,500.00
103. Suburban	Not	NV	Single	Affordable	£50.00	£750.00
104. Suburban	Not	NV	Single	Environment	£25.00	£500.00
105. Suburban	Not	NV	Two	Environment	£25.00	£1,500.00
106. Suburban	Not	NV	Single	Affordable	£15.00	£500.00
107. Suburban	Necessary	AC & NV	Single	Convenient	£50.00	£5,000.00
108. Suburban	Necessary	AC & NV	Two	Environment	£25.00	£500.00
109. Suburban	Not	NV	Single	Convenient	£25.00	£750.00
110. Suburban	Necessary	NV	Single	Affordable	£15.00	£500.00
111. Suburban	Not	NV	Single	Environment	£45.00	£500.00
112. Suburban	Not	NV	Single	Environment	£45.00	£500.00

Household Number and Dwelling Location	Is AC Vital	Cooling System	Type of House	Preferred House	Monthly Spend Energy	Annual Income
113. Suburban	Not	NV	Two	Environment	£25.00	£4,000.00
114. Suburban	Not	NV	Two	Convenient	£25.00	£5,000.00
115. Suburban	Not	NV	Single	Affordable	£50.00	£750.00
116. Suburban	Not	AC & NV	Single	Affordable	£60.00	£5,000.00
117. Suburban	Not	AC & NV	Single	Affordable	£60.00	
118. Suburban	Necessary	NV	Single	Environment	£25.00	£1,500.00
119. Suburban	Necessary	AC & NV	Two	Environment	£50.00	£1,500.00
120. Suburban	Necessary	AC & NV	Two	Convenient	£75.00	£1,500.00
121. Suburban	Not	NV	Single	Affordable	£25.00	£500.00
122. Suburban	Not	NV	Single	Environment	£50.00	£500.00
123. Suburban	Not	NV	Two	Affordable	£25.00	£500.00
124. Suburban	Not	NV	Two	Convenient	£25.00	£500.00
125. Suburban	Nearly	AC & NV	Two	Environment	£15.00	£500.00
126. Suburban	Not	NV	Two	Environment	£25.00	£1,500.00
127. Suburban	Not	NV	Single	Convenient	£15.00	£500.00
128. Suburban	Not	NV	Two	Affordable	£25.00	£5,000.00
129. Suburban	Necessary	AC & NV	Two	Environment	£25.00	£500.00
130. Suburban	Not	NV	Single	Convenient	£25.00	£750.00
131. Suburban	Necessary	NV	Single	Affordable	£15.00	£500.00
132. Suburban	Not	AC & NV	Single	Environment	£50.00	£5,000.00
133. Suburban	Not	NV	Two	Affordable	£35.00	£500.00
134. Suburban	Nearly	AC & NV	Two	Affordable	£25.00	£1,500.00
135. Suburban	Very	AC & NV	Two	Affordable	£15.00	£4,000.00
136. Suburban	Necessary	AC & NV	Single	Environment	£50.00	£4,000.00
137. Suburban	Necessary	NV	Two	Environment	£25.00	£750.00
138. Suburban	Necessary	AC & NV	Single	Environment	£25.00	£1,500.00
139. Suburban	Not	NV	Two	Environment	£25.00	£500.00
140. Suburban	Necessary	AC & NV	Two	Affordable	£45.00	£5,000.00
141. Suburban	Necessary	AC & NV	Single	Environment	£50.00	£4,000.00
142. Suburban	Necessary	NV	Two	Convenient	£60.00	£750.00
143. Suburban	Nearly	NV	Two	Security	£25.00	£500.00
144. Suburban	Not	NV	Two	Convenient	£25.00	£500.00
145. Suburban	Nearly	AC & NV	Two	Environment	£45.00	£750.00
146. Suburban	Not	NV	Two	Environment	£25.00	£500.00
147. Suburban	Necessary	AC & NV	Two	Convenient	£25.00	£750.00
148. Suburban	Nearly	AC & NV	Multi	Convenient	£60.00	£750.00
149. Suburban	Most	AC & NV	Single	Convenient	£60.00	£1,500.00
150. Suburban	Not	NV	Two	Convenient	£25.00	£750.00

