A SYSTEMATIC APPROACH FOR LOW ENERGY BUILDINGS IN BAHRAIN

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CONTENTS

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ABSTRACT

This thesis was mainly motivated and initiated by the need of Bahrain to develop building energy standards. The main concern, therefore, has been the establishment of a systematic approach for evaluating building energy performance using a state-of-the-art building simulation.

The approach was established based on the discussion of energy standards, building simulation, office building design and performance evaluation methods. This study first investigated the most recent types of energy standards, and then examined two of them with respect to Bahrain. To evaluate the impact of energy standards on building performance a weather data file for building simulation was developed and a methodology for performing the evaluation introduced. For better understanding of how the application of energy standards influences the energy performance and how this influence can be measured the evaluation methodology was implemented to case studies in Bahrain.

In order to show how researches and contributions described in this thesis can support the development of new standards the methodology was integrated into a systematic framework with the aim of optimising building energy design in Bahrain. The optimisation outcome represents a source of prescriptive and performance standards for office buildings. The building designer is giving more flexibility with respect to the prescriptive standards by providing a performance sensitivity scale. This scale was tested on a multi-storey office building in Bahrain.

In conclusion, not only has a methodology for performance evaluation been introduced, but also an energy benchmark has been established, a weather data file developed and a systematic framework for setting new standards presented. However, in order to build on the achievements of the present study more work is required in two areas. One is concerned with energy performance benchmarks for different types of commercial buildings. The other is concerned with integrating the building regulation in Bahrain into the simulation programs.

Chapter 1 ENERGY AND BUILDINGS

Proliferation of energy consumption and CO_2 emissions on the built environment have made energy efficiency strategies a priority for energy policies developing new building regulations and certification schemes which now include minimum requirements.

(P'erez-Lombard et al., 2008)

1.0 Introduction

The depletion of non-renewable resources and the environmental impact due to energy consumption, particularly energy use in buildings, has awakened considerable interest in the means of conserving energy, and promoted a series of revisions to codes of practice for energy efficiency requirements set by building regulations. The tools used for the development of evaluation and optimisation methods are also receiving great attention, particularly in relation to building performance. This chapter first studies the energy scenario during the last few decades and highlights its relationship with buildings. It then casts light on the situation of Bahrain. It proceeds to an introduction of the research problem and research questions and objectives, followed by a brief description of the research methodology. It gives the limitations and the structure of the study.

1.1 Energy Scenario

The energy crisis of the 1970s has made many nations aware of how critical energy is to the everyday functioning of their society and brought an end to the era of secure and cheap energy (Hinrichs & Kleinbach, 2002; Kreider *et al.*, 2002; Nkicenovic *et al.*, 1998) However, in the 1980s, steady oil supplies and low energy prices reduced people's immediate interest in energy conservation. With the emergence of the twenty first century, the rise in energy prices and the awareness of the close link between energy use and the environment brought energy efficiency to the front of the world agendas (Baker & Steemers, 2000; Henderson, 1992; NASEO, 1998; Waters, 2003). The emphasis started first on energy efficiency, and now improving comfort and indoor air quality are simultaneously emerging as important requirements of low energy design.

1.1.1 Driving forces

Generally speaking, saving energy has been driven by political, socio-economic and environmental factors. From the political and economic point of view, energy provides all sectors with the means to operate and function, thus it plays a very critical role in the development of nations. Thereby, if any nation encounters any significant restriction to its sources of energy, through either reduced supplies or a large price increase, its economy would suffer considerable damage. Indeed, the less a country depends on finite resources such as natural gas and oil, the stronger and more stable the economy will remain in the face of energy cost increases (World of Information, 2004).

From an environmental point of view, the growing awareness of the environmental impact due to energy use, and the associated CO_2 emissions, draw a considerable attention to energy efficiency. Environmentalists suggested that the expenditure of non-renewable energy has a direct impact on the environment, with potentially devastating results. This expenditure is said to be one of the major factors affecting the environment. It causes three major environmental problems, namely air pollution, acid rain and greenhouses effects. Today, the increased use of non-renewable energy has increased the CO_2 concentration in the atmosphere and has also increased the earth's temperature, which is known as “Global Warming”.

To tackle with the above issues two fundamental changes in patterns of energy consumption are required: first, effective measures to protect the depleted resources and second, valid policies to replace fossil fuels with non-fossil fuels through the use of free and clean energies such as wind and solar energy (Butt, 1992; Trudenu, 1991). It must be stated that it is not practical to start with the latter pattern because the former pattern represents the energy efficiency and, therefore, reducing the energy demand seems to be the first logical and practical step to achieve the low energy target.

1.1.2 Energy demand and efficiency trends

Even the briefest scrutiny of energy consumption immediately reveals that 70% of the total global energy consumption belongs to the developed world. However, in future, this situation may change: the presently developing world which consumes only 30% of the total energy is likely to greatly increase its consumption. Many sources assume that the demand for energy will increase substantially and there will be a major shift in energy use towards the developing countries (Rigg &

Lahav, 2001). These studies assumed that the regions where energy demand will grow the most are the "developing regions of Asia". It was estimated (IEA, 2002) that the share of these countries in world demand will increase from just 30% today to more than 40% by 2030, and hence energy related emissions of CO_2 will grow slightly more quickly than total primary energy supply.

In some respects, it seems, the energy plans of developing countries are following the example of developed nations whose economic growth occurred through the use of technologies, fossil fuels and electricity. However, conservation and energy efficiency in developing countries have grown rapidly, particularly in the urban metropolitan centres such as Singapore, Kuala Lumpur and Hong Kong (APERC, 2003). As for the oil rich developing countries, such as the Gulf States, there has been a consensus to legislate for energy efficiency. For instance, Kuwait, Saudi Arabia, the United Arab Emirates and Bahrain realise the benefits of energy efficiency not from the point of view of the balance between energy supply and demand, but rather from an economic and environmental standpoint (Aasem, 1993; NCBB, 2002). In the Gulf States energy is consumed in five broad sectors defined by four end-uses, including residential, commercial, industrial and transport sectors. If electricity generation is included, the five sectors account for all energy consumption in the economy of these countries.

1.1.3 Energy consumption in building sector

The building sector is not only one of the major consumer of energy, it is also one of the largest contributors to the increase of CO_2 in the atmosphere and hence to global warming and climate change. Several factors have contributed to the growth of energy use in buildings, namely the increase in population, improvement of comfort level and the increasing number of energy using devices in buildings (Kreider *et al.*, 2002). The energy consumed in the building sector comprises the energy consumption in building use and also the energy consumed in constructing these buildings (Kegle, 1978; Nicholls, 2002; Thormark, 2002; Tiwari, 2001). In general, there are three major energy requirements in building: energy required for fabricating materials and equipment, energy required for erecting materials and equipment and energy required to operate buildings. It was estimated that the energy used in the construction of buildings is about 5% of global energy consumption, while energy consumption for operating buildings accounts for about 45% of the total global energy consumption (Rigg & Lahav, 2001). Fig. 1.1 shows the global energy use by sector in 1986.

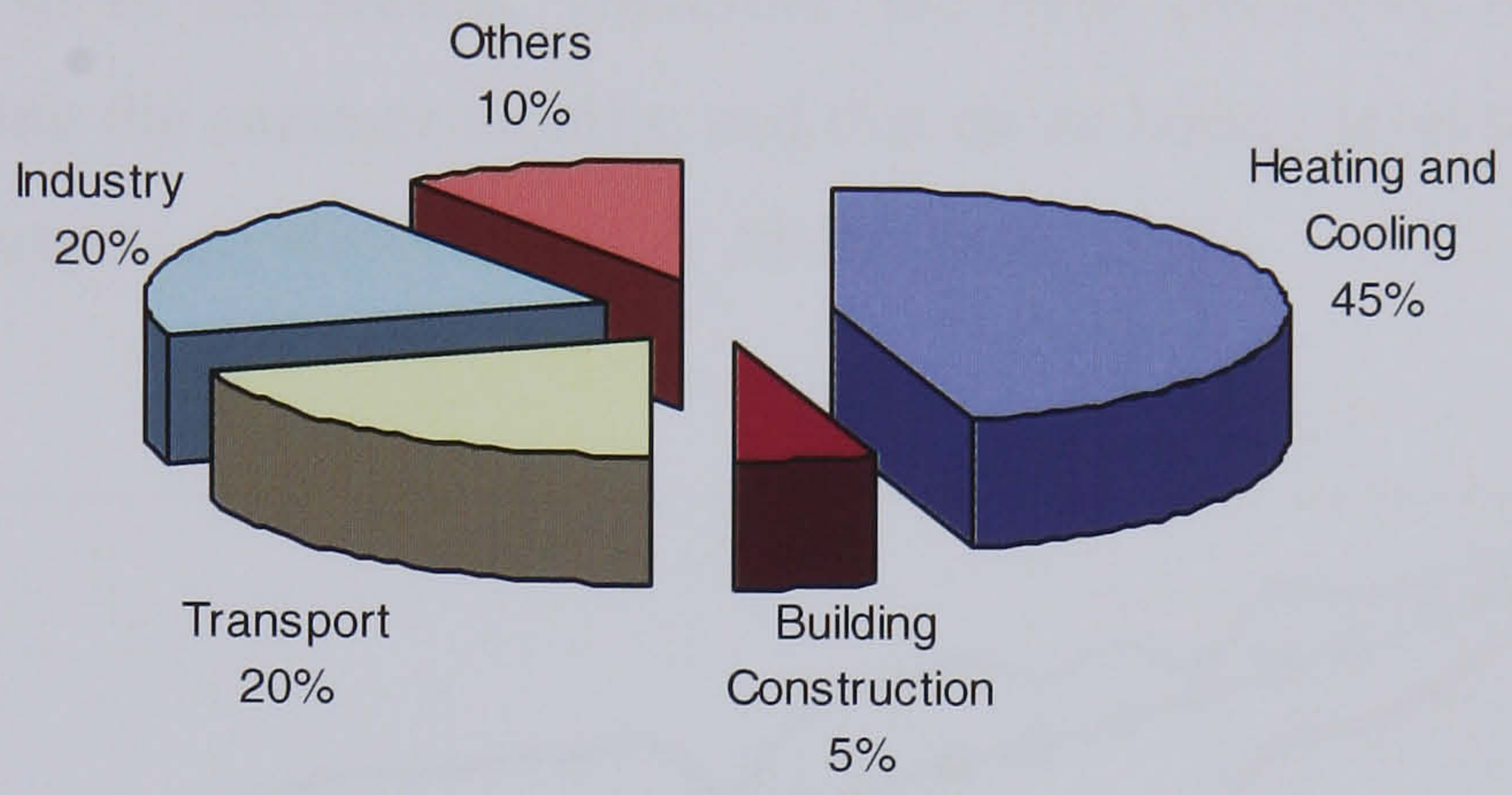

Figure 1.1 Global energy use in 1986 (Rigg & Lahav, 2001)

At the international level, the consumption of energy for the building sector is a significant factor in the economy of many countries. Recent studies show such trends in different parts of the world. In the United States, for example, 40% of the total national energy production and nearly 70% of electricity production is used in buildings, as well as 28% in transportation, which is at least partly influenced by urban design (EIA, 2005). In the United Kingdom the building sector consumed about 50% of all the country's energy (Steemers, 2003). In Brazil 48% of the national electric energy was consumed in buildings (Westphal & Lamberts, 2004), while in China building sector currently accounts for 23% of the country total energy use (Yao *et al.*, 2005). The same situation can be seen in the Gulf region. For instance, buildings in Kuwait account for nearly 45% of the yearly electric energy consumption (Maheshwari & Al-Murad, 2001); while in Saudi Arabia the building sector consumes about 70% of the total electricity consumption (Iqbal & Al-Homoud, 2007). As for Bahrain, the smallest country in the Gulf region, buildings make up 83% of the national consumption of electricity (MEW, 2004).

1.2 Bahrain Situation

Bahrain is the smallest country in the Gulf region and the only island state. It has a hot and arid climate coupled with occasional high humidity. The mean of monthly maximum and minimum temperature for months from May to October are in excess of 41°C and 30°C respectively. The cooling season is thus long and extends over six months of the year with air-conditioning required on a 24 hours per day basis for most of the season. Therefore, the most electricity is used for air-conditioning during the summer months, and that on an hourly level the share of the AC demand can approach 80% (Morsy & Al-Baharna, 1995).

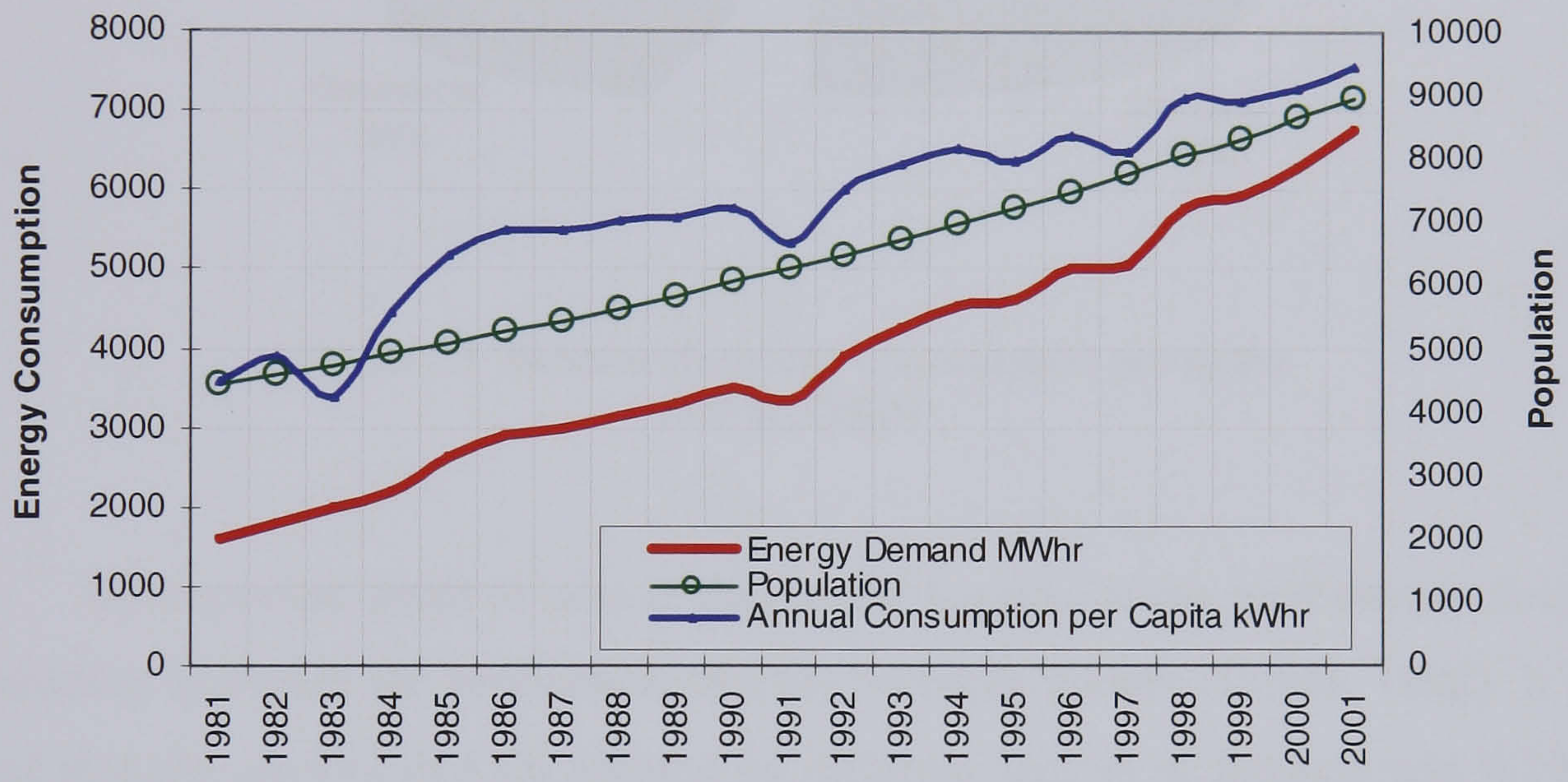

Figure 1.2 Annual consumption of electricity per capita
(MEW, 2004)

In Bahrain electricity is the major form of energy (over 99%). Since 1972, the installed capacity, electricity demand and the annual electricity use have grown substantially (MEW, 2004; NCBB, 2002). Fig. 1.2 illustrates the growth of electricity consumption from 1981 to 2001. There seems to be a variety of reasons for this increase. The most notable one is the rapid and increasing economic expenditure with huge architectural projects. Although Bahrain has realised the benefits of energy efficiency and has already made official appeals for mandatory conservation, the current process of motivating and strengthening the economics seems to be opposed to conservation of energy resources. Fig. 1.3 shows Bahrain electricity consumption per sector. As illustrated, 54% is used in the residential sector and 29% in the commercial sector. It is clear that the residential sector is the highest in terms of electricity consumption. However, with the recent economic boom, the commercial sector has become increasingly a major consumer of electricity. Within the commercial sector office buildings are, together with retail, those with the largest electricity consumption.

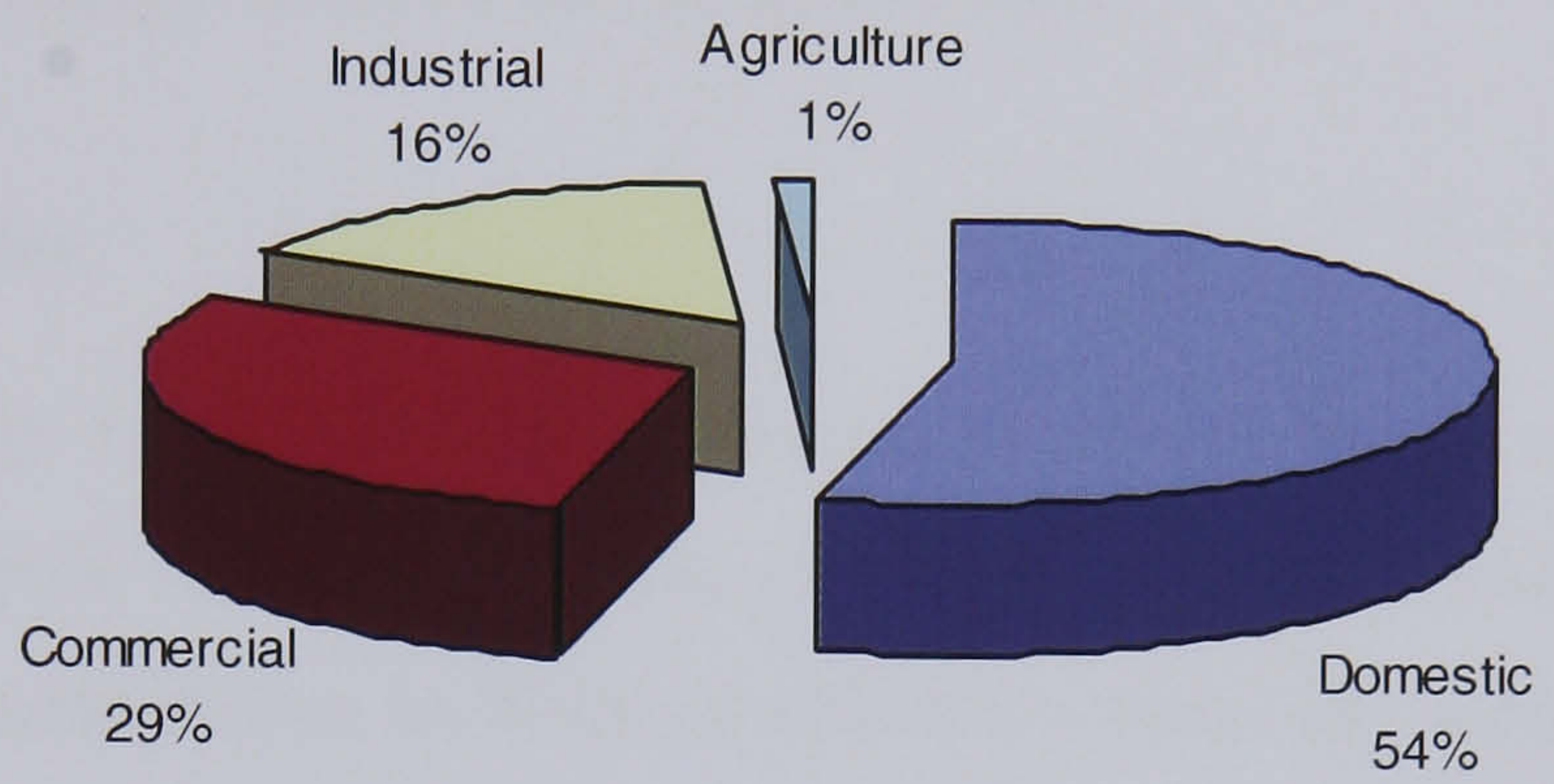

Figure 1.3 Bahrain electricity consumption per sector
(MEW, 2004)

An important point to note is that as the fraction of the total energy devoted to building increases the production of CO_2 becomes greater (Littler, 1992). It was found that the amount of CO_2 emitted by different sectors in Bahrain was 0.1% of the total global CO_2 production. This amount seems small when countries such as China and the United States are considered. However, when a small country such as Bahrain (700 km^2) is concerned, this amount does not seem small. It is interesting to mention that 34% of this production is caused by electricity generation and 24% by buildings (World Resources Institutes, 2005). As illustrated above, the building sector is one of the major consumers of electricity and, therefore, is important when conservation is considered. Building sector, particularly office buildings, have the greatest and easiest potential for conservation. It is quite possible to achieve a reduction of 50% to 70% on the building consumption level and with more effort by 70% to 85% by using some sophisticated efficiency techniques and conservation strategies (Rigg & Lahav, 2001).

1.3 Building Energy Efficiency Roadmap

Recently, the research communities and building efficiency bodies have introduced various strategies to enhance and strengthen energy savings in buildings. Examples of these strategies are good practice, codes of practice and building simulation. These strategies will be explored further in the next sub-sections and discussed in more detail in the chapters which deal with the relevant concern of energy standards, energy analysis and energy design.

1.3.1 Good practice

Simple steps taken into account during the design stages can yield buildings that use 20% to 50% less energy when compared to typical buildings. Such steps involve using climatic design techniques efficiency measures such as passive design strategies and active design technologies. Many of these techniques have a significant impact on the total energy consumption and play a critical role in terms of the environmental impact. Thus, energy efficiency principles and techniques need to be kept in mind throughout the design process, from the broad issue such as orientation and building form through the details such as the type of lamps and equipment (Pitts & Willoughby, 1992). Further, more consideration should be given to the integration between building elements and system variables throughout the design process (ASHRAE, 2004; CIBSE, 2004).

1.3.2 Codes of practice

It has been argued that the most effective strategy to enforce good practice in the design of buildings is appropriate legislation for energy efficiency (Negrao, 1995). Over the last few decades, nations have been responding with suitable codes of practice. These codes have been used and developed in many countries to provide a degree of control over building design and to encourage awareness and innovation of energy conscious design in buildings (Hui, 2002). In such situations there is an important issue that should be addressed in the design of these codes which is, at what levels to set the codes and whether or not to make them prescriptive with assigned specific values for building components, or performance-based that can set the overall energy consumption per square metre of the floor area (WEC, 2005).

However, one drawback of these codes as reported by Rumsey and Flanigan (1995) is that they are difficult to enforce. Without enforcement, codes may be ineffective.

1.3.3 Building simulation

The ability of simulation programs to simulate a building reality in its future life provides a very effective tool for improving the energy efficiency of buildings (Clarke, 2001). Many benefits can be obtained from using simulation tools: (1) evaluation of decisions making, (2) optimisation of building design and operation, (3) estimation of building impact on the environment, (4) compliance with building regulations, (5) establishment of new energy standards and benchmarks and (6) calculation of energy life-cycle cost. By predicting the energy consumption of a building, for instance, simulation can help in reducing the cost, both in terms of initial, capital and recurring costs such as energy use and maintenance, while predicting the amount of CO_2 emissions due to the energy use can reduce the impact of buildings on the environment. Furthermore, assessing and evaluating the new concept, new materials and technical systems represents an important means to achieve the low energy target (CIBSE, 1998).

1.4 Problem Statement

> *"In the developing countries...energy conservation has had a lower priority than in the industrial countries. Moreover, energy conservation in buildings has been neglected in the national conservation plans that have been developed"*
>
> *(Levien & Deringer, 1987)*

In North America and Western Europe and recently in some developing countries in Asia and Latin America a great deal of effort has been spent to encourage and enhance energy efficiency in buildings. However, in the Gulf States, particularly in Bahrain, only a small consideration has been given to this important issue. Its rapid economic growth with huge architectural project such as Bahrain Financial Harbour (see Fig. 1.4) and many others seem to be opposed to conservation of energy resources. Many of these projects, though purposeful and attractive, are not necessarily cost-effective in energy terms. It was estimated that more than 65% of the energy wastage in Bahrain is accounted for by air-conditioning system of buildings in the six months of May, June, July, August, September and October (MEW, 2004). To overcome this problem there is a need to promote building energy efficiency and develop an energy policy and implementation programmes (Akbari *et al.*, 1996).

Bahrain Financial Harbour

World Trade Centre

Al-Moaeed Tower

Figure 1.4 Architectural boom in Bahrain

In light of the above suggestions, the Bahrain government began planning regulation energy efficiency codes for buildings in 1998. As a first step of the task, new codes were regulated. Article-32 is an envelope components design approach that considers the heat flow through individual components of the building shell (e.g., external wall, roof, window, and door). Other codes on building system and equipment are now being considered by the Ministry of Electricity and Water. The codes have long-reaching effects on the next generation of buildings in Bahrain. However, there is a serious lack of knowledge and experience that enable the codes to achieve the objectives, and there is also an absence of measures to improve these codes. Therefore, more efforts, include research to establish a systematic approach for evaluating the impact of energy codes on the building performance, are needed, so as to strengthen the technical basis of the building energy codes and to help designers achieve the low energy goal.

1.5 Purpose of Research

The aim of this study is to establish a systematic approach for evaluating building energy performance in Bahrain. The intention is to investigate the energy performance of air-conditioned office buildings with respect to energy standards.

1.5.1 Research questions

- What factors affect energy performance of buildings, and how is this performance evaluated in Bahrain?
- Can building energy performance in Bahrain be improved by adopting current energy standards from other countries, and can such standards be adjusted with respect to the Bahrain context?
- What methodology offers a comprehensive approach for evaluating building energy performance, and what elements are needed to establish this methodology?
- How can energy performance evaluation be employed to develop energy standards?

By answering these questions the researcher studies the current status of building energy performance, explores different approaches to building energy standards, establishes a methodology to asses building energy performance and employs the performance evaluation to develop energy standards for office buildings in Bahrain. These can be translated to the following objectives.

1.5.2 Research objectives

The objectives of this thesis depicted in the chapters that follow are:

- To investigate the different factors affecting the energy performance of buildings.

- To examine existing building energy standards in order to distil experience and knowledge that can help in developing current energy standards in Bahrain.
- To develop a reliable weather data file of Bahrain required for building simulation.
- To establish a procedure to evaluate the energy performance of buildings.
- To present a systematic framework to develop energy standards for office buildings in Bahrain.

1.6 Justification for Research

> *"...building performance evaluation contributes to the state-of-the-art knowledge of environmental design research and this makes significant contributions towards improving the profession of architecture and increasing quality of the building industry."*
>
> *(Preiser & Schramm, 2005:26)*

Evaluating the energy performance of air-conditioned buildings is important for developing countries as Bahrain. This has become obvious over the last few years with the consolidation of global views of high economy and healthy environment. In Bahrain the residential and commercial buildings (offices, together with warehouses and retail premises) are the most significant consumers of energy and contributors to CO_2 emissions. Within the commercial sector offices seem to offer the greatest potential for action to achieve significant savings. Furthermore, as the office buildings are the principle energy using category in the commercial sector and encompass many key design features, investigation into their energy performance has been subject to many detailed studies in other countries. Also, the methodology used for studying the office buildings can be extended to help characterise other building types.

1.7 Research Limitations

This study is limited to the investigation into the energy performance of office buildings in Bahrain. Since they have the highest construction volume, energy consumption and CO_2 emissions, the analysis process concentrates primarily on air-conditioned office buildings.

1.8 Methodology

An attempt was made from the inception of the research to carry out a study that embodied a balance of analytical and empirical investigation including computer simulation. The study was carried out through five overlapping stages, as shown in Fig. 1.5. Chapter 3 discussed these stages in more detail, while the text below briefly describes them:

Stage 1: contextual and theoretical background to establish the problem definition and review of the literature on the related research
Stage 2: investigating building energy standards and codes
Stage 3: developing weather data and introducing evaluation methods
Stage 4: implementing the evaluation method to develop energy standards
Stage 5: conclusion and recommendations for future studies

1.9 Thesis Structure

Fig. 1.5 displays the structure of this thesis. Chapter 2 provides a summary and review of the main features found in the literature relating to the research problem and casts light on some studies in low energy buildings. Chapter 3 describes the methodology for the research execution. Chapter 4 investigates the most recent approaches of building energy standards and codes (BESC). In order to introduce a methodology that evaluates the impact of BESC on building performance, Chapter 5 studies the climatic properties of Bahrain and develops a weather data file, while Chapter 6 presents a simple procedure to analyse the energy behaviour in buildings. Chapter 7 then shows how research developments in the previous chapters are brought together and integrated into a systematic framework in order to develop energy standards. Chapter 8 concludes the thesis with a review of the research contributions and suggestions for future work.

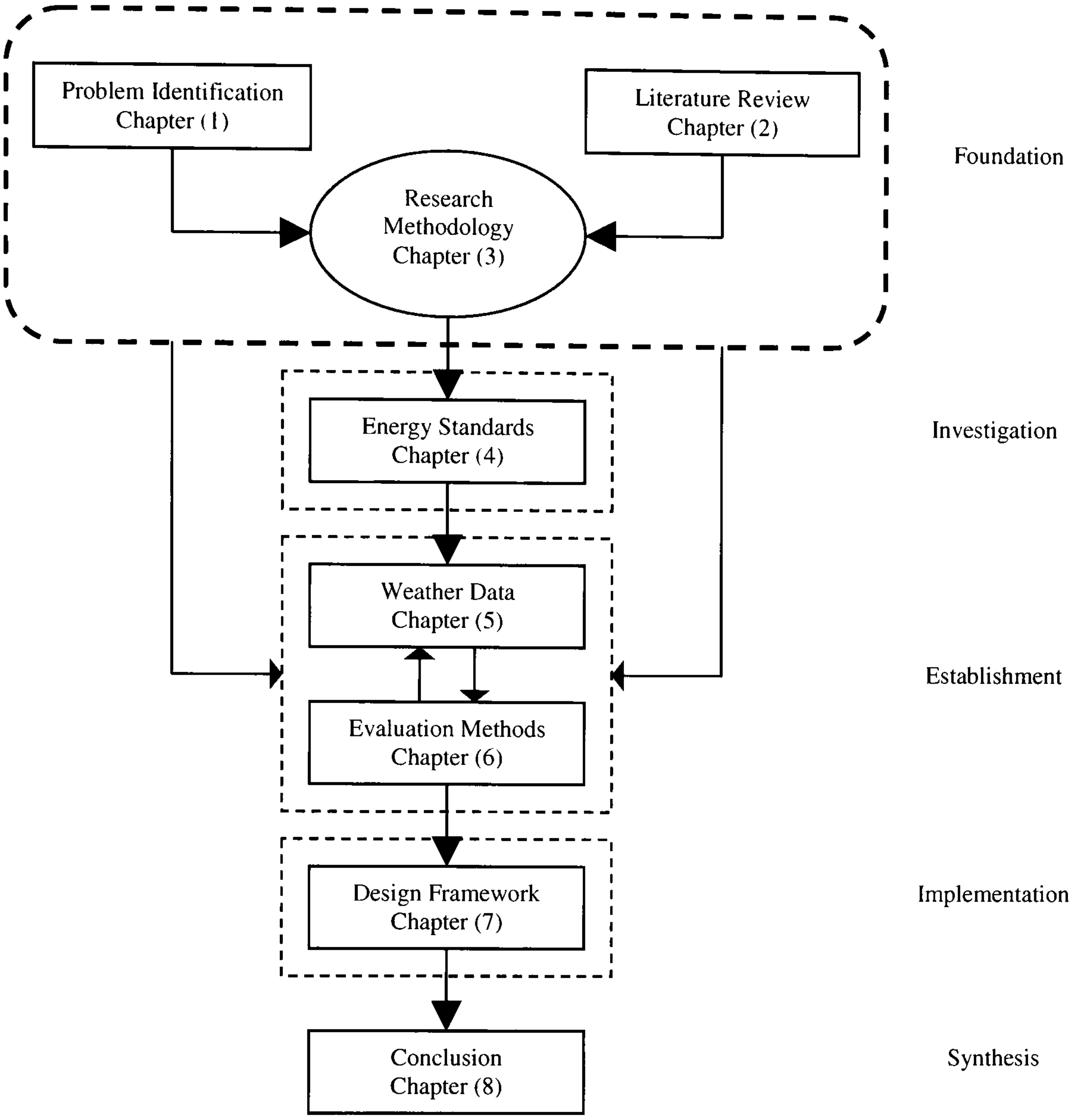

Figure 1.5 The Structure of the thesis

1.10 Closing Remark

This chapter has shown that energy is a key factor in our daily life. Approximately 45% of this energy is consumed by building operation. At the same time, buildings are a primary contributor to CO_2 emissions and global warming. With the increase in population, improvement in comfort levels and the boom in the architectural field coupled with a lack of experience and consideration to the basic principles of energy efficiency and environmental sustainability, the electricity and CO_2 emissions have increase rapidly in Bahrain. In recent years, Bahrain has made few attempts to find the best possible approach to control the energy consumption in buildings and to limit its impact on the environment. Some techniques have been used such as the thermal insulation of building envelope. However, there are no evaluation methods to test the impact of this and other techniques on the overall energy consumption with respect to different building types and functions.

For promoting building energy efficiency in Bahrain a great deal of effort, including research is needed. As this type of study is not advanced in this country, it is essential to learn and evaluate the experience of more advanced countries in order to establish information and methods in the local context. To provide such information inferences may be drawn from the research in developed countries such as the United Kingdom and the United States. Some information may be obtained from the research in developing countries such as Singapore and Hong Kong. However, the validity of the materials needs to be verified when applied to Bahrain. The first logical and practical step to do so is to provide a summary and review of the main feature in the literature relating to the research problem and questions outlined in section 1.5.

Chapter 2 CRITICAL REVIEW

The driving force behind all these studies has been the desire to understand the factors that affect energy use in practice, a need to find ways of measuring and evaluating building energy performance, and doubts about the accuracy of the design prediction provided by the current building simulation methods.

(Baird et al., 1983: preface)

2.0 Introduction

The literature for this study has been obtained from a variety of sources and not limited to research and theoretical development over the past few years, though recent works are emphasised. This chapter provides a summary of the main features found in the reviewed literature relating to the research problem and questions outlined in Chapter 1. Fig. 2.1 shows the process of this review. In general, this chapter addresses two main points: firstly, the previous studies and secondly, a theoretical background for the research area. The former casts light on studies and projects in low energy buildings, and then focuses on studies related to Bahrain and the Gulf region. The latter reviews the relevant literature pertinent to the energy performance of buildings as it is the main area of interest in this study.

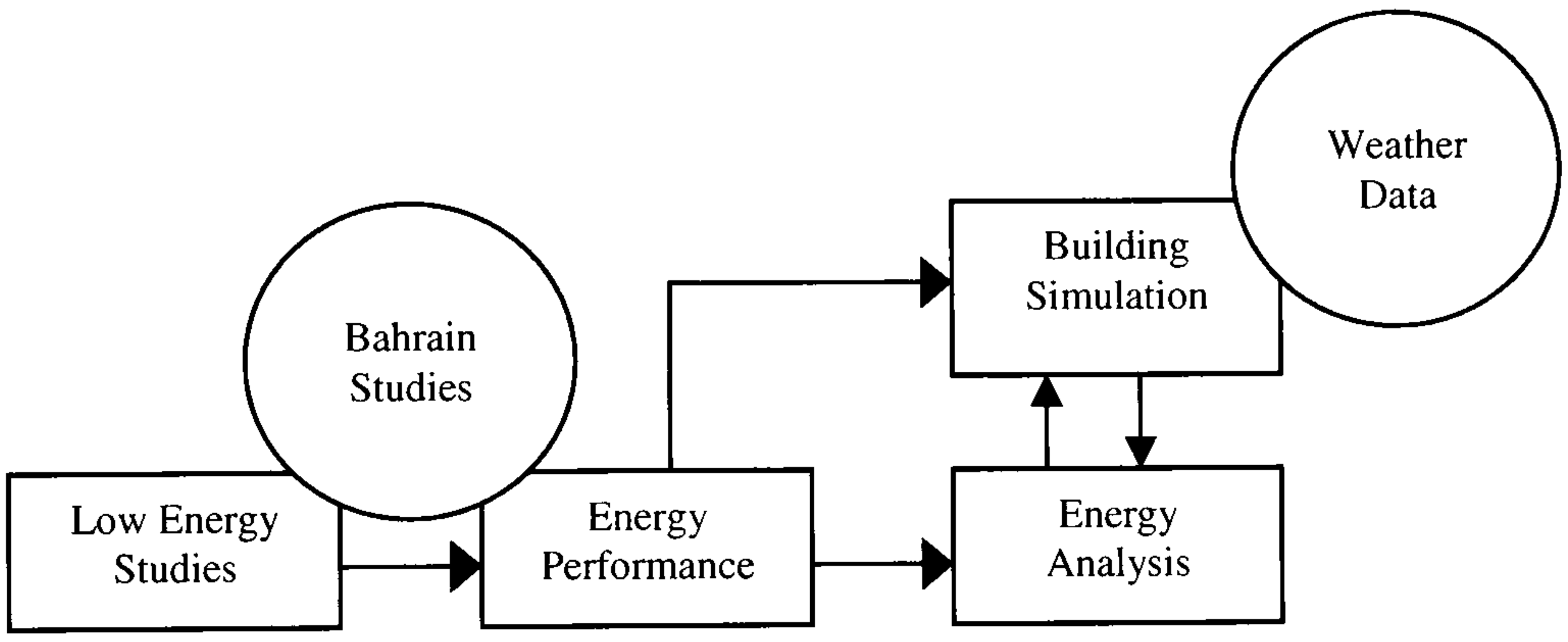

Figure 2.1 Process of reviewing the literature

2.1 Low Energy Buildings

2.1.1 Basic concept

In general use, the meaning of the term low energy buildings has changed over years, and may change in the future. Some basic concepts has been used in building energy design, starting with efficient energy buildings to low energy buildings and more recently zero energy buildings. These concepts, in general, aim to meet the requirements of the occupants and reduce the energy consumption as well as limit the impact of energy use on the environment (Abel, 1994). To make distinction between them some definitions can be presented:

Energy efficient buildings: those buildings strive towards the lowest possible energy requirements with reasonable utilisation of resources through the use of efficiency measures.