Household Number and Dwelling Location	Is AC Vital	Cooling System	Type of House	Preferred House	Monthly Spend Energy	Annual Income
151. Suburban	Not	NV	Two	Security	£45.00	£1,500.00
152. Suburban	Not	NV	Single	Environment	£25.00	£750.00
153. Suburban	Nearly	NV	Two	Affordable	£25.00	£500.00
154. Suburban	Not	NV	Two	Affordable	£25.00	£1,500.00
155. Suburban	Nearly	AC & NV	Two	Affordable	£25.00	£0.00
156. Suburban	Necessary	AC & NV	Two	Convenient	£75.00	£1,500.00
157. Suburban	Not	NV	Multi	Affordable	£25.00	£0.00
158. Suburban	Not	NV	Single	Security	£25.00	£750.00
159. Suburban	Nearly	AC & NV	Single	Affordable	£50.00	£4,000.00
160. Suburban	Necessary	AC & NV	Multi	Environment	£45.00	£1,500.00
161. Suburban	Not	NV	Single	Environment	£25.00	£1,500.00
162. Suburban	Not	NV	Single	Environment	£25.00	£1,500.00
163. Suburban	Not	AC & NV	Two	Affordable	£50.00	£1,500.00
164. Suburban	Necessary	AC & NV	Two	Environment	£45.00	£500.00
165. Suburban	Not	NV	Two	Environment	£60.00	£5,000.00
166. Suburban	Very	AC & NV	Single	Security	£60.00	£5,000.00
167. Suburban	Not	NV	Single	Affordable	£25.00	£500.00
168. Suburban	Necessary	NV	Single	Affordable	£45.00	£500.00
169. Suburban	Not	AC & NV	Two	Affordable	£25.00	£4,000.00
170. Suburban	Necessary	AC & NV	Multi	Convenient	£60.00	£5,000.00
171. Suburban	Not	AC & NV	Single	Environment	£60.00	£5,000.00
172. Suburban	Necessary	AC & NV	Two	Convenient	£0.00	£5,000.00
173. Suburban	Not	AC & NV	Single	Convenient	£25.00	£5,000.00
174. Tourism	Not	NV	Single	Affordable	£45.00	£5,000.00
175. Tourism	Not	NV	Single	Affordable	£45.00	£5,000.00
176. Tourism	Not	NV	Single	Convenient	£45.00	£500.00
177. Tourism	Not	NV	Single	Convenient	£45.00	£500.00
178. Tourism	Not	AC & NV	Multi	Security	£45.00	£1,500.00
179. Tourism	Not	AC & NV	Multi	Security	£45.00	£1,500.00
180. Tourism	Not	NV	Two	Affordable	£60.00	£500.00
181. Tourism	Not	NV	Single	Environment	£60.00	£5,000.00

Table IX.3. Results of the Survey Research

Household Number and Dwelling Location	Ideal House											
	Traditional	Modern	Comfort	Affordable	Accessible	AC	NV	Healthy	Save Energy	Expensive	Small	Large
1. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
2. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
3. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
4. Inner City	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
5. Inner City	Yes	No	Yes		Yes	No	Yes	Yes	Yes	No	Yes	No
6. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
7. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
8. Inner City		Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
9. Inner City	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes
10. Inner City	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
11. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
12. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
13. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
14. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
15. Inner City		Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
16. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
17. Inner City		Yes	Yes	Yes	Yes	No	Yes	Yes				
18. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
19. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
20. Inner City	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
21. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
22. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
23. Inner City	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
24. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
25. Inner City	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
26. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
27. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
28. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
29. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
30. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
31. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
32. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
33. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
34. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
35. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
36. Inner City	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	NO