Low energy buildings: those buildings use less energy than typical buildings by utilising low energy standards and technologies such as high level of insulation, energy efficient windows and low level of air-infiltration to lower heating and cooling energy. They may also use passive solar building design techniques and active solar technologies.

Zero energy buildings: the concept of zero energy buildings has been a progressive evolution from low energy buildings. Zero energy buildings (ZEB) are any residential or commercial buildings with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. The concept of ZEB can be dealt with from a variety of views, depending on the project goals and the values of the building designer and owner. For instances, owners typically care about energy costs, so, it can be seen as zero cost energy buildings. Governments are concerned with national energy figures, and are typically interested in source energy, and therefore, it possible to say zero source energy buildings. A building designer may be interested in site energy use for energy code requirements (zero site energy buildings), while those who are concerned about pollution from power plants and the burning of fossil fuels may be interested in reducing emissions (zero emissions energy buildings) (Hui, 2001; Torcellini *et al.*, 2006). The view we deal with the ZEB can have a significant impact on the design and characteristics of zero energy buildings.

This thesis studies low energy buildings as the first step towards zero energy buildings. It deals with these buildings from site and carbon emissions point of view. As a good zero energy building definition should first encourage energy efficiency, and then use renewable energy sources available on site, this study focuses on the first stage which is achieving the low energy target by reducing building energy demands.

2.1.2 Low energy studies

This section reviews studies and projects related to low energy buildings in countries with different economic and technical developments.

Developed world

Nowadays, a great deal of effort is ongoing in the field of low energy buildings. Building America Programme (Anderson, 2004; Christensen *et al.*, 2006; Christensen *et al.*, 2005), the High Performance Metric Project (Deru & Torcellini, 2005) by the U.S. Department of Energy (DOE) and the European Energy Performance of Building Directive (EPBD) (European Union, 2003) are such efforts. Most these efforts have focused on finding the best possible methods for performance evaluation. This, in particular, can be seen in the EPBD, which primarily aims to improve the energy efficiency of buildings through developing methodologies to estimate the energy performance of buildings. At an individual level, many studies have attempted to achieve this target. Poel *et al.* (2007), for example, presented a method and software that can be used to perform building energy assessment in a uniform way. Corrado & Fabrizio (2007) conducted a study to implement a simplified calculation procedure in order to predict year-round energy needs, while Rey *et al.* (2007) proposed a methodology called Building Energy Analysis (BEA) to assess building energy labelling.

At a broader level, methodologies and frameworks to achieve efficient and low energy buildings have always been subject to development process by many organisations and research communities. In the UK, for instance, the Energy Efficiency Guide F (2004) published by the Chartered Institution of Building Services Engineers (CIBSE) presented a framework for improving the energy efficiency of buildings during the design and operation process, as can be seen in Fig. 2.2.

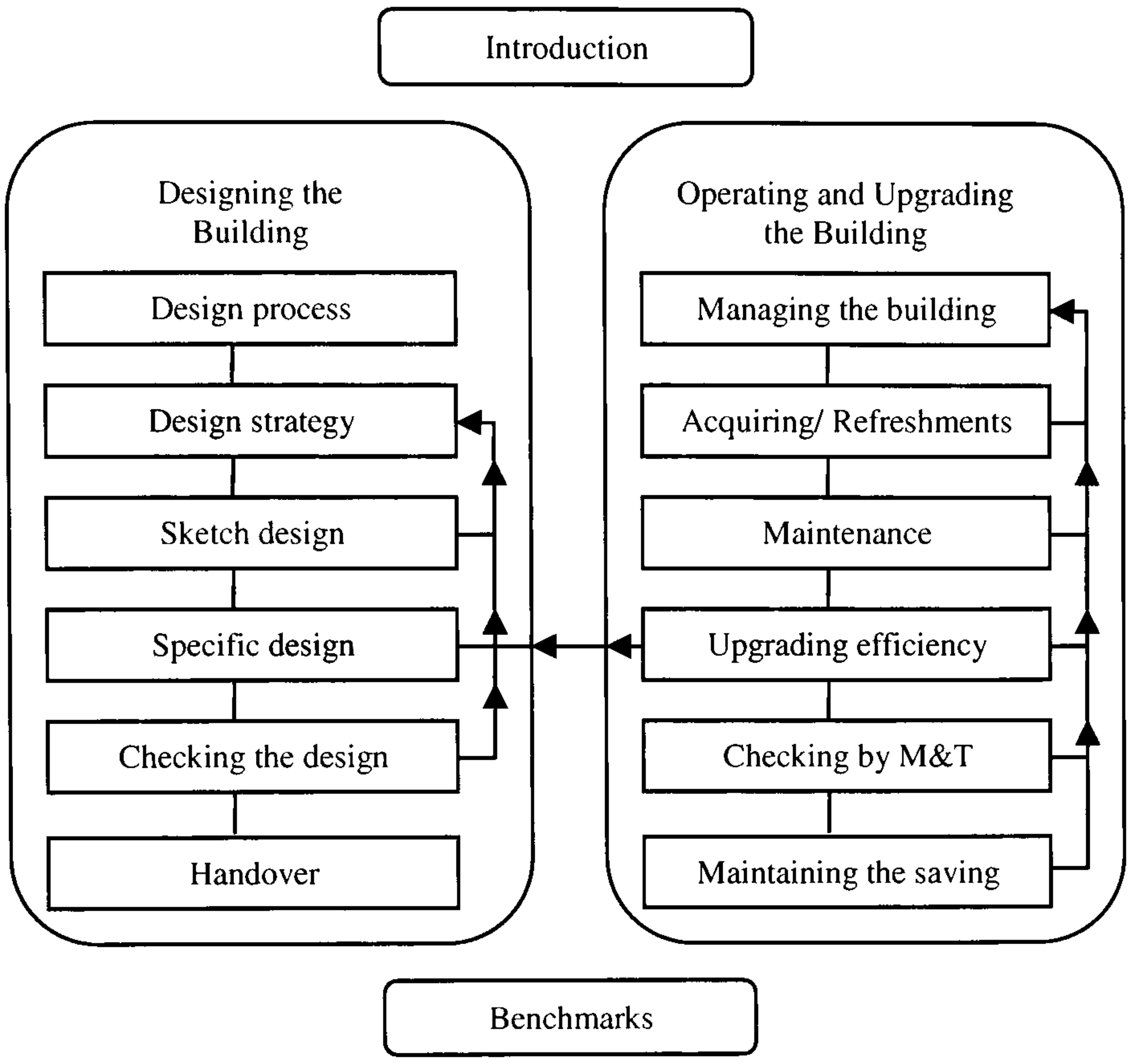

Figure 2.2 Energy efficiency guide F (CIBSE, 2004)

At the same time, the Advanced Energy Design Guide (2004) prepared by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provided a simple framework for low energy office design. The main concern of this guide is the integration of building elements through their life-cycle, as illustrated in Fig. 2.3.

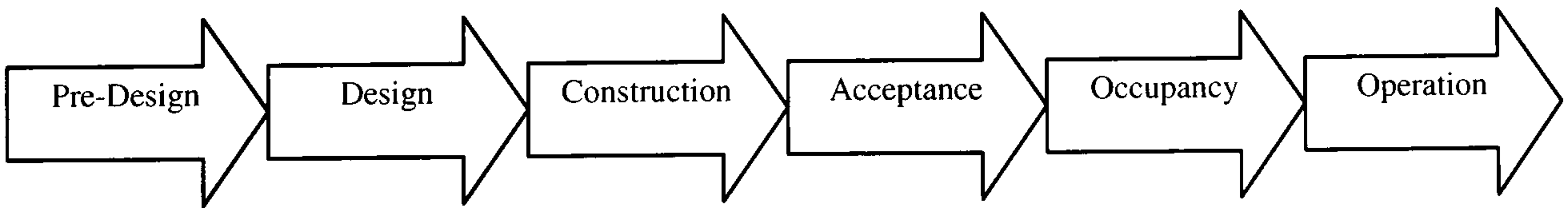

Figure 2.3 Process of integrating energy design (ASHRAE, 2004)

Developing countries

In the developing countries a large number of researches and projects have been conducted to present methodologies for evaluating the energy performance of buildings. In Singapore, for example, a research project (Lee, 2001) was conducted to benchmark the energy performance of office buildings with the aim of examining the correlation between different building parameters and the energy consumption. The benchmarking process started with data collection including information about the architectural, functional and operation characteristics of the buildings. The collected data were then analysed using statistical methods. The most important finding was that the energy consumption of office buildings is directly proportionate to the gross floor area and that based on the gross floor area alone one can predict and estimate the energy consumption of a building to a good degree of accuracy. The conclusion was that detailed energy performance data and indices are required to set benchmarks in order to review consumption patterns in buildings and to compare them. In this way, strategies and database to improve the energy performance of buildings can be developed.

In Hong Kong an important research in evaluating the energy performance of air-conditioned buildings was that of Hui (1996). The climate conditions of Hong Kong were first studied and then a weather data file was developed. Based on the developed file, the simulation programs DOE-2 and BLAST were used to analyse the interaction between building design and performance parameters. It was found that the building performance approach addresses energy consumption of the building as a whole. This is to avoid the prescriptive requirements which may limit trade-offs among different components and systems. Another finding was that building energy simulation gives designers greater control on the design and performance of buildings.

Building simulation has been used in many studies and projects with different agendas. In Egypt the DOE-2 and DOE-2.1E simulation programs were a key technique in developing the building energy codes (Huang *et al.*, 2003). Developing the Egyptian standards passed through four main stages:

- First, developing models for buildings based on physical characteristics of the existing buildings.
- Second, using analytical methods to determine the factors influencing the energy consumption.

- Third, developing the standards.
- Fourth and finally, performing building simulation to evaluate the impact of the developed standards on the energy performance of the case models.

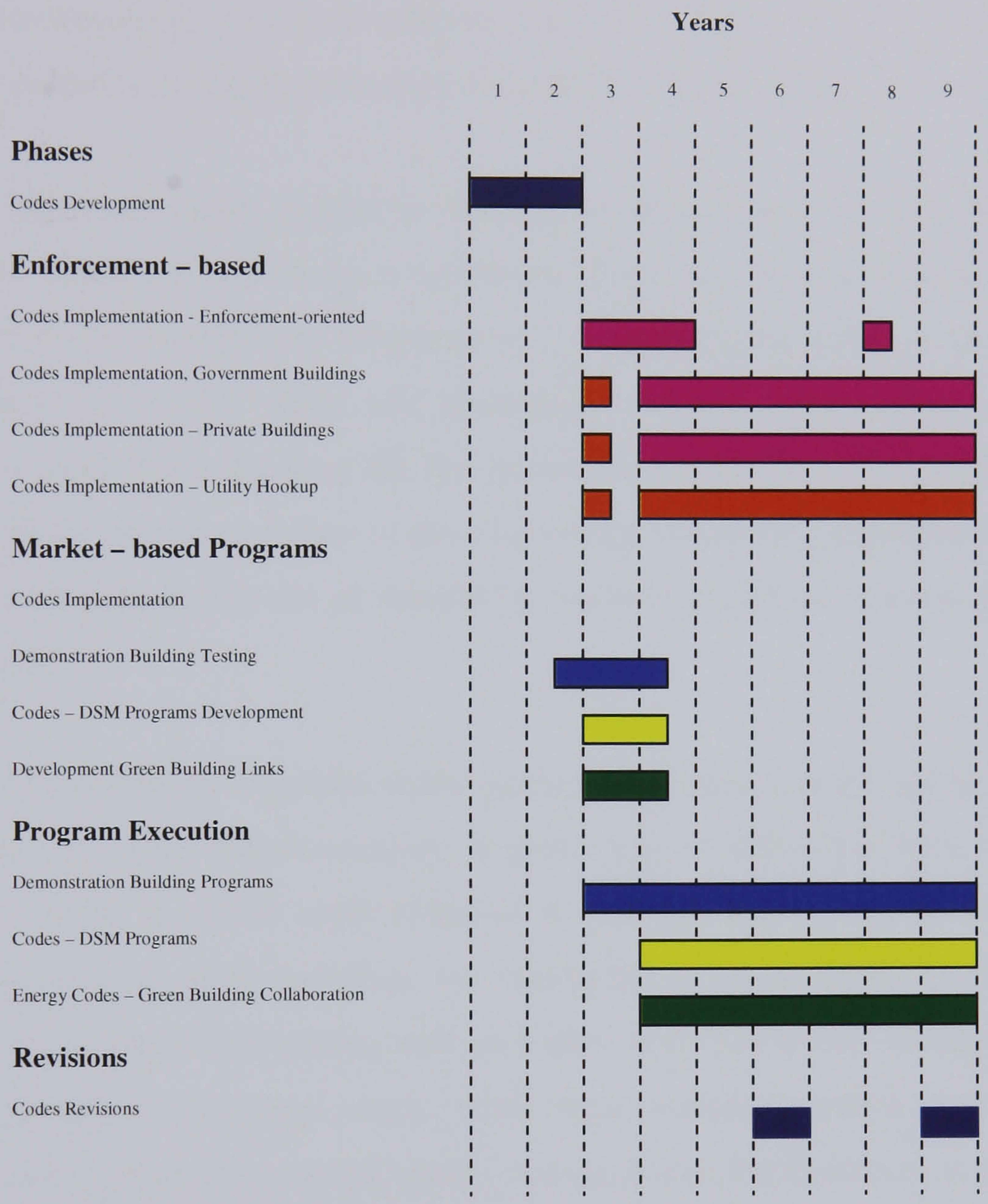

Figure 2.4 Procedure for developing energy codes
(Deringer *et al.*, 2004)

The above methodology helped in developing standards for commercial and residential buildings in Egypt similar to those of ASHRAE-90.1. Fig. 2.4 shows the procedure used in developing these standards where the development is just the first step. The illustrated procedure shows the development, implementation and revision phases for BESC. The first phase involves writing the BESC document, while the second "implementation" phase involves steps 1, 2, 3 and 7. It is code-enforcement oriented and prepares the infrastructure, administrative structure, procedures and tools needed to permit compliance with the BESC. The third phase involves using the BESC either in a voluntary or mandatory enforcement program. This procedure implies that a successful use and development of energy codes demands a support of compliance methods in combination with simulation tools (Deringer *et al.*, 2004).

An important recent project to develop building energy codes was that of Shaviv *et al.* (2008). In this study, a conceptual framework was first proposed and then an optimisation model was incorporated into a simulation program to provide optimum prescriptions for office and residential buildings. The outcome of this optimisation represented the base for the prescriptive standards. This optimisation used the climatic design as a base to develop energy standards. A prime advantage of this methodology is the use of sensitivity analysis techniques to find different design solutions.

In the developing countries many studies have been carried out to develop building energy codes. Simultaneously, a great deal of effort has been spent to assess those codes. A recent study (Masoso & Grobler, 2008) into the impact of thermal insulation on office buildings was conducted in the hot and dry climate of Botswana. It was found that adding wall insulation does not always reduces annual energy consumption. In some cases, there were instances where adding wall insulation directly increases annual energy consumption. Furthermore, at a certain level of insulation the office building switched from pro-insulation to anti-insulation. This behaviour occurred in annual cooling energy, but excluded the heating energy.

In the ASEAN countries a great deal of research has been carried out to evaluate the ability of energy codes to achieve their objectives. Some studies reported on the effect of including a thermal insulation layer in the fabric and how to optimise the thickness of thermal insulation (Bojic & Yik, 2002; Li & Chow, 2005). Other studies (Chan & Yeung, 2005) evaluated the codes and their improvements on the environment by considering the energy saving, reduction of fuel use and pollutants emission from the power plants. The others concentrated on the overall thermal transfer value (OTTV) standard (Chow *et al*, 2000; Lam, 2000). The OTTV standard represents an envelope thermal performance code. The OTTV and the thermal transmittance aim to the same target and have the same concept, which is the optimisation of the thermal performance of building envelope. The difference is that the OTTV deals with the envelope as a whole, while the thermal insulation deals with certain components of building envelope. A recent study (Yik and Wan, 2005) evaluated the appropriateness of using the OTTV standard to regulate envelope energy performance of air-conditioned buildings and concluded that the OTTV can be effective in residential buildings because of the small internal heat gains, while its use in internal load dominated buildings is critical and, therefore, a second thought should be given to the use of the OTTV in this type of buildings.

Gulf Cooperation Council (GCC)

There is no question that the energy use in Bahrain and the Gulf region is much less efficient than in most developed countries. In terms of energy studies, a number of researches have been conducted with respect to energy use in buildings. In Oman Al-Jabri *et al.* (2005) developed lightweight concrete blocks for thermal insulation. In the United Arab Emirates Aboulnaga (2006) investigated the impact of glazing façade on the daylight and energy consumption of commercial buildings. In Saudi Arabia Al-Ajlan (2006) reported on the measuring technique of thermal insulation produced by manufactures in Saudi Arabia. Al-Homoud (2005a) presented an overview of the basic principles of thermal insulation and its uses and the performance characteristic and proper application. Al-Homoud (2001) highlighted a number of building energy analysis techniques and reviewed the most popular techniques used in building simulation and design optimisation. Al-Rabghi and Hittle (2001) explored the use of building simulation in analysing cost effective energy efficiency measures. Al-Rabghi *et al.* (1999) estimated the electric energy consumption due to the cooling load. Al-Sanea *et al.* (2005) investigated the effect of electricity tariff on the optimum insulation thickness in building walls. Khaled (2006) analysed the heat transfer through various thermal insulation systems. In Kuwait Maheshwari and Al-Murad (2001) studied the impact of energy conservation measures on the cooling load and HVAC system, while Omar and Al-Ragom (2002) presented a methodology for choosing the glass type and glazing area.

As reviewed, some studies in the Gulf States investigated envelope thermal codes such as the window codes and emphasised the importance of glazing parameters, particularly shading coefficient and window area, to reduce the cooling loads. Many studies have focused on the thermal insulation of building envelope and emphasised the benefits of using low level of thermal transmittance value in skin load dominated buildings, but this level should remain below the threshold that would lead to the installation of expansive huge air-conditioning system in internal load dominated buildings. Another critical point discussed by those studies was the impact of thermal insulation envelope on cooling energy use. The conclusion was that the use of thermal insulation was dependent on climate, schedules of operation and certain features related to thermal insulation such as the orientation of the wall, the thickness of insulation and its position relative to the mass, and therefore, the applicability of thermal insulation must consider the type, activity, design, use and schedules of operation. This is of importance when setting building energy codes, particularly those relate to building envelope.

Important studies for the current research were that of Al-Homoud (1997) and Al-Homoud (2005b), which investigated the impact of envelope design optimisation on the energy consumption. A systematic framework was presented with the aim of optimising the thermal design of building envelope during the early design stages. Another important research was that of Iqbal and Al-Homoud (2007). This study examined the use of building simulation to investigate the impact of efficiency measures on the energy use in office buildings. The study was conducted on a six storey building located in Saudi Arabia. The monthly utility bills were first collected and analysed in order to obtained information about the historical energy consumption and to calibrate the energy simulation program. This program was then used to evaluate the impact of several efficiency measures. This study provided a quick performance index, as shown in Table 2.1.

Table 2.1 Annual energy use indices in Saudi Arabia
(Iqbal & Al-Homoud, 2007)

Year	kWh/m^2/Yr
2001	410
2002	377
2003	315
2004	330

The tabled data show the indices of four years from 2001 to 2004. These indices were important to measure the level of efficiency of the studied building relative to itself and to other similar buildings. Clearly, the electricity consumption was varied from one year to another. However, more annual electric energy was consumed in the year 2001 with 410 kWh/m^2/yr compared to the 315 Kwh/m^2/yr for the year 2003. The reason behind this, as indicated by the study, was the extremely hot summer in the year 2001 which led to an intensive use of the air conditioning system and consequently the annual electricity consumption. This study indicted that the implementation of envelope, system and operation measures can result in about a 36% reduction of electricity used in office buildings.

Kingdom of Bahrain

In Bahrain a few studies have been carried out with regard to energy use in buildings. Alnaser and Flanagan (2005), for instance, introduced the use of solar enery to achieve the sustainable buildings, while Saeed (2000) emphasised the use of passive design for energy savings. An important study for the current research was that of Akbari *et al.* (1996). It studied the electricity consumption in the residential sector of Bahrain and presented cost / benefits analysis of energy efficient technology, as shown in Table 2.2. This table illustrates the estimates of energy savings potentials as efficiency measures are added, assuming a geometric saving for series measures applied to the same end use of traditional residential buildings. It is clear that a significant amount of electricity savings was achieved due to improvements in electric and mechanical energy technologies along with implementing envelope components codes such as thermal insulation and window. The largest amount of energy savings was due to the use of thermal insulation of building envelope. This was simply because of the large amount of external heat gain in residential buildings. This may imply that as the amount of external heat gain through building envelope increases the impact of thermal insulation become greater.

Table 2.2 Conservation supply curve for residential space cooling (Akbari *et al.*, 1996)

Measures	Base saving (Fils/kWh)	Base saving (MWh)	Adj. CCE (Files/kW.h)	Adj. saving (MWh)
Thermostat set point	0.0	91.6	0.0	91.6
Reduced infiltration	0.3	57.2	0.3	52.6
High Eff. AC	3.7	160.3	4.2	140.1
Insulation	7.7	217.5	10.2	163.5
Window treatment	20.3	103	33.3	62.7
Total				510.5 (44.5%)

Some strategies were recommended by the study, including the establishment of building energy standards, introducing guideline for new building design and setting up an electrical consumption monitoring programme. The study also stressed the need to investigate the electricity consumption in the commercial buildings as they represent a major consumer of electricity in Bahrain. This study has eliminated a large area of the ambiguity of the energy behaviour of the residential sector. However, it would be more useful if the electricity performance of each building as a whole has been objectively measured and related to its floor area. This measurement is a good means to assess the effectiveness of the energy strategies that were recommended by the same study.

2.1.3 Discussion of low energy buildings in Bahrain

Based on the above review, low energy buildings must meet the requirements of building energy efficiency, including conserving energy, protecting the environment and maintaining good internal conditions. A principal concept of low energy buildings is to design with climate and the use of low energy standards and technologies. Today, methodologies to evaluate the impact of different design configurations and energy standards are important to reach the low energy target. The majority of studies in low energy buildings emphasised the significant role that the simulation programs have played to evaluate the energy performance of buildings when compared to manual methods.

It is important to mention that the study of low energy buildings in Bahrain is still in its infancy and that the problem surrounding the energy performance of buildings results from the lack of evaluation and optimisation methods. To a certain extent, the research and knowledge in building performance and energy standards are uncommon in Bahrain. Although there is a small number of research and writing which is relevant to energy conservation, to date, there is no research on the evaluation of building energy performance appears to have done in Bahrain. This thesis, therefore, makes a direct contribution to literature concerned with building energy performance in terms of its relevance and application to the Gulf States in general and to Bahrain in particular.

Having briefly reviewed some studies about low energy buildings in selected countries which represent the first point of this chapter, the review now turns to the second point. This point investigates the concept of building energy performance and highlights the theoretical background for measuring and evaluating the energy performance of buildings.

2.2 Building Energy Performance

2.2.1 Basic concept

The awareness of building energy poor performance has been a growing concern around the globe for the last few decades. Various definitions were introduced. Some of them are presented below.

The basic understanding of building performance can be seen as "...the practice of thinking and working in term of ends rather than means and is concerned with what the building (or building product) is required to do, rather than prescribing how it is be constructed" (Baird *et al.*, 1983, p: 5). With more focus on energy building performance is the amount of energy actually consumed by building services or estimated to satisfy the building's needs (Poel *et al.*, 2007). CIBSE (2004) assumed that the energy performance can be expressed as an energy performance indicator, which refers to electricity or fossil fuel consumption usually in kWh/m^2. ASHRAE (1990) stated that the energy performance is the annual energy consumption or use for an existing or proposed building.

2.2.2 Types of building energy performance

There are three important types related to the energy performance of buildings. Graphically, the performance of buildings could be represented by three overlapping circles representing environmental, thermal and energy performance (see Fig. 2.5). These terms are used to express the thermo-physical behaviour of buildings, their systems, components or individual elements. A precise meaning of each type is depended on the context of the study. In the literature, however, a general description can be obtained. The environmental performance, for example, often concentrates on the indoor environment, including thermal comfort, lighting, air movement and acoustic (Jackman, 1987), while the thermal performance focuses on heating and cooling loads as well as the equipment's performance (Kreider *et al.*, 2002). As for the energy performance, it studies the energy end-uses of buildings and their energy consuming equipment (Hui, 1996). As illustrated in Fig.2.5, the energy consumption in buildings is influenced by the interaction between the environmental, thermal and energy performance. Although these types of performance have different evaluation measures and a variety of views to deal with the energy consumption in buildings, there is an overlap between them and they complement each other.

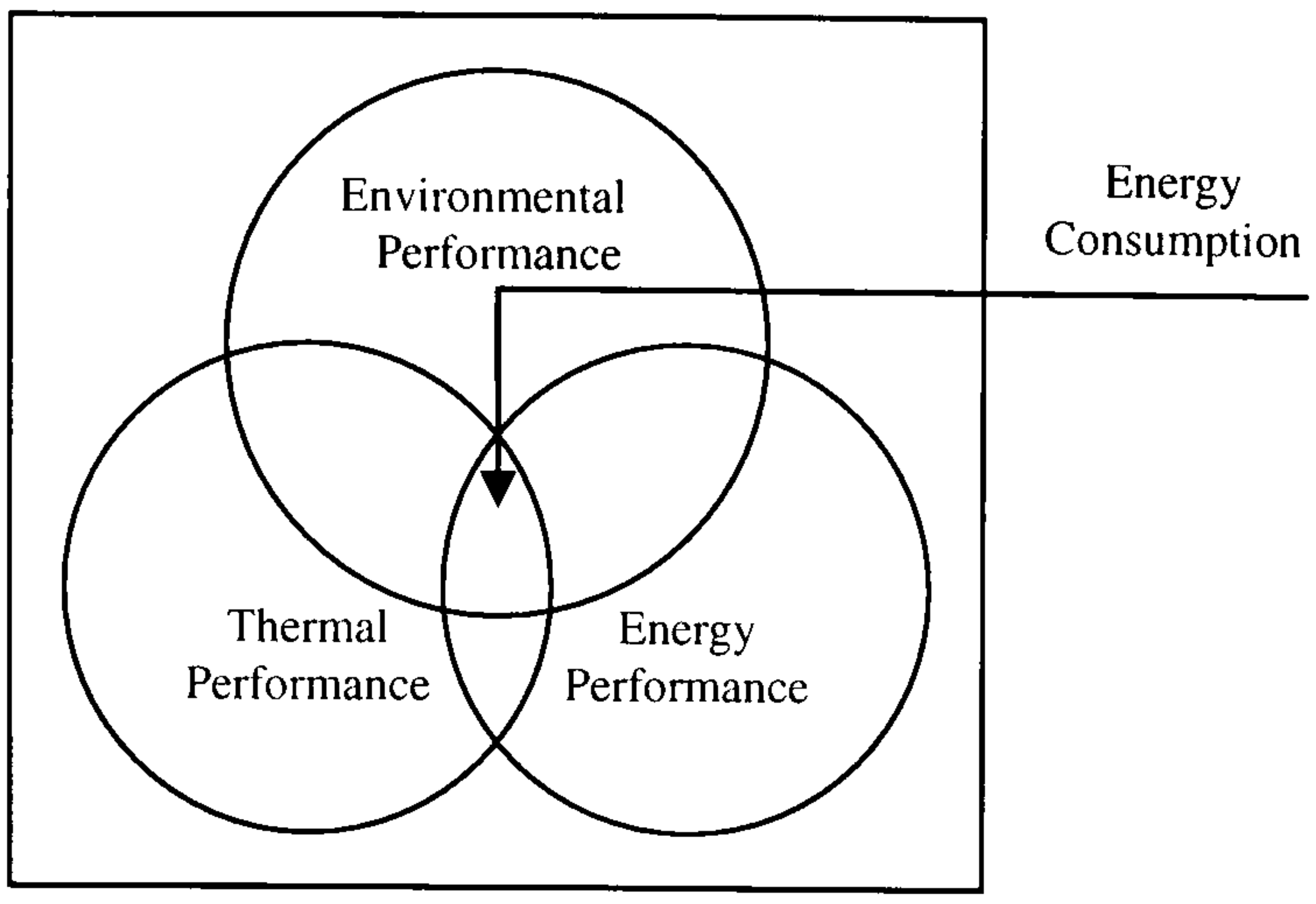

Figure 2.5 Types of building performance (Hui, 1996)

2.2.3 Factors affecting building energy performance

Given the influence described in the previous section there are some factors that have a major effect on building energy performance, including envelope design, system design and occupant's behaviour. The first two factors are related to the decisions made in the early stages of building design. Some studies (Baker, 1992; Baker & Steemer, 2000) indicated that the above three factors may be not entirely independent and there can be interaction between them. Among these factors, the occupant's behaviour typically accounts for a two folds variation, in total variation of ten folds, as illustrated in Fig. 2.6. As illustrated, there is a sequential process to reach the high energy performance target. This process starts with an optimum design of building envelope and ends with an efficient operation of building system by the occupants. The optimum design of building envelope positively impacts the building system, particularly the HVAC and lighting system. The optimum design may reduce the building loads and equipment size and consequently the cost and energy use. However, to obtain the maximum benefits of this design the occupants should operate the building systems in an efficient way because they can directly alter the system performance through controllers. The importance of each of these factors may vary from building to another, and the amount of energy consumption is subject to the way these factors behave and interact with each other.

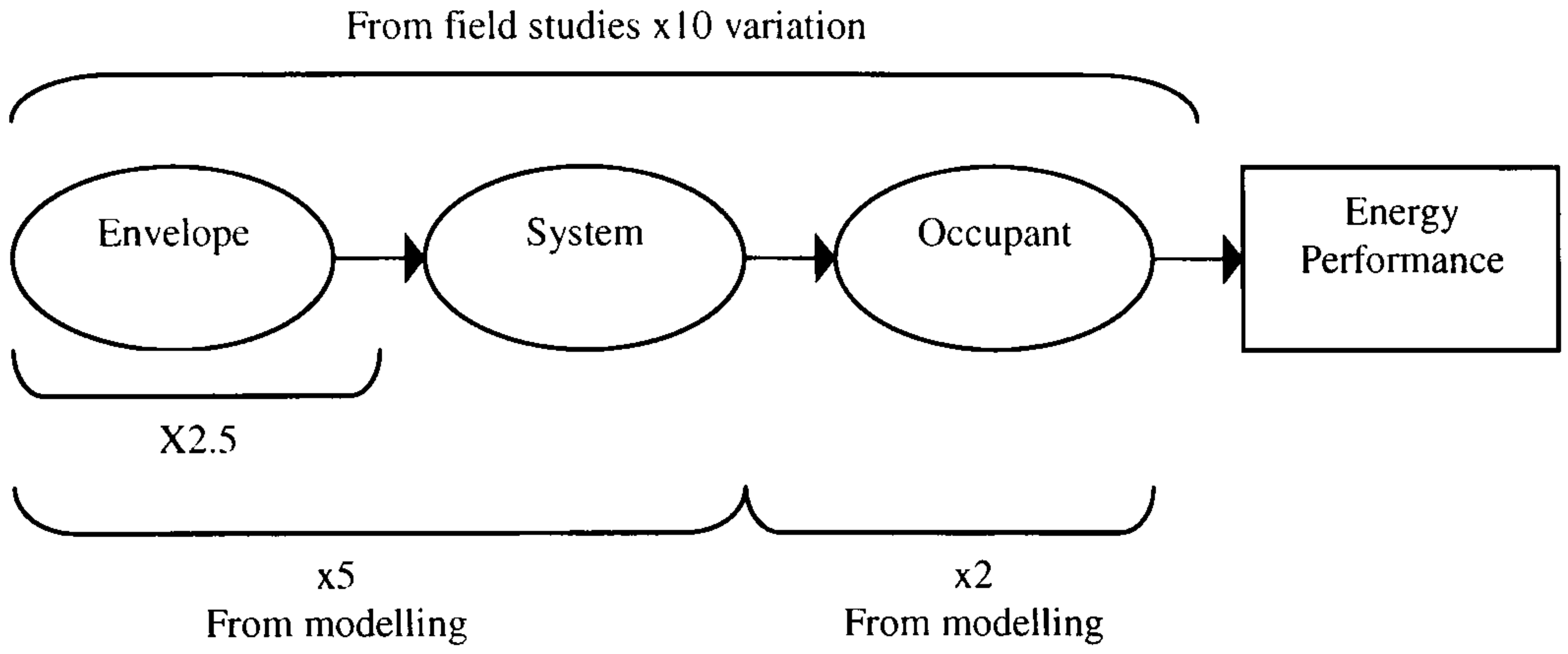

Figure 2.6 Connection between buildings factors
(Baker, 1992)

To investigate the energy performance of buildings different approaches are available. Each has been developed according to the requirements of different disciplines involved in the building industry, including engineering approach, architectural approach and energy approach. The first approach concerns the energy consuming devices. The second approach focuses on the prediction of the indoor environment resulting from a given configuration of building envelope, while the energy approach takes into account the occupant factor. Therefore, in putting a model for assessing the energy performance of buildings it is necessary to consider the building as a whole (envelope, system and occupant). The whole building approach not only assesses how systems that make up a building connect and overlap but also recognises that each feature impacts the energy use and efficiency of the whole building (Anon, 2000).

2.2.4 Performance assessment

To assess the energy performance of buildings several criteria are used. Each relates to one or more disciplines involved in the building industry. Nowadays, a great deal of effort is ongoing to standardise these criteria to be used as a guide throughout the building life-cycle. In the UK, for instance, an air-tightness measure has been introduced as an index of the energy performance of large buildings

(Sharples *et al.*, 2005). The following texts define the performance indices and introduce the most popular types.

Performance indices (PIs)

Basically, any combination that is aggregated to measure the behaviour of buildings or their system can be considered as a performance index (PI). It is therefore, a "...defined measures for the performance that a particular building system has towards a given function of that system" (Augenbroe, 2004, p: 19). This measure makes it possible "to compare two different levels of energy use in the provision of particular of service" (Baird *et al.*, 1983, p: 25). Today, for assessing the energy performance of buildings, three types of indices are widely used and presented below.

Area energy use index

Area energy use index is based on just the annual energy use per square metre of building floor area. In other words, the ratio of the total energy consumed to the total number of treated square metres of the space is the energy performance index for that space. This is seen in the energy utilisation index (EUI). This index can be obtained through dividing the total annual energy use by the net, gross or the air-conditioned area of the building. An argument can be made that the gross floor area may be misleading if some buildings contain a lot of non-air-conditioned areas and have very different functions and hours of operation. Therefore, it is suggested that the EUI might be expressed in consumption per air-conditioned area, per hour of operation, per defined function and per defined functional activity within the facility. Because this type of indices is very simple; it is the most quoted one (Baird *et al.*, 1991; Baird *et al.*, 1983).

Energy cost index

Energy cost index (ECI) is an expression of the annual cost of the energy used per square metre of the air-conditioned area (Capchart *et al.*, 2002). It is therefore, the ratio of the total cost of energy consumed to the total number of square metre of the treated (air-conditioned) space per year.

Carbon emissions index

Carbon emissions index (CEI) is an expression of the annual CO_2 emissions in kilogram per square metre of the building floor area. As there is a direct correlation between energy consumption and CO_2 emissions, the estimation of the CEI is often done after the calculation of the EUI and multiplying the results by the conversion factor for the used fossil fuels (Moss, 2006).

Use of performance indices

In general, the above types of indices are used to measure the energy performance of buildings. Sometimes, they are used as benchmarks or targets for future performance. Setting an achievable and realistic performance index can be used as a tool to improve the energy performance of buildings (CIBSE, 2004). A popular phrase used to express this concept is tracking performance metrics. A metric is a "measurable quantity that indicates some aspects of performance" (Deru & Torcellini, 2005). This metric is often used to indicate a performance objective or goal. The former refers to a general statement of the desired achievement such as minimising the energy consumption, while the latter focuses on a specific level to be achieved such as reducing the energy consumption to a particular level. Many attempts have been made to use established performance indices to improve the energy efficiency of buildings. To do so, there are three logical steps (Sizemore *et al.*, 1979):

- Studying building performance
- Identifying opportunities for improvement
- Evaluating these opportunities

In the first stage, studying building performance can be related to the past, present or the future performance. Each has its own methods and techniques. The past performance can be studied from the monthly utility bills of the past two to five years. This enables performance indices such as EUI, ECI or CEI to be obtained.

These indices can be compared with similar building figures or to energy standards and benchmarks. However, the most effective tool for estimating the current and future performance is the "energy analysis".

2.3 Energy Analysis

Much work in energy analysis has attempted to understand how, when and where energy is used. Different approaches were introduced to analyse the energy behaviour in buildings.

2.3.1 Approaches for energy analysis

Several approaches are found in the literature (CIBSE, 2004; Pedersen, 2007; Perez de Vinaspre *et al.*, 2004; Rey *et al.*, 2007; Turiel, 1984). This study concentrates on two of them:

Statistical approach and regression analysis

This approach is helpful to carry out an analysis to determine the relationship between energy use and the factors affect this use. It can be seen in the degree-day (see Table 2.3) to provide a measure of the average outside temperature, which has a direct influence on heating or cooling loads. To meet a good degree of accuracy, however, this approach needs a great amount of data for energy consumption and a high level of statistical significance. It is useful to carry out internal performance benchmarking or an analysis to determine the advantages and drawbacks of building design.

Building simulation

As will be recognised in this review, simulation is considered by building performance bodies and research communities as the most appropriate tool for energy analysis. It "...supports the emulation of future realistic at the design stage. It gives practitioners the ability to appreciate the underlying behaviour of systems and, thereby, to take judicious steps to improve performance across the range of relevant criteria" (Clarke, 2001, preface). For achieving a good result, however, a considerable amount of building information and weather data are required. Today, there is a great number of simulation programs used for energy analysis. This will be discussed in section 2.4.

The choice of any of the above approaches largely depends on the availability of data, time and the place of use. The following section focuses on the second approach. The use of simulation approach follows a general procedure:

- Detailed study of the building design and operation
- Calculation of the building loads and equipment
- Estimation of the energy consumption

In terms of building design, many studies (Al-Homoud, 2005b; Gupta, 1970; Wilson & Templeman, 1976) viewed buildings as thermal systems where the building envelope represents the boundary, and the heat flows in and out across this boundary (Carter & Villiers, 1987; Coad, 1978; Underwood & Yik, 2004; Thumann, 1992). This flow is influenced by two types of heat gain:

- External heat gain, including conduction, convection, radiation and air infiltration. Fig. 2.7 shows the process of heat transfer through building envelope.
- Internal heat gain from occupants, lighting and equipment

The sum of heat generated internally and heat flowed from the outside represents the total heat gains of a building. The amount of each type is depending largely on the type and use of buildings. In general, buildings are categorised as skin load dominated (SLD) and internal load dominated (ILD). The former is seen in those buildings with a residential profile, where the largest amount of heat is gained from the outside. The latter is seen in commercial and office buildings, where the largest amount of heat is generated inside. Calculating the amount of each type is important, especially when building loads and energy analysis are involved.

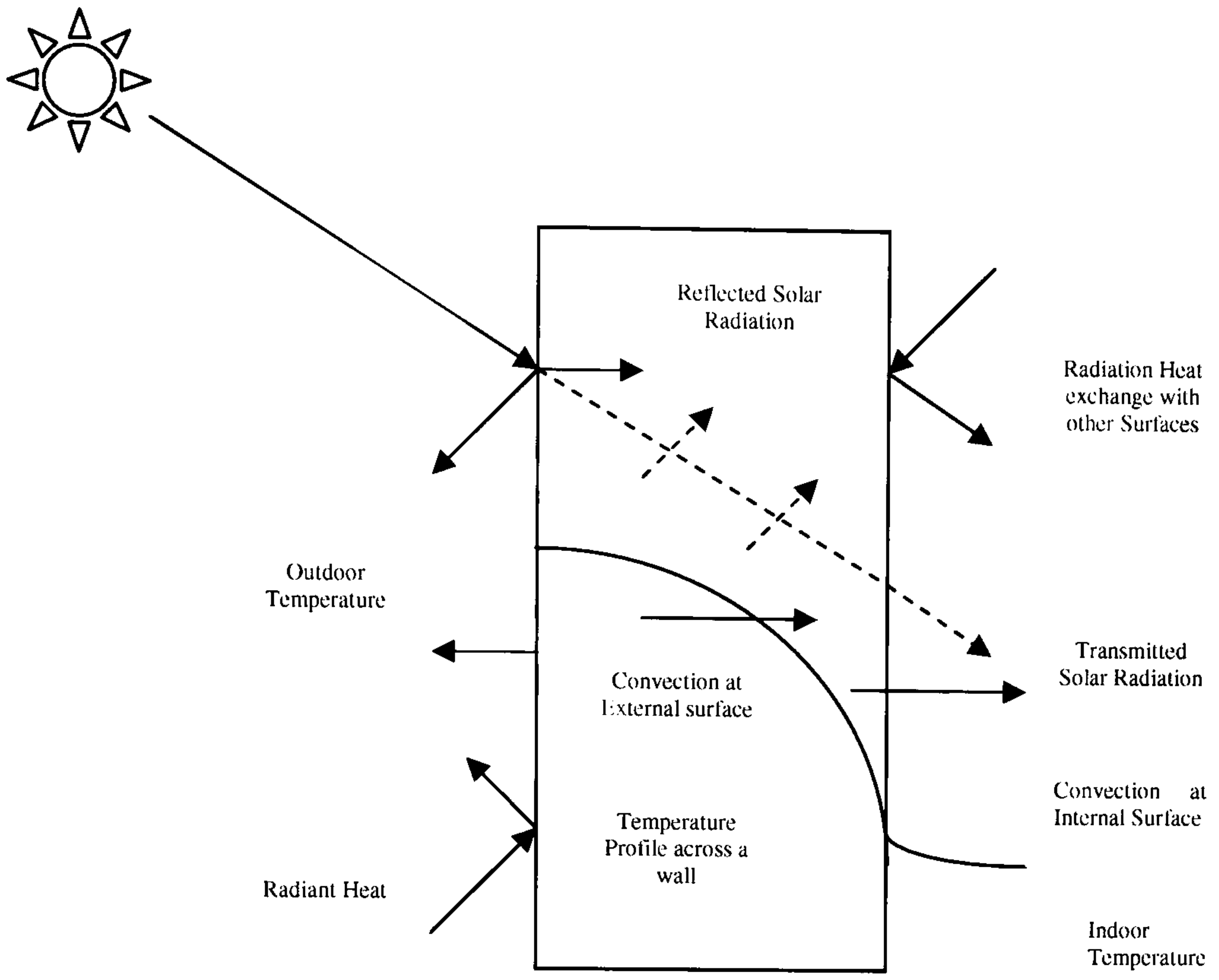

Figure 2.7 Heat transfer through building envelope
(Underwood & Yik, 2004)

2.3.2 Building loads and energy analysis

Building load is described as the energy requirements to control the internal conditions and provide power for lighting and equipment, as well as to convert energy into useful forms for heating and cooling (Dubin & Long, 1978). The calculation of cooling load may represent the most complicated one. The cooling load is the rate at which heat must be removed to reach a comfortable temperature (ASHRAE, 2005). Its calculation, therefore, consists of an accounting of all the thermal energy elements (internal and external heat gains) in the building. Various methods are used to calculate cooling loads. A quick review shows two primary approaches ranging from simple steady states to complex dynamic approach. A brief discussion of the advantages and drawbacks of these methods is presented below.

2.3.3 Comparative discussion of methods for load calculation

Methods for load calculation are categorised into manual methods and computer simulation methods as shown in Table 2.3. Introducing manual methods will provide a basis for understanding current computer-based calculation methods.

It is, therefore, the intention of this review to focus on the use of computer simulation programs.

Table 2.3 Methods for load calculation

Approach	Category	Method	Concept
Steady states	Manual	Degree-days	Based on a baseline (18°C)
		Bin method	Average of outside temperature
Dynamic		Transfer function	Response factor – Weighting factors
		Heat balance	Finite difference techniques
		Radiant time series (RTS)	Simplified heat balance
	Computer	Various	Building performance in real life

Steady states approach

Before the computer revolution, designers and services engineers relied heavily on manual calculation methods. These methods differ in many ways in terms of type, input data, time and place of use. They are, to a great extent, depend on the need and purpose or the problem that is expected to be solved, as well as the required accuracy and complexity of the outcome.

The steady state methods can measure thermal performance of building envelope and estimate the amount of heating and cooling the HVAC system will need to provide a certain internal temperature (CIBSE, 1998). Within the steady state category, there are a number of methods such as the degree-days method, bin and modified bin methods. The degree-days method, on the one hand, is a good way to give an idea about the energy trend for small buildings, and also to compare its system alternatives. However, its use is limited and sometimes inadequate when the day-to-day weather data variations and internal heat gain are of importance (Al-Homoud, 2001). On the other hand, the bin method is based on the principle that the required load related to the outside temperature gives a better choice. However, as the analysis is done for only one or more typical days of each month, this may reduce the accuracy of the estimate by eliminating extremes of weather data conditions (Morbitzer, 2003). The modified bin method represents another option, especially for internal load dominated buildings due to the consideration of the internal load, solar radiation and wind effect. But it is not recommended for the use with large buildings with an area of more than 2500 m^2 (Al-Rabghi & Hittle, 2001).

In brief, the steady state method can be accurate and useful when the internal and external temperature is considered constant. However, the internal temperature varies from one case to another. Therefore, a dynamic approach is needed when calculating loads and estimating the energy consumption of buildings with respect to weather parameters and internal conditions during a whole year.

Dynamic approach and computer methods

The transfer function and heat balance are two types of calculation methods. Both are used to capture the dynamic response of buildings. Technically, the transfer function uses the response factor technique to calculate heat gain and cooling load. The principle of this method is the calculation of loads as a building responds to different effect parameters (e.g., weather, internal load, etc). It can calculate building loads, sizing system and equipment for each of the year's 8760 hours (Kreider *et al.*, 2002). The heat balance uses the finite difference technique to simulate buildings where there are no linear components. The principle of this method is the simultaneous combination of the building and its systems. Today, with the quest for more accurate and simplified energy prediction procedure, new methods are being developed that are relatively similar to the aforementioned methods. The radiant transfer series (RTS) is a simplified method for performing load calculations derived from the heat balance (ASHRAE, 2005). The RTS method is capable to calculate loads. However, it is not suitable to be used for annual energy simulation as most of the above methods are today incorporated with the computer simulation programs.

Recently, computer programs have been used to analyse energy and evaluate the performance throughout building developments, in which the steady state and dynamic methods represent the base for the computer programs. These programs allow the simulation of different tasks related to the building and its operation. They have impressive capabilities to manipulate a large amount of building and weather information and perform a great number of calculations and estimations. Fig. 2.8 shows the concept of simulation programs where building information is input, and energy consumption and indoor conditions are the outputs, while the climate is the boundary and the basic driven potential for load calculations. Computer simulation programs are briefly discussed in the next section.

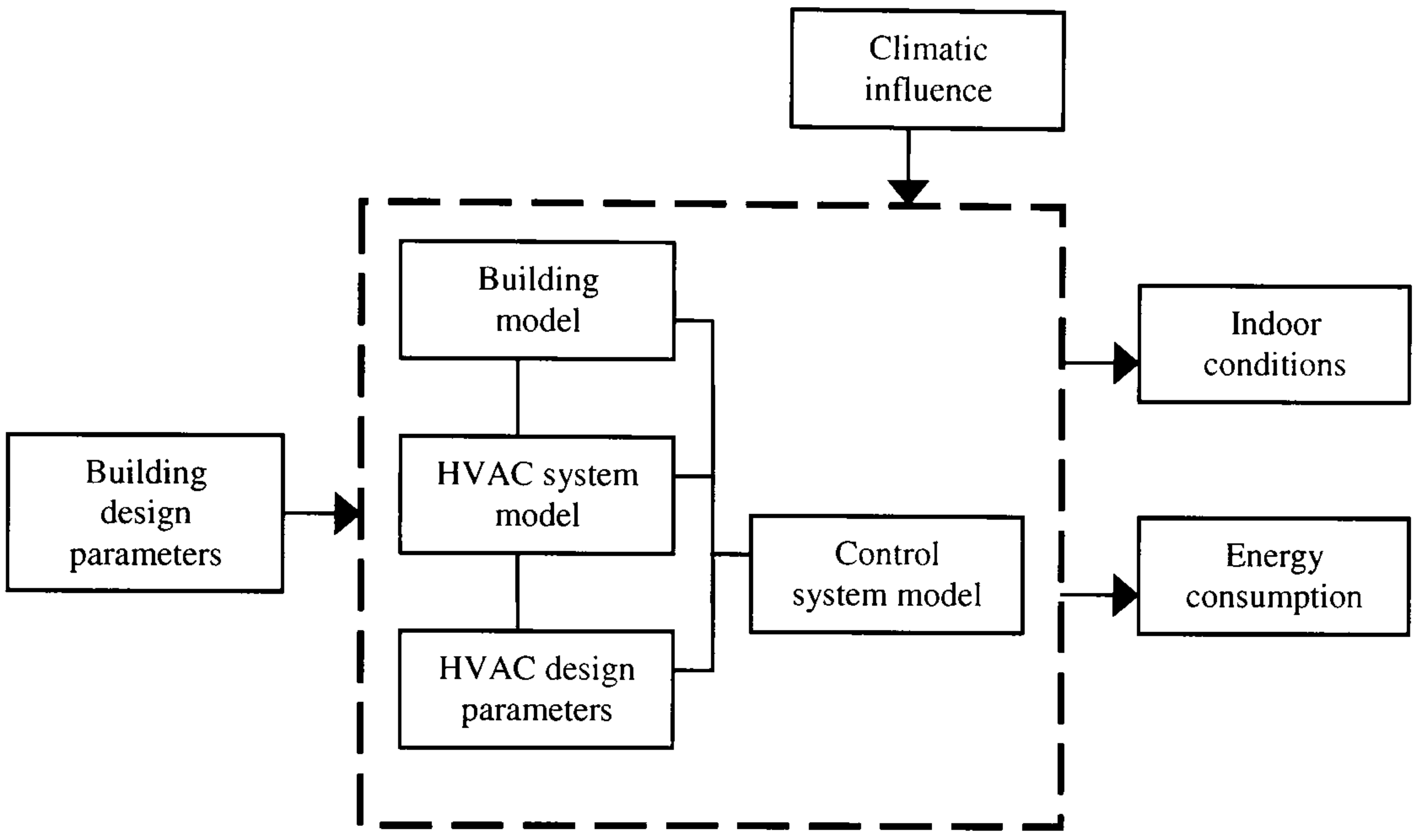

Figure 2.8 Concept of simulation system (Clarke, 1982)

2.4 Building Simulation

Building simulation is an attempt to simulate future building performance through the creation of a computer model. A great number of studies have conceptualised and interpreted this broad idea from their own view point (Augenbroe, 2004; Degelman, 2004; Hong *et al.*, 2000; Morbitzer, 2003). The process of emulating the future performance is illustrated in Fig. 2.9.

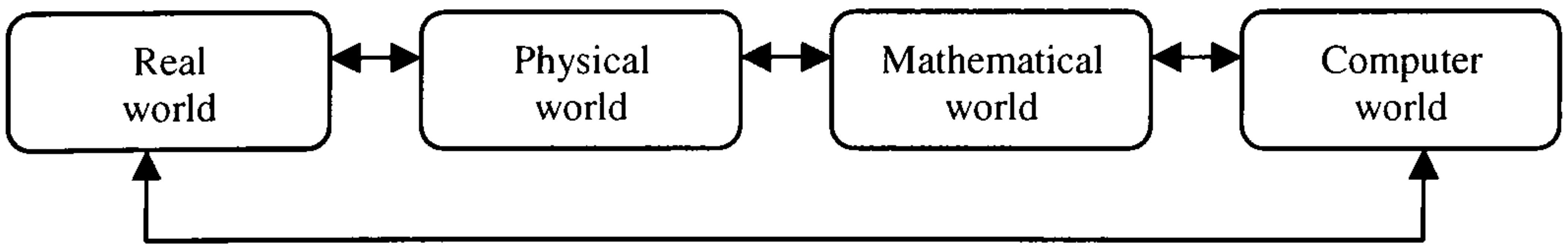

Figure 2.9 Process of simulating building performance
(Hong *et al.*, 2000)

2.4.1 Types of simulation programs

The use of the so-called simulation programs has been advocated in connection with many aspects of building performance such as energy performance, lighting, HVAC system, air flow and many others. In general, simulation programs can be categorised as:

- Envelope load calculation tool
- System tool
- Integrated simulation programs

The last type (integrated simulation programs) provides a means to simulate different aspects within the same program. The aim of this type is to maintain the integrity of the whole building and its systems. Many sources (Citherlet & Hand, 2002; Citherlet, 2001; Clarke, 1999) assumed that only the integrated programs can take into account the dynamic behaviour of buildings.

2.4.2 Available building simulation programs

There has been a rapid growth in the building simulation field. Hundreds of simulation programs have been developed all over the world. Although most of those developments have occurred in the United States and Europe, there have been a few attempts in some developing countries such as Hong Kong and Singapore to participate to those developments. At present, most simulation programs are concerned with the whole building performance which estimates energy performance and indicates various aspects in buildings such as energy consumption, lighting level, comfort, cost calculation and CO_2 emissions estimation. The online directory (www.eren.doe.gov/buildings/tools_directiry) sponsored by the U.S Department of Energy lists more than 350 simulation software developed worldwide. A comprehensive survey was conducted (Crawley *et al.*, 2005) to provide up-to-date comparison of the most popular simulation programs from different aspects as can be seen in Table 2.4. Some of these programs are complex and others are simplified. However, most of them require complete descriptions of building parameters, operation schedules and hourly observations of weather conditions for the building's location. The next section reviews the different types of weather data used with simulation programs.

Table 2.4 Comparison of simulation programs
(Crawley *et al.*, 2005)

General modelling features	BLAST	DOE-2.1E	ECOTECT	Energy Plus	Energy- 10	eQUEST	ESP-r	HAP	HEED	SUNREL	TRACE	TRANSYS
Full geometric description	X	X	X			X	X		X	X	X	*
- Wall, roof, floor	X	X	X			X	X		X	X	X	X
-Window, skylight, door, external shading												
Day-lighting illumination and control		X	X		*	X	X		X		X	X
- Interior illumination from window and sky-light		X	X			X	X					
- Glare simulation and control												
Infiltration and ventilation												
-Single zone infiltration	X	X	X	X	X	X	X	X	X	X	X	X
- Natural ventilation			*		X	*	X			X		*
- Multi-zone air-flow			*				X			X		*
Electrical load distribution and management												
- On site generation and utility electricity management including demand	X	X	*	X		X	X				X	X
HVAC system												
- Discrete HVAC components				X			X			X		X
-Idealised HVAC system	X		X	X			*	*		*		*
User-configuration HAVC system				X		X	X	X	X	X		X
CO_2 modelling												
CO_2 concentration, mechanical and natural							X	X				*
Automatic sizing HACV components		X		X	X	X		X	X	*		*

* convert to other software.

2.5 Weather Data

2.5.1 Need for weather data

A great number of studies (Arens *et al.*, 1980; CIBSE, 1998; Crawley & Hunag, 1997) emphasised the role of weather data in the process of load calculation and energy analysis. They stressed the importance of weather data type in determining the accuracy and characteristics of simulation results. Other studies cast light on time saving when simplified weather data are used, especially for users running multi-simulation analysis during the design stages (Westphal & Lamberts, 2004).

Obtaining reliable weather data has always been a challenge to perform an accurate energy analysis. In the simplest case, weather data libraries in the simulation programs may be the easiest way to obtain the weather data. However, most recent simulation programs provide weather data only for limited number of locations in North America, Europe and some developing countries. To overcome this lack, some web-sites offer raw weather data for a large number of locations around the world. Examples of these sites are the official web-sites of the U.S Department of Energy[1], Weather Bank[2], NOAA[3] and WMO[4]. Raw weather data can be also obtained from the meteorological stations for locations in question. However, data from these stations sometimes are insufficient due to two reasons:

- Uncompleted and limited to only some climatic parameters.
- Inadequate timescale

The main climatic elements required for weather data design are shown in Table 2.5. It is important to note that any selection to design weather data must be based on the combination and integration between the various effects of these elements on the energy performance of buildings (Straaten, 1967). Furthermore, some sources (Lacy, 1977) showed that the smaller the timescale and the longer the period of records and the more recent the data, the better the results. However, due to the absence of real weather data of small timescale and long period, which in some cases represent a period of 30 to 35 years, several statistical methods have been developed to generate synthetic weather data (Guan *et al.*, 2007).

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1 http://www.doe.gov
2 http://www.weatherbank.com/about-weatherbank.html
3 Hhttp://www.noaa.gov/oindex.html
4 http://www.WMO.ch

Table 2.5 Weather parameters required for weather data generation

Weather elements	Units
Dry bulb temperature	°C
Wet Bulb temperature	°C
Wind speed	m/s
Wind direction	Degree from north
Atmospheric pressure	Bar
Net long wave radiation	W/m^2
Precipitation	mm
Global horizontal solar radiation	W/m^2
Diffuse horizontal solar radiation	W/m^2
Cloud cover and type	%
Sunshine hours	Hr

As mentioned above, to overcome the difficulty of obtaining actual weather data many attempts have been made in developing statistical methods in order to generate synthetic weather data. The Monte Carlo method, for example, was introduced to generate weather data from simplified databases (Degelman, 2004; Degelman, 1991). Another attempt was the representation of the TRNSYS to give an average year with regard to the main climatic statistics of the desired location (Knight *et al.*, 1991). The Multi-years (MY) technique was also presented in Hong Kong (Hui & Cheung, 1997). In Europe the MeteoNorm generator and database has been presented. It is a comprehensive source of weather data covering 7400 meteorological stations worldwide (Remund & Kunz, 2003; Remund *et al.*, 1999). This generator uses statistical methods to generate synthetic weather data ranging from simplified to hourly weather data. In addition, it offers models for calculating the inclined surface irradiance and support data exporting in a variety of simulation program formats.

2.5.2 Comparative discussion of weather data

A majority of studies have emphasised the use of 8760 hours of weather data in building simulation (Waltz, 2000). Table 2.6 shows the most popular weather data toolkit in the United States, Canada and Europe, including the organisation which published or generated them.

Table 2.6 Popular weather data (Harriman *et al.*, 1999)

Use	Item	Data type	Publisher
Sizing equipment	2005 ASHRAE handbook fundamental	Long-term extremes	ASHRAE, GRI
	Sequence of extreme temperature and humidity		ASHRAE
Estimation long-term behaviour of energy consumption	TMY-2 typical meteorological year	Typical hourly observations	GRI
	WYEC-2 weather year for energy calculation		ASHRAE
	WWEC Canadian weather year for energy calculation		AES
	EWY example weather year		CIBSE
	TRY test reference year and DRY design reference year		CEC
Simulation equipment behaviour for specific year	SAMSON solar and meteorological surface observation network	Actual hourly observation for specific year	NOAA
	CWEEDS Canadian weather for energy and engineering		NOAA
	INSWO International surface weather Observation		NOAA

Many studies have been conducted to find the best possible methods of generating weather data. Simultaneously, a great deal of effort has been spent to assess weather data and the impact of the generation methods on the energy performance. For example, sequential comparisons (Crawley, 1998; Crawley *et al.*, 1997) assessed the influence of locally measured weather data and typical weather data set on the annual energy consumption for a set of North American locations. The comparison was done with respect to the simulation results using different types of weather data (TRY[5], TMY[6], TMY2, WYEC[7] and WYEC2) and the result based on actual hourly weather data. The conclusion was that the user of simulation programs should avoid using a single year such as TRY type because no single year can represent the typical long term weather patterns. One limitation of the use of the TRY is the absence of global solar radiation data. Methods attempting to produce a synthetic year to represent the temperature, solar radiation and other climatic

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[5] Test Reference Year

[6] Typical Meteorological Year

[7] Weather Year Energy Consumption

elements within the period of record are more appropriate. They will result in predicting energy consumption closer to the long term average. Both TMY2 and WYEC2 are example of this type. They are based on improved solar models, and more closely match the long term average conditions.

2.6 Outcome of the Review

In the light of the review in section 2.2, it is clear that a meaning of building energy performance is the total annual energy consumption per square metre of the space floor area, and it is involved with all physical and operational aspects of energy use in buildings such as energy end uses, spaces and schedule of operation. There are three interacting factors influencing the energy performance, including envelope design, building systems and the occupant's behaviour. The interaction between these factors should be considered at the evaluation time. The performance indices such as EUI, ECI and CEI are useful measuring tools that allow evaluating and improving the energy performance of buildings. They permit comparing buildings with each other in order to assess the energy performance in the regional levels. This will be illustrated in Chapter 4.

Section 2.3 introduced two approaches for the energy analysis, including regression analysis and building simulation. The choice of any of these approaches is subject to the input data, time, place and use, as well as the desired results. For analysing the energy behaviour using the simulation approach, it is necessary to calculate the building loads, particularly cooling load. Various methods can be used, ranging from simple steady state methods to complicated dynamic methods. The former methods are not capable of analysing the dynamic behaviour of building envelope and systems. Analysing such behaviour requires a dynamic approach in order to calculate loads and estimate the energy consumption for the whole year. Today, the dynamic methods represent the base of simulation programs that are capable to make a large number of calculations in a short time. With all these in place, it is possible to optimise building design and evaluate the impact of efficiency measures on the energy performance in the economical and accurate way.

Evaluating and optimising the energy performance of buildings using building simulation will be discussed in Chapter 6.

In section 2.4, it was indicated that building simulation is an important tool to evaluate the energy performance of buildings. It gives the ability to predict the energy performance of different design configurations. For providing a representation for the energy behaviour different simulation programs are available. Some of these programs are simplified and are used for simple purposes such as the calculation of the U-Value of building envelope. This type of program is more useful in the early stages because it requires simple inputs. Other programs are sophisticated programs for hourly simulation of heat, light and air flow which may be used in more advanced design process or when the quick and simple programs are not providing sufficient results. The others are integrated programs, combining a number of features of the above two types. This type can be used at any stage of the design and operation process for various purposes. The choice of any of these programs is subject to some criteria, including accuracy, sensitivity, speed, reproducibility, ease of use and the level of detail, availability of required data and the quality of the desired output. The use of building simulation programs will be implemented in Chapters 5, 6 and 7.

In section 2.5 of this review, the generation methods of weather data were investigated and their types were evaluated. The evaluation revealed that the type and characteristics of weather data play a significant role in determining the accuracy of simulation results. Today, although there are many types of weather data, the most trustworthy one is the hourly data. However, some hourly data, such as the single year TRY, should be avoided if possible because of the lack of solar data and the failure to represent the typical long term weather patterns. Conversely, weather data that produce a synthetic year to represent the temperature, solar radiation and other climatic variables within the period of record such as the TMY2 are encouraged to be used in building simulation. This is because the TMY2 more closely matches the long term average climatic conditions. For many locations, such as Bahrain, however, there is almost no actual hourly raw weather data available for long periods to generate such a type. The solution is to use statistical methods and weather data generators to develop a typical year weather data that represents as closely as possible the long record in energy terms. The process of developing weather data with respect to the current climate of Bahrain will be explained in Chapter 5.

2.7 Closing Remark

This chapter provided the study with a sound basis to progress the research. It reviewed the main features found in the literature relating to the research problem and explained the current developments and understanding in this field. The first part of the review cast light on studies in low energy buildings, and then focused on researches related to Bahrain and the Gulf region. The second part presented a theoretical background for the current research. It reviewed the relevant literature pertinent to the concept of building energy performance. The next chapter briefly describes the methodology for the research execution.

Chapter 3 RESEARCH METHODOLOGY

Ultimately, any researcher who is able to wield an array of tools, not just the hammer she is most familiar with, gains an enormous power to begin to answer all those troubling questions that led her to the research enterprise in the first place.

(Groat & Wang, 2000: preface)

3.0 Introduction

The previous chapter identified several aspects related to the energy performance of buildings; Chapter 3 describes the methodology used to investigate them. An introduction to the methodology was provided in section 1.8 of Chapter 1, this chapter aims to build on that introduction and provide assurance that an appropriate methodological procedure was followed. The adopted procedure provides in-depth, relevant, up-to-date and reliable information for the research execution. This chapter starts with providing a brief discussion on the research methods, in section 3.1.1. Section 3.1.2 explains the research process, while section 3.1.3 describes the techniques used for data collection and analysis.

3.1 Research Methodology

A research methodology consists of research methods[1], research processes and techniques for data collection and analysis. The following sections introduce the method, process and techniques adopted for this research.

3.1.1 Research methods

Broadly speaking, methods for building researches can be grouped under seven headings: interpretative-historical research, qualitative research, correlation research, experimental and quasi-experimental research, simulation and modelling research, logical argument research and case study research (Groat & Wang, 2002). It must be noted that these methods should not be thought of as being mutually exclusive; rather it is possible to combine two or more of these methods within the same piece of research. However, the choice of any combination is subject to the research aim and objectives (Robson, 2002). As the aim of the current research is to establish a systematic approach for evaluating the energy performance of buildings in Bahrain, and there is support in the reviewed literature for the use of simulation

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[1] Sometimes is called a strategy. It refers to the overall research plan or the structure of the research

programs in examining the energy consumption of case buildings, building simulation and case studies will be used in the current study as research methods. These two methods were chosen among others due to many reasons such as time and cost savings coupled with the availability of data of chosen buildings as well as the desired outcome. The simulation programs give a detailed analysis of energy behaviour in buildings and estimate the energy and environmental performance of those buildings.

3.1.2 Research process

An attempt was made from the inception of this research to carry out a study that embodied a balanced analytical and empirical investigation under the umbrella of computer simulation. The research process passed through five overlapping stages. An overview of these stages is presented below.

Contextual and theoretical background

The contextual stage consists of establishing the problem definition, carrying out contextual and climatic analysis and reviewing the literature related to low energy buildings. These processes can be summarised as:

☞ First, a general background of energy scenario (outside the margin of buildings) was studied and the concept of energy efficiency with respect to different sectors was explored. The focus was then directed to the building sector.

☞ Second, the building energy efficiency in Bahrain was investigated with especial emphasis on office buildings. Architectural, functional and operation data were obtained from working drawings and audit reports provided by the Electricity and Water Conservation Directorate (EWCD, 2004a; EWCD, 2004b; EWCD, 2003a; EWCD, 2003b; EWCD, 2003c; EWCD, 2002a; EWCD, 2002b; EWCD, 2002c; EWCD, 1999a; EWCD, 1999b). This allows representative case studies and a case model to be developed and the physical and operational characteristics of offices to be analysed.

- ☞ Third and finally, a study of the climatic properties of Bahrain was carried out coupled with gathering climatic information from various sources including the Directorate of Meteorology of Bahrain, and where the relevant information are unavailable, they were generated using weather data generators.

Gathered and generated climatic information and the case studies were to later serve as climatic and building parameters to calculate a proposed energy standards for the building envelop and to establish benchmarks for the building energy performance. They were also used as input for weather data generators and computer simulation in later stages. This stage, therefore, did not only establish a background to the study and the modus operandi of its execution, but also provided a general overview, as well as the necessary theoretical and empirical framework for the study. Further, it provided a contextual underpinning for the criteria to evaluate the energy performance in Bahrain. This part of the study forms the foundation stage and climatic part of the establishment stage consisting of Chapters 1.2.3 and 5.

Investigating energy standards

As mentioned, the weather information and the physical and operational characteristics of office buildings were used to calculate the proposed envelope performance standard and to establish the energy benchmarks for office buildings. The envelope standard takes the form of the OTTV (overall thermal transfer value). In general, the OTTV standard is a measure of the amount of heat gain through the building shell over an entire year. Sometimes, it is used as a scale to gauge and compare the thermal performance of buildings. It was mathematically calculated through a widely used equation in Hong Kong (Lam, 2000). The OTTV standard is discussed in more detail in section 4.3.2. The energy benchmarks were established in the light of a well established method used in the UK (CIBSE, 2004). Detailed data of standard and best practice buildings in Bahrain were obtained from Electricity and Water Conservation Directorate as indicated in the first stage. These data studied and analysed to provide performance indices in order to obtain energy benchmarks for six representative office buildings in Bahrain. This part is explained more fully in Chapter 4.

Establishing evaluation methodology

The elements required to establish the evaluation methodology were developed in this stage. It started with the development of a statistically-based weather data file. This was done using the gathered climatic information coupled with weather data generators. Furthermore, a procedure that takes into account all the parametric effects and follows a systematic method for load calculation was introduced to ensure that the energy performance was being evaluated in a systematic way. This producer and the weather data file were served as input for the simulation stage in Chapters 5, 6 and 7

Implementation

In this stage, a series of computer simulation was carried out based on the developed weather data file. Two simulation programs (Visual DOE and Energy-10) were used to evaluate the energy performance of two representative case buildings, one case model and a basic conceptual design. The Visual DOE program was used for evaluating the performance of the existing buildings and the conceptual design, while Energy-10 was used for optimising the energy design of the case model. In addition to providing various data and information, an attempt was made to present a systematic framework to develop prescriptive and performance energy standards. In order to avoid the limitation of the prescriptive standard a performance sensitivity scale was presented. This can be seen in Chapter 7.

Conclusion

The last stage synthesises the result of the study and draws conclusions, as well as makes generalisation. These conclusions were considered in conjunction with other obtained results to recommend some principles for low energy buildings in Bahrain, and to make suggestions for areas of future research. These provided the necessary feedback linkage the broad theoretical background at the beginning of the study, complete the cycle planning process.

3.1.3 Data collection and analysis techniques

The use of a particular research technique is subject to the research type and the desired outcome. Fig. 3.1 shows the data collection and analysis techniques used throughout the study. These techniques are briefly discussed in the texts below.

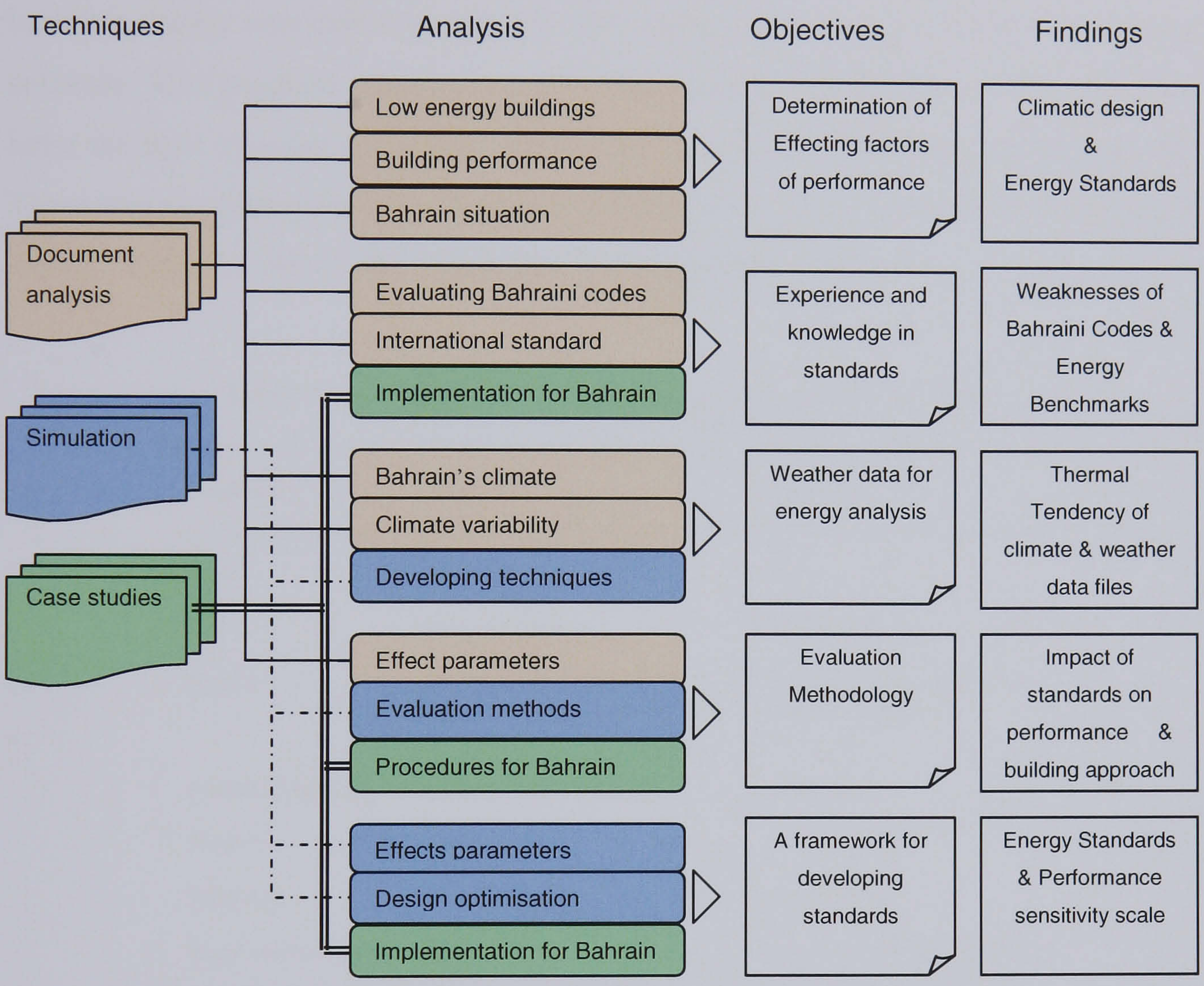

Figure 3.1 Data collection and analysis techniques

Document analysis

In this study, various types of documents were analysed, including books, journals, conference proceedings, theses, government publications and design and operational reports. This analysis identified the important variables related to the investigated area and documented the significant findings from earlier research that served as foundation, on which the theoretical framework for the current study was built. This analysis was carried out primarily on particular aspects concern energy standards, office design, performance evaluation methods and simulation programs, which were highly correlated and supportable.

Simulation programs

Two types of programs were used: first, weather data generators and second, building energy simulation programs. The former is seen in using the MeteoNorm software. This program was used to generate statistical based weather data files. The latter are seen in using the energy simulation programs Visual DOE and Energy-10. These two programs are integrated detailed programs that consider the building as a whole. Table 3.1 shows the characteristics of each program.

Table 3.1 Comparison between Energy-10 and Visual DOE

Attribute	Energy -10	Visual DOE
Type	Simplified	Detailed
Use	Early design stage	Building life-cycle
Purpose	Design optimisation Impact of energy strategies on performance	Performance assessment close to real performance
Analysis time-scale	Hour-by-hour	Hour-by-hour
Method	Energy balance	Transfer function
Technique	Finite differences	Response factors
No. of thermal zone	Max: two zones	Complex thermal multi-zones

Energy-10, on one hand, is a design tool used in the early design stages. This program, in particular, has been developed for design optimisation purpose. It considers the impact of efficiency measures on energy performance and supports the whole building approach. It uses an exact energy-balance method and is based on the finite difference technique that allows running simultaneous combination between the building and its systems with a 15-minute time step (Energy-10 manual, 2005). Energy-10 was used in Chapter 7 to optimise the energy design of the developed case model. On the other hand, Visual DOE is a detailed simulation program. It has been developed to provide energy performance assessment that is as close as possible to the real performance of the building throughout its life-cycle. The program is based on the transfer function which calculates response factors for transient heat flow in walls and weighting factors for the thermal response of building spaces (Visual DOE 4.0 manual, 2004). The choice of these two programs was done with the consideration to the following:

Availability: Visual DOE and Energy-10 are available in Bahrain. The former was used in some research projects by the University of Bahrain (Akbari et al, 1996), while Energy-10 was implemented by Electricity and Water Conservation Directorate (MEW, 2004).

Ease of use: Visual DOE which utilises the DOE-2 calculating engine provides graphical user interface for input and output processing, while energy-10 is easy-to-use. It automatically generates a base case and energy efficient alternate building descriptions. It also automatically applies energy efficient features and rank ordering of results.

Level of detail and output: Visual DOE performs hourly simulation of a building's energy consumption and energy cost given a detailed description of the building's climate, architecture, materials, operating schedules and HVAC equipment. Energy-10 also performs whole-building energy analysis for 8760 hours of the year, including dynamic thermal and day-lighting calculations. The output of Energy-10 provides detailed quantitative measures on the best combination of the physical components of the building parameters.

Accuracy: the accuracy of Visual DOE and Energy-10 has been demonstrated using the BESTEST procedure, developed within the International Energy Agency Solar Heating and Cooling Program(http://www.iea-shc.org/task34/index.html), which has been adopted by the U.S. Department of Energy and the international community as the accepted basis for verifying the credibility of computer simulation programs.

Case studies

Six existing office buildings, one conceptual design and a case model were used. The existing buildings were chosen based on the suitability and availability of information. These buildings were used for the performance benchmarking and developing the case model. Two of the benchmarked buildings (MEW-Bldg and BSE-Bldg) were used for further investigation. First, both buildings were used to examine the reliability of the developed weather data files in Chapter 5. Second, MEW-Bldg was used to calculate the OTTV standard in Chapter 4 and to implement the systematic methodology in Chapter 6. The conceptual design was used, in Chapter 7, as a case study to show the applicability of the performance sensitivity scale.

3.1.4 Interpreting the results

For evaluating the energy performance it is necessary to analyse the output profiles of the simulation programs because not all the outputs are relevant or suitable for the evaluation. Therefore, a number of analysis techniques were used in this study including:

- o Graphical methods
- o Statistical analysis
- o Sensitivity analysis

In addition to these techniques, a statistical test (two-tailed *t*-test) was used to know the similarities and differences between the developed weather data files.

Nature of *t*-test

The *t*-test is one of the most commonly used statistical data analysis procedure for hypothesis testing. A principal advantage of this test is ability to examine the equality of the means underlying each group and can be used even if the sample sizes are very small. The *t*-test simply tests whether or not two independent populations have different mean values on some measure. It allows one to answer this question by using the *t*-test statistic to determine a *p*-value that indicates how likely these results could be obtained by chance. The *p*-value is "the probability". The smaller the *p*-value, the more strongly the test rejects the null hypothesis, that is, the hypothesis being tested. 5% and 10% are common significance levels to which p-values are compared.

By convention, if there is a less than 5% chance of getting the observed differences by chance, the hypothesis is rejected. This test can be done by Microsoft "Excel". The hypothesis in this study is that the monthly electricity consumption results from simulating case buildings based on weather data generated from two weather periods have different values from the electricity bills of the case buildings. This is to find out which weather data make less difference when used in building simulation. This hypothesis is tested in section 5.3.3 of Chapter 5.

3.2 Closing Remark

The used methods and techniques provided the study with the means to obtain information and data at different stages. Document analysis and weather data generators were used to collect materials about the climate and buildings. This help to generate a weather data file, obtain a number of case studies and develop a case model. In general, the first stage served as a platform for the second stage, where climatic information coupled with building statistics used to calculate the OTTV standard and to benchmark the energy performance of the studied buildings. The generated weather data and the case buildings were served as inputs for computer simulation. By following a presented systematic procedure, a series of runs was carried out. Outputs from simulation programs were interpreted using various analysis techniques, including graphical methods, statistical and sensitivity analyses. In the next chapter, these techniques are used to investigate building energy standards and codes (BESC) in Bahrain and in selected countries.

Chapter 4 ENERGY STANDARDS AND CODES

Building energy standards can be very effective implementation strategies for electricity conservation in Bahrain...based on the compiled information, building energy standards should be developed in Bahrain.

(Akbari et al., 1996)

4.0 Introduction

A brief exploration was presented in Chapter 1 for the role that codes of practice can play to improve building energy efficiency in Bahrain, while in Chapter 2 a detailed description was introduced for the concept of building energy performance. Recently, the performance approach has been used in conjunction with building energy standards and codes (BESC). This chapter reviews the state-of-the-art of BESC for commercial buildings in Bahrain and in selected countries. Section 4.1 investigates the concept and types of BESC and highlights their differences and relationship. In light of this investigation, the current Bahrain energy regulation was explored and evaluated, in section 4.2. Section 4.3 casts light on BESC in the United Kingdom and Hong Kong. Two types of BESC were examined in this chapter: first, the Overall Thermal Transfer Value (OTTV) in section 4.4.1 and second, the energy performance benchmarks in section 4.4.4.

4.1 Building Energy Standards and Codes (BESC)

4.1.1 Basic concept

Standards and codes are two terms used to express a mechanism of conserving energy in buildings. In practice, they are complementary, working together to provide the means for controlling building design and promoting more energy savings. Their meanings are interchangeable and sometimes confusion arises when energy efficiency in buildings is discussed. The next section makes a distinction between the two terms and briefly clarifies their meaning and relationship.

In general, a standard can be a document or part of a document containing a set of conditions to be fulfilled. This standard often serves as some kind of a common benchmark. In terms of energy, the standard is a technical document that benchmarks or standardises different aspects related to building energy design and operation such as quality or efficiency and sometimes size, procedure or activity (Nagrajann, 1976). A building code, on the other hand, is seen as a document used by an authorised body to control building practice and enforce energy efficiency in building through a set of statements of acceptable requirements of building efficiency (Walker, 1997). From the above perspective, standards and codes are different in terms of legal status. The former is a technical design guideline, while the latter has a legal role to ensure that the building will achieve a minimum expected level of efficiency. Therefore, the standard is a code when it has enacted into law by an authority (Huang *et al.*, 2003). From a technical point of view, however, standards and codes are the same.

The main objectives of this chapter are to examine the different approaches of building energy standards and to assess the various methodologies of codes reflected by energy regulations. This will be done with the aim of distilling experience that can help to improve the energy performance of buildings in Bahrain.

4.1.2 Building energy standards

There are two approaches of building energy standards: prescriptive and performance. The former is applied to the individual elements of a building or a system. The sole purpose of this approach is to set minimum design requirements for key energy use aspects in buildings (Deringer *et al.*, 2004). The latter is applied to a building or a system as a whole. The sole purpose of this approach is to set a target or a benchmark for the level of energy performance without prescribing the procedure and methods to achieve this benchmark (Chan & Yeung, 2005; Lam & Hui, 1996). For instance, the Bahraini code "Building Thermal Insulation", which is an envelope components thermal design method that considers the heat transfer through three components (external walls, roof and windows), is an example of the prescriptive standard, while the maximum allowable energy consumption of a building is a performance standard. The Bahraini energy code will be examined in more detail in section 4.2. The next section discusses the nature of prescriptive and performance standards.

4.1.3 Comparative discussion of energy standards

This section makes a comparison between the prescriptive and performance approaches in terms of purpose and implementation.

Prescriptive standard approach

This type of standard can be seen in the level of thermal insulation of building envelope and the HVAC and lighting systems efficiencies. It has been used for many reasons. The most important one is that the prescriptive standards are simple to use and relatively easy to implement. The use of prescriptive standards influences building loads in direct and indirect ways as can be seen in the impact of thermal insulation on cooling load and heating energy. However, their effect, in some cases, is uncertain and difficult to measure in terms of the building as a whole. In other cases, they come into conflict with one another due to incompatibility, because of which the performance of the building may be negatively effected (Baird *et al.*, 1983). This can be seen in the impact of thermal insulation on cooling load of internal load dominated buildings and the impact of window codes on lighting load.

Performance standard approach

Unlike the prescriptive standards, the performance approach concerns with the energy performance of the building as a whole. The concern of performance standards is the results not the method employed to achieve those results. The performance standards, therefore, focuses on what benchmarks a building performance is required to achieve, rather than specifying the method for achieving those benchmarks. Nowadays, the performance standards and benchmarks are becoming increasingly important. Many researches have been carried out to establish energy benchmarks (Chung *et al.*, 2006; Filippin, 2000; Lee, 2001; Kamaruzzaman & Edwards, 2006). According to the Chartered Institution of Building Services Engineers (CIBSE, 2004) the performance benchmarks can be set by following two methods:

- Benchmarking by design: this method is related to the design stages where benchmarks can be predicted by simulation program. This will be illustrated in Chapters 6 and 7.
- Benchmarking by practice: this method is related to the in-use buildings where benchmarks can be set by monitoring the energy consumption of best and standard practice buildings. This will be shown in section 4.4.4.

Energy benchmarks are normally set in the form of performance indices such as ($kWh/m^2/yr$). With the emphasis on sustainability, these indices are set in terms of CO_2 emissions ($kgCO_2/m^2/yr$). In practice, performance benchmarks are very useful tools in the process of encouraging low energy designs. However, they are difficult to enforce, without enforcement, they may ineffective.

Enforcement and codes of compliance

Similarly, building energy codes are complied on a prescriptive basis (e.g., identifying whether specific prescriptive components of the codes such as thermal insulation was installed to a particular level) or a performance basis (e.g., comparing the energy use with energy benchmarks required by building codes). In many cases, with both approaches, mandatory measures, criteria and evaluation methods are included (Vine, 1996). They are fundamental issues which must be satisfied, as will be explained in the acceptable U-Value in part L2 of the UK regulations. However, this is not the case in the Bahraini building energy regulations. The next section discussed the BESC in Bahrain.

4.2 Status of BESC in Bahrain

4.2.1 Development of the codes

In Bahrain energy regulations virtually did not exist prior to the mid 1990s. They were created by the government as one of many policy instruments in response to the new economic and political situations. In 1997, the government set up a National Committee of Buildings in Bahrain (NCBB) to advise on the best possible ways to conserve electric energy in buildings. The committee recommended the thermal insulation as the most suitable and practical energy code with respect to the current situation of Bahrain (NCBB, 2002). A final report of the Bahrain national building codes was first introduced in 1998 with the overall aim of maintaining minimum standards for electric energy efficiency within buildings. In theory, every new building in Bahrain now meets the Article-32 requirements which by themselves are mandatory requirements that must be satisfied before a building is allowed to be built. However, there is no practical method for evaluating and verifying the impact of Article-32 on the overall energy consumption of buildings with different types and functions.

It has been almost a decade since the inception of Bahrain energy codes. However, neither have those codes been developed nor have evaluation or verification methods been implemented, although the current trend of efficiency supports the introduction of new codes and development of methods. The current trend in BESC, as will be seen in section 4.3, suggests that a comprehensive approach, not limited to building envelope components, would be more effective. In the next sub-sections, the philosophy of Article-32 is discussed and its impact on building energy performance is evaluated.

4.2.2 Philosophy of the codes

Reference was made in section 2.3.2 to the meaning of cooling load. It was stated that the cooling load is the sum of external and internal heat gains. Cooling load can be expressed as:

$$Q = Qs + Qg \tag{4.1}$$

where Q is the cooling load (W), Qs, outdoor solar and conductive heat gains (W), Qg, indoor heat gains (W)

For reducing the cooling load it is necessary to reduce the external and internal heat gain. In Bahrain Article-32 has recognised the important role that thermal insulation plays to prevent or, at least, to reduce the amount of conductive external heat gain by setting a maximum standard for thermal transmittance value (U-value). Basically, thermal transmittance is the rate of heat (W) transferred through a square metre of the building envelops per ^{o}C temperature, and can be expressed as:

$$U = \frac{1}{R} \tag{4.2}$$

where *U* is the thermal transmittance (W/m^2.°C), and *R*, thermal resistance of heat transferred through a square metre of the building envelops (m^2.°C/W).

Article-32 considers the maximum U-value for two elements of building envelope. For roofs and walls these are 0.6 and 0.75 W/m^2.°C respectively. However, there are no mentioned values for floors and windows. The regulation allows the use of single glass in buildings with an area of glazing less than 20% of the facade. When the area exceeds this percentage, the regulation obligates the use of double glazing. In order to comply with Article-32 the U-value and window area calculations are required to be included in the submission of building plans for approval. The requirements are applicable to all buildings without any reference to the type, design, use and schedules. The only criterion is that the walls and roofs of new and retrofitted constructions with more than three storeys should be insulated to the level mentioned above.

4.2.3 Main critical issues of the codes

Having a clear understanding of the current energy codes in Bahrain and their limitations will help to establish a platform for their effective use and future development. In general, the envelope components codes are simple and easy to apply. They influence the heat flow through building boundaries. However, there are some deficiencies that can be found in Article-32.

- ☞ First, the sole purpose of Article-32 is to measure the thermal performance of the envelope in air-conditioned buildings. In general, several elements must be considered to ensure the optimum thermal performance of building envelope. These are U-Value or its reciprocal the R-value, thermal mass, air-tightness and moisture tolerance. In the Bahraini codes, however, the three latter elements have been neglected. The most attention has been paid to the R-Value. It takes the form of steady state clear R-Values. *Clear R-Value reflects only the wall area containing thermal insulation and the structure elements belong to this area (no corner or connection with other envelope elements).* Considering such R-value may put the accuracy to assess the envelope thermal performance in question, simply because the thermal disturbances area caused by wall elements (e.g. wall corner, window header, door header, etc.) may reach more than half of the concrete wall (Kosny *et al*, 1994). These elements can reduce the overall value. However, some of them have a higher R-Value, from which the overall R-value may be increased. Technically, this method is neither accurate in reflecting the R-value of the whole wall, nor is it sufficient to estimate the dynamic behaviour of complex envelopes of high mass materials such as those used in Bahrain. For an accurate analysis a whole wall R-Value is required, and advanced simulation programs that can estimate thermal loads and analyse energy performance on an hourly basis are needed (Al-Rabghi & Hittle, 2001).

☞ Second, as it was originally developed to keep heat within buildings when the outside is cold, the U-Value and R-Value calculations ignore the direct impact of solar radiation on the envelope of air-conditioned buildings (Stein *et al.*, 1986).

☞ Third, as reviewed in section 2.1.2, the impact of building envelope codes on cooling energy use is dependent on climate, schedules of operation and certain features related to thermal insulation such as the orientation of the wall, the thickness of insulation and its position relative to the mass. The current codes, however, are applicable to all buildings without any reference to the type, activity, design, use and schedules of operation. The only criterion is that the walls and roofs of new and retrofitted constructions with more than three storeys should be well-insulated, or at least, insulated to the level mentioned above. As a consequence, the codes can be into conflict with the internal heat gains, which are the dominant source of heat in internal load dominated buildings such as offices.

☞ Fourth, Article-32 disregards the other aspects of building thermal performance such as systems and services components

☞ Fifth and finally, the Bahraini codes are prescriptive in nature, and critics state that the use of these codes, particularly the window area, is limiting the freedom of architects and restricting innovation in building design.

In light of the aforementioned deficiencies, it is clear that the use of the envelope components codes regulated by Article-32 alone to improve the thermal performance is inadequate because they cannot guarantee the optimum energy design for complex building envelope nor are they able to ensure the efficient use of energy by building services. Therefore, it is possible to say that Article-32 is limited and restrictive.

It is often said that a good knowledge and experience of how regulations work in other countries is a useful way of predicting local trend. In order to develop the BESC in Bahrain the following section casts light on the recent BESC trends in two representative countries, namely the United Kingdom and Hong Kong.

4.3 Light on Recent BESC

The United Kingdom was selected as an example of developed countries, while Hong Kong was selected as a developing country. The selection of the UK was because that the current energy codes in Bahrain are partly based on the experience and methodology of the Department of the Environment and Welsh Office (1995). Hong Kong was selected because the OTTV is an area of interest.

4.3.1 AD Part L2 of building regulations in the UK

The first interest of BESC in the UK was reflected by the use of thermal insulation with the purpose of maintaining minimum standards of health and comfort in domestic buildings. Recently, this purpose has extended to include the conservation of energy in new and retrofitted domestic and commercial buildings. With the European Union Energy Performance Building Directive (EPBD) and the UK's additional desire to reduce greenhouse gases under the Kyoto protocol, reducing the CO_2 emissions has been utilised with the conservation of energy (Moss, 2006).

As far as the BESC of office buildings are concerned only the approved Document (AD) Part L2 will be studied. The general purpose of this part is to reduce the greenhouse gases, notably the CO_2 emissions by 60% by 2050 related to 2000.

To ensure that the objectives of the BESC are achieved Part L2 controls certain areas of building design and performance (CIBSE, 2006a; CIBSE, 2006b):

- Heat transmission through the fabric of buildings
- Air leakage of building shell
- Space heating and hot water
- Heat transmission from vessel and pipes used for hot water and from hot air duct for space heating
- Energy efficient internal and external systems

The advantage of the AD Part L2 is the flexibility given to the building designer to comply with the regulations. Part L2 provides a number of options. Basically, there are two approaches reflected by three methods for demonstrating that a building meets the requirements of the regulations. The first approach sets criteria for building design in order to achieve a certain performance. The second approach measures the energy performance with different scale. With each approach, certain mandatory requirements always apply. These requirements must be met with any of the following method:

Elemental method

This method specifies certain requirements for the building envelope and systems. Such requirements are the maximum U-values for the opaque and transparent parts of building shell and the percentage of their maximum combined area. Table 4.1 illustrates the maximum allowable U-value for the shell components. This method also specifies the minimum level of efficiency for building systems such as boilers, fans and chillers. Coupled with this are mandatory requirements to avoid thermal bridge and air leakage. Some flexibility is provided by allowing trade-off between the elements of the envelope and building systems. However, the performance level obtained should not be worse than that of a notional building[1]of the same size and shape. In practice, this method does not require complex calculation because each aspect of the building is considered individually. Therefore, a minimum level of efficiency must be achieved in each element. The main drawback of this method seems to be the limited scope given to building designer.

Table 4.1 Maximum allowable U-Values for the envelope components (Waters, 2003)

Type of shell components	Maximum allowable U-Value
Flat roof	0.25 W/m^2K
Floor	0.25 W/m^2K
Window/door (metal)	2.20 W/m^2K
Window/door (wood)	2.00 W/m^2K
Roof-light	2.20 W/m^2K
Wall	0.35 W/m^2K

Whole building method

Unlike the elemental method, the whole building method gives much freedom to the building designer. With some requirements such as those involved with thermal bridge and air leakage, this method specifics a benchmark for the overall energy performance either in terms of maximum energy consumption or in terms of the total CO_2 emissions without prescribing the process, materials and methods to be employed to achieve this benchmark. For example, an office building can be treated by means of the whole office energy consumption level or the amount of CO_2 emissions due to the energy consumption. Once this has done, the result is compared to established benchmarks. Table 4.2 shows energy benchmarks for office buildings.

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[1] A clone of the building with respect to design, occupancy and plant operation, but is subject to energy codes.

Table 4.2 Energy benchmarks (CIBSE, 2004)

Fossil and Electricity Building Benchmarks

Building type		Good practice ($kWh/m^2/yr$)		Typical practice ($kWh/m^2/yr$)		
		Fossil fuels	Electricity	Fossil fuels	Electricity	Basis of benchmark
Air-conditioned	Prestige	114	234	210	358	Treated floor area
	Standard	97	128	178	226	Treated floor area

Carbon emission method

This method is said to be the most flexible one among the others. To comply, the annual CO_2 emitted from the proposed building should be no greater than those from an equivalent notional building that satisfies the criteria of the elemental method. Although the calculation procedure in this method is simple, in some cases, it requires an aid from a simulation program such as iSBEM (Building Research Establishment, 2005).

4.3.2 Performance–based building energy codes in Hong Kong

In Hong Kong although building energy efficiency activities began in the early 1980s, the first draft on BESC was introduced after 1991. It took the form of the OTTV handbook which became active in 1995. More recently, four other codes for building services (lighting system, air-conditioning system, electrical system and lifts and escalator codes) have been included (Chan & Yeung, 2005; Hui, 2000). Over the last few years, Hong Kong has moved towards performance codes which consider the performance of the building as a whole.

Although the main concern of this chapter is the overall energy performance of buildings, it will be recognised that this performance is subject to a range of individual parameters. Therefore, before studying the latest building energy codes in Hong Kong, the following paragraph shall briefly examine the OTTV standard.

Overall Thermal Transfer Value (OTTV)

The so-called OTTV or the Overall Thermal Transfer Value originated from ASHRAE for the legislative control of building envelope design. According to this standard, buildings are required to be designed and built in a way which prevents aggregated heat gains for air-conditioned buildings from exceeding permitted levels (Rumsey & Flanigan, 1995). In the case of Hong Kong, the OTTV is a measure of the amount of heat gain through the building envelope over an entire year. It is seen as a scale to gauge and compare the thermal performance of buildings, thus the larger the OTTV the more heat gain (Chow & Yu, 2000; Hui, 1997). Basically, there are three components that play the main role in the OTTV equation:

- Conduction through opaque walls and roofs
- Conduction through windows
- Solar radiation through windows

In practice, the OTTV is divided into two sets: first, wall thermal transfer value (WTTV) and second, roof thermal transfer value (RTTV). Both of these sets are calculated using the same equations.

$$OTTV = \frac{Qwc + Qgc + Qsol}{Ai} \tag{4.3}$$

where Qwc is rates of heat conduction through opaque walls (W), Qgc, heat conduction through window glass (W), $Qsol$, solar radiation through window glass (W), Ai, gross area of building walls (m^2)

Clearly, the OTTV standard considers all the thermal parameters of building shell. The concept also seems simple and easy to implement. Using this kind of standard was important for many developing countries, such as Hong Kong, which, to a large extent, did not have enough experience to apply and enforce complicated BESC. Gaining experience in BESC has led Hong Kong to move towards the whole building energy performance codes, where the OTTV is only one parameter that can be adjusted and manipulated with other parameters in order to achieve the highest energy performance of buildings.

Performance-based building energy codes

It follows from the above that to promote and ensure the energy efficiency in buildings the prescriptive and performance standards should be considered together. From this perspective, various BESC have been integrated into Hong Kong regulations, including building envelope (OTTV), HVAC system, lighting system, electrical installation, lifts and escalators and water heating system (EMSD; 2005; EMSD, 2003). The main purpose of this combination is to promote efficient use of energy in buildings and to encourage innovative approach to achieve high building energy performance. Each of these codes provides criteria and minimum standards for one or more aspects of energy performance. However, a general criterion is provided through the whole building energy consumption and cost.

Compliance methods

The benefits of the new developed codes are reflected by the large scope that has been provided to building designers to comply with the regulations. Fig 4.1 illustrates the general framework of compliance methods and the major building components. There are two levels. The first is fundamental basic requirements which must be satisfied before going to the second level. In the second level, there are two approaches. The former is a prescriptive approach with specific requirements for each component, while the latter is a performance approach with two options of compliance including energy consumption and energy cost (budget).

The compliance with the prescriptive approach requires following certain specifications for the design and the performance of building components. The performance approach requires the calculation of energy consumption and the cost of the proposed design. The consumption or cost then is compared against a total energy consumption or budget of a reference design (a notional building in the case of Part L2 in the UK). Since the calculation of energy consumption is a complicated process, it is usually done with the aid of computer simulation programs such as BLAST, DOE-2, Energy Plus, ESP-r, Hap or Energy-10.

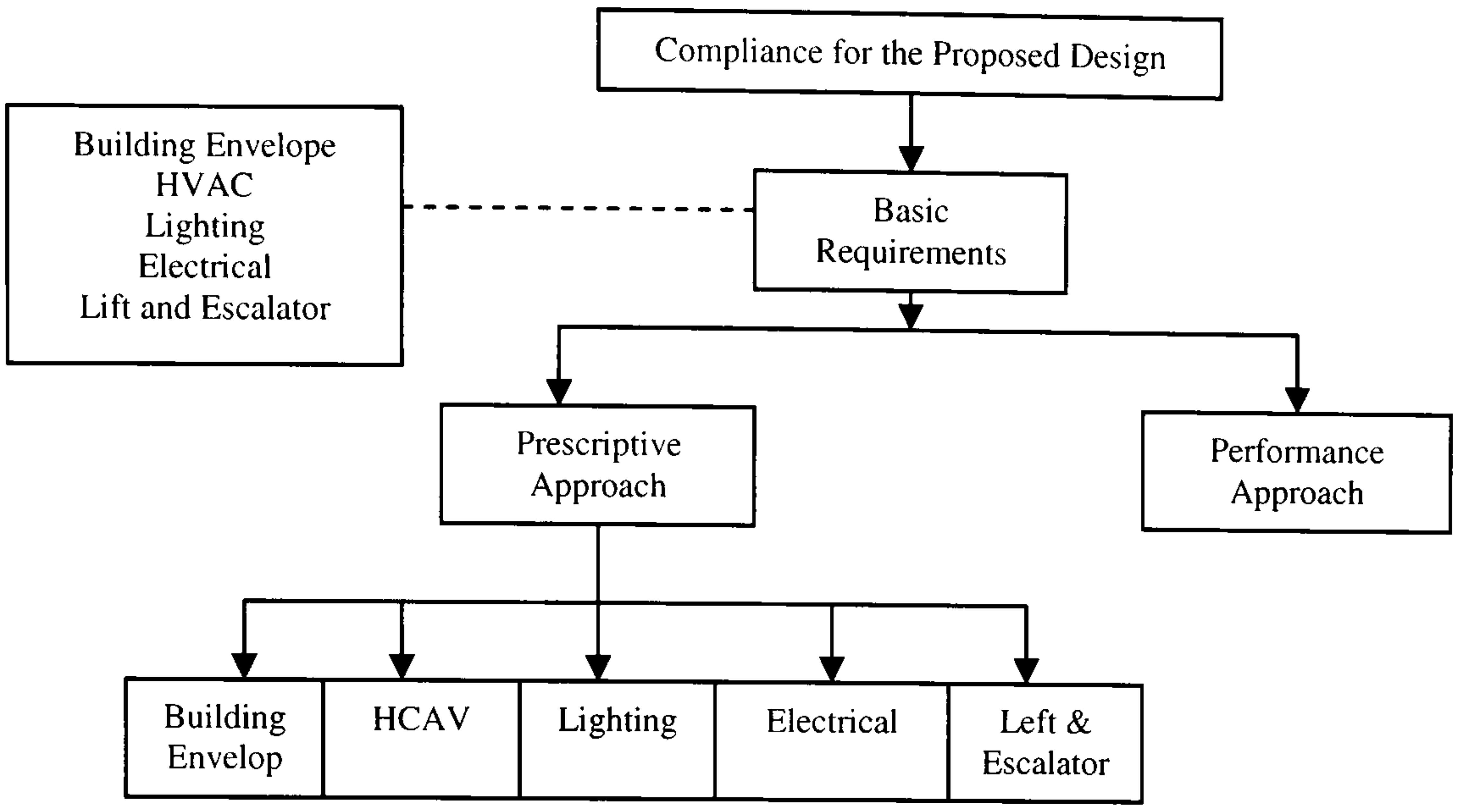

Figure 4.1 General framework of compliance methods
(EMSD, 2005)

4.3.3 Lesson learned

Based on the above, there are two approaches for BESC: prescriptive and performance. The prescriptive approach, on one hand, is simpler to comply with where each building component is passed separately from the others, and the requirements often contain required maximum or minimum values in order to enable the proposed design to meet specific energy efficiency criteria. However, if the design fails to meet even one requirement, then the component does not comply with the standards. Above all, this approach limits the freedom of the building designer and gives less flexibility for architectural innovation as can be seen in the elemental method of the UK regulations.

On the other hand, the performance approach provides greater flexibility to the building designer for choosing alternative energy efficiency measures since it considers in its evaluation the energy consumption, CO_2 emissions or the energy cost for the building as a whole. This can be seen in the whole building method in the UK and the performance-based building energy codes in Hong Kong. The performance approach also tries to combine several parameters and provides trade-off among them. It gives a better opportunity for the integration of various BESC. However, compliance through this approach will need to study and estimate the likely consumption levels based on the integrated performance of the building concerned. This may lead to making the calculation more complicated (Waters, 2003). Sometimes, as in the case of the UK and Hong Kong, computer programs are used to simulate the building performance in order to calculate the energy consumption and to estimate the CO_2 emissions.

4.4 Implication for Bahrain

After having raised the issue of BESC development and methods related to compliance with building energy regulations, the next task is to examine the most applicable approach for developing BESC in Bahrain. The main thrust of the research into BESC as described in this chapter is to enable the understanding of the outcome of performance approach, but section 4.4.4 will also expand in more detail on how likely to establish energy benchmarks for office buildings in Bahrain.

4.4.1 Energy performance standards for building envelope

As stated earlier, the overall energy performance of buildings largely depends on a number of individual parameters such as the building envelope, mechanical system and lighting systems. Therefore, different BESC are set to reduce the building loads, particularly the cooling load due to its significant impact on the overall energy consumption. For a country with little experience in BESC, like Bahrain, reducing the cooling load by setting envelope performance standards may represent the first step towards performance standards for the building as a whole.

In equation (4.1) it was shown that to reduce the cooling load it is necessary to decrease the amount of external and internal heat gains. The text below examines the use of the OTTV to control the amount of external conductive and radiative heat gain through the building envelope. This method was chosen among many others because of its simplicity and the ease of implementation considering the situation of Bahrain. Although the OTTV and the thermal transmittance concept aim to the same target, the OTTV may represent a better performance index than the U-value because it takes into account the impact of direct solar heat gain on the envelope of air-conditioned buildings (McDowell, 2006; Yik & Chan, 1995). In general, there are four major parameters impacting the amount of external heat gains (CIBSE, 2006b; CIBSE, 2003):

- o Conductive heat gain through building shell
- o Solar heat gain through glazing
- o Shading devices
- o Infiltration

The OTTV concept accounts only for the first three parameters. With reference to equation (4.3) the OTTV can be expressed as:

$$OTTV1 = \frac{(Aw \times Uw \times TDeq) + (Af \times Uf \times \Delta T) + (Af \times SC \times SF)}{Ai} \qquad (4.4)$$

where *OTTVi* is the OTTV for wall or roof, *Aw*, area of opaque wall (m^2), *Uw*, U-value of the opaque wall ($W/m^2.^oC$), *TDeq* [2], equivalent temperature difference (^oC), *Af*, area of fenestration (m^2), *Uf*, U-value of fenestration ($W/m^2.^oC$), ΔT, temperature difference between interior and exterior (^oC), *SC*, shading coefficient of fenestration, *SF*, solar factor of fenestration (W/m^2), and *Ai*, is the gross area of the walls (m^2).

To emphasis the role of solar gain through the transparent part and to give more consideration to the window-to-wall ratio (WWR) equation (4.5) can be used instead (Lam, 2000):

$$OTTV = [(1 - WWR) \times TDeq \times Uw] + [WWR \times \Delta T \times Uf] + [WWR \times SC \times SF] \qquad (4.5)$$

This equation calculates the OTTV first for individual walls in each orientation. This is because walls in different orientations receive different amount

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[2] TDeq is the temperature different equivalent between outside and inside of the building, including the absorption of solar ray by solid walls and roofs

of solar radiation. The OTTV for all walls in the building then can be calculated according to the following equation:

$$OTTVwall = \frac{\Sigma(OTTVi \times Ai)}{Adw} \tag{4.6}$$

where $OTTV_{wall}$ is the OTTV of the whole exterior wall (W/m^2), Σ(Ai), the total gross exterior area of the walls of the building (m^2) and *Adw* is the gross area of doors and windows.

The procedure of calculating the OTTV for roofs (RTTV) is similar to that of the walls (WTTV). However, the RTTV is often more simpler than the WTTV because in many cases the roof has a smaller area of glazing and in some cases does not have any.

4.4.2 Calculation of the OTTV for buildings in Bahrain

For the purpose of this calculation the MEW-Bldg described in section 6.3.1 of Chapter 6 was used. The calculation of the OTTV followed equation (4.5). To calculate the OTTV for the studied building this section precedes by introducing three important parameters: temperature difference between outdoor and the indoor (ΔT), solar factor (SF) and equivalent temperature difference (TDeq).

Temperature difference (ΔT)

A study to the standards for air-conditioners in Bahrain (Ministry of Commerce, 2003) indicated that the air-conditioning systems should maintain an indoor temperature between 24°C and 27°C. Therefore, 27°C can be assumed to be the border between the cooling and non-cooling need. Furthermore, a result of 10 years analysis of weather data (see Chapter 5) shows that during the six months from May, where the cooling season starts, to October, where the cooling season ends, the ambient temperature exceeds 27°C, as can be seen in Fig. 4.2. For the cooling seasons 32.9°C was found to be the average of the outside temperature, while 25.5°C was calculated as the average of the indoor temperature. As a result, the difference between the outdoor and the indoor temperatures is 7.4°C.

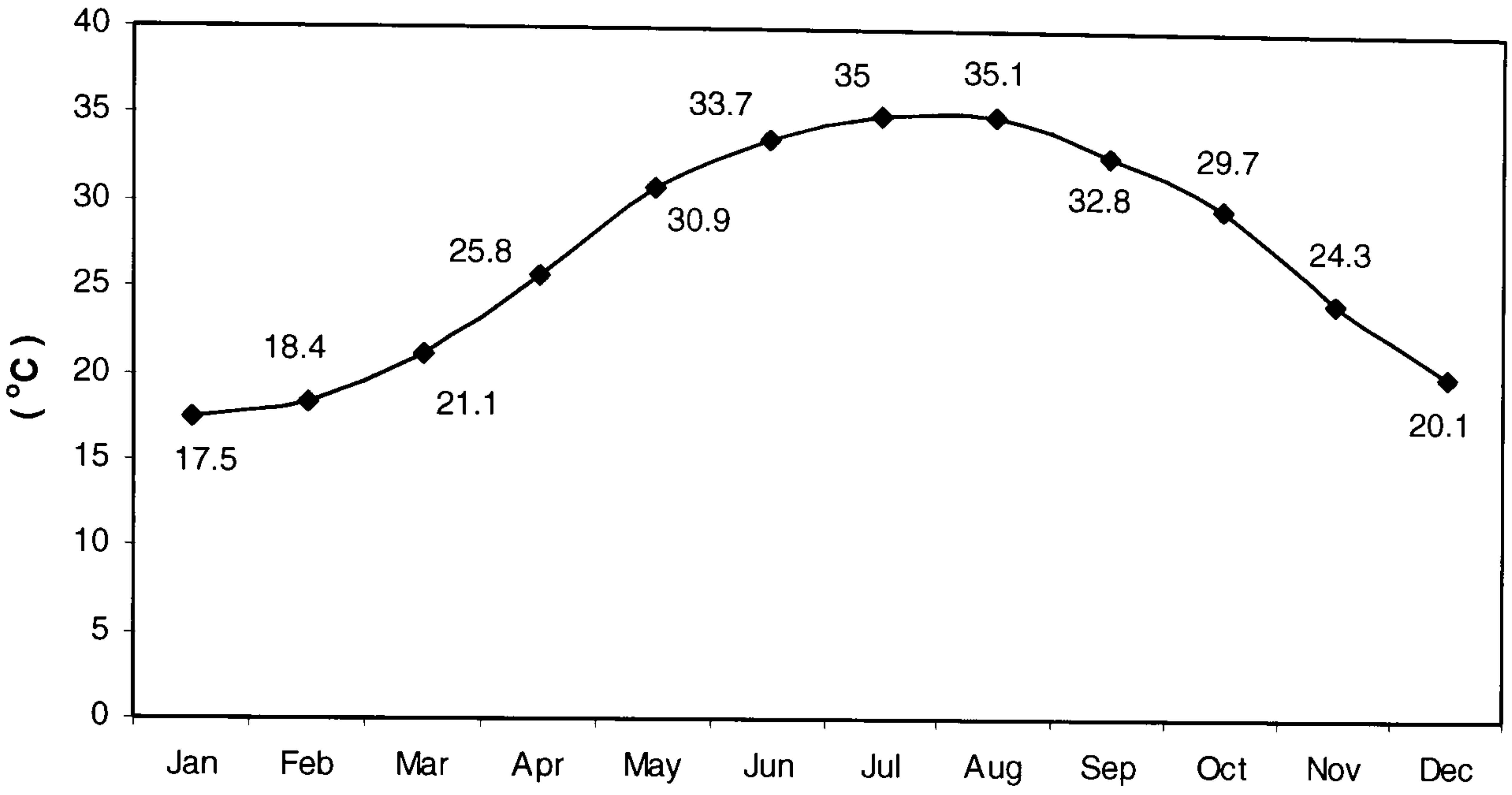

Figure 4.2 Mean monthly temperature in Bahrain (airport)

Solar factor (SF)

Most sites in Bahrain receive the same amount of solar radiation (Alnaser & Al-Attar, 1999). This is due to the small area of Bahrain. The climatic conditions of Bahrain are discussed in chapter 5. The estimation of solar radiation indicates that the average monthly value on the horizontal surface is 473.3 W/m^2. Fig. 4.3 shows the behaviour of solar radiation during different time of the year. For the solar radiation on vertical surfaces MeteoNorm was used to calculate the values for the four directions as shown in Table. 4.3.