Household Number and Dwelling Location	Ideal House											
	Traditional	Modern	Comfort	Affordable	Accessible	AC	NV	Healthy	Save Energy	Expensive	Small	Large
37. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
38. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
39. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
40. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
41. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
42. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
43. Inner City	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
44. Inner City	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
45. Inner City	No	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No
46. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
47. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
48. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
49. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
50. Inner City		Yes	Yes	Yes	Yes			Yes				
51. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
52. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
53. Inner City			Yes	Yes	Yes		Yes	Yes				
54. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
55. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
56. Inner City	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes
57. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
58. Inner City	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
59. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
60. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
61. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
62. Inner City	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
63. Inner City	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes
64. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
65. Inner City	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
66. Inner City	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
67. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
68. Inner City	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes
69. Inner City	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes
70. Inner City	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
71. Inner City	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
72. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
73. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
74. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No

Household Number and Dwelling Location	Ideal House											
	Traditional	Modern	Comfort	Affordable	Accessible	AC	NV	Healthy	Save Energy	Expensive	Small	Large
75. Inner City	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes
76. Inner City	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
77. Inner City	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
78. Inner City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
79. Inner City	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
80. Inner City	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
81. Inner City	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
82. Inner City	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	
83. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
84. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
85. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
86. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
87. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
88. Suburban	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No
89. Suburban	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes
90. Suburban	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
91. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
92. Suburban	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
93. Suburban	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes
94. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
95. Suburban	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes
96. Suburban	yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
97. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
98. Suburban	No	Yes	Yes	Yes	yes	Yes	Yes	Yes	Yes	No	No	Yes
99. Suburban	No	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No
100. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
101. Suburban			No		Yes	No	Yes	Yes	Yes	No	No	Yes
102. Suburban	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
103. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
104. Suburban	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes
105. Suburban	Yes	No	Yes		Yes	No	Yes	Yes	Yes	No	Yes	No
106. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
107. Suburban	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
108. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
109. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
110. Suburban	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
111. Suburban	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes
112. Suburban	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes

Household Number and Dwelling Location	Ideal House											
	Traditional	Modern	Comfort	Affordable	Accessible	AC	NV	Healthy	Save Energy	Expensive	Small	Large
113. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
114. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
115. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
116. Suburban		Yes	Yes	No	Yes	No	Yes	Yes	Yes			Yes
117. Suburban		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes
118. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
119. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
120. Suburban	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No
121. Suburban	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No
122. Suburban	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	No
123. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
124. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
125. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
126. Suburban	Yes	No	Yes		Yes	No	Yes	Yes	Yes	No	Yes	No
127. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
128. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
129. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
130. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
131. Suburban	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
132. Suburban	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
133. Suburban			No		Yes	No	Yes	Yes	Yes	No	No	Yes
134. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
135. Suburban	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
136. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
137. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
138. Suburban	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
139. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
140. Suburban	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
141. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
142. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
143. Suburban				Yes								
144. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
145. Suburban		Yes	Yes		Yes	Yes	Yes	Yes				
146. Suburban	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes
147. Suburban	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
148. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
149. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
150. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes

Household Number and Dwelling Location	Ideal House											
	Traditional	Modern	Comfort	Affordable	Accessible	AC	NV	Healthy	Save Energy	Expensive	Small	Large
151. Suburban	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
152. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
153. Suburban	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
154. Suburban	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
155. Suburban	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
156. Suburban	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No
157. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
158. Suburban			Yes	Yes	Yes		Yes	Yes	Yes		Yes	
159. Suburban	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
160. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
161. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
162. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
163. Suburban	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes
164. Suburban	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes
165. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No
166. Suburban	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
167. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
168. Suburban			Yes									
169. Suburban	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
170. Suburban	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes
171. Suburban	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
172. Suburban	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No
173. Suburban	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
174. Tourism	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
175. Tourism	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
176. Tourism	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
177. Tourism	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
178. Tourism			Yes		Yes	Yes	Yes	Yes	Yes			Yes
179. Tourism			Yes		Yes	Yes	Yes	Yes	Yes			Yes
180. Tourism	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
181. Tourism	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes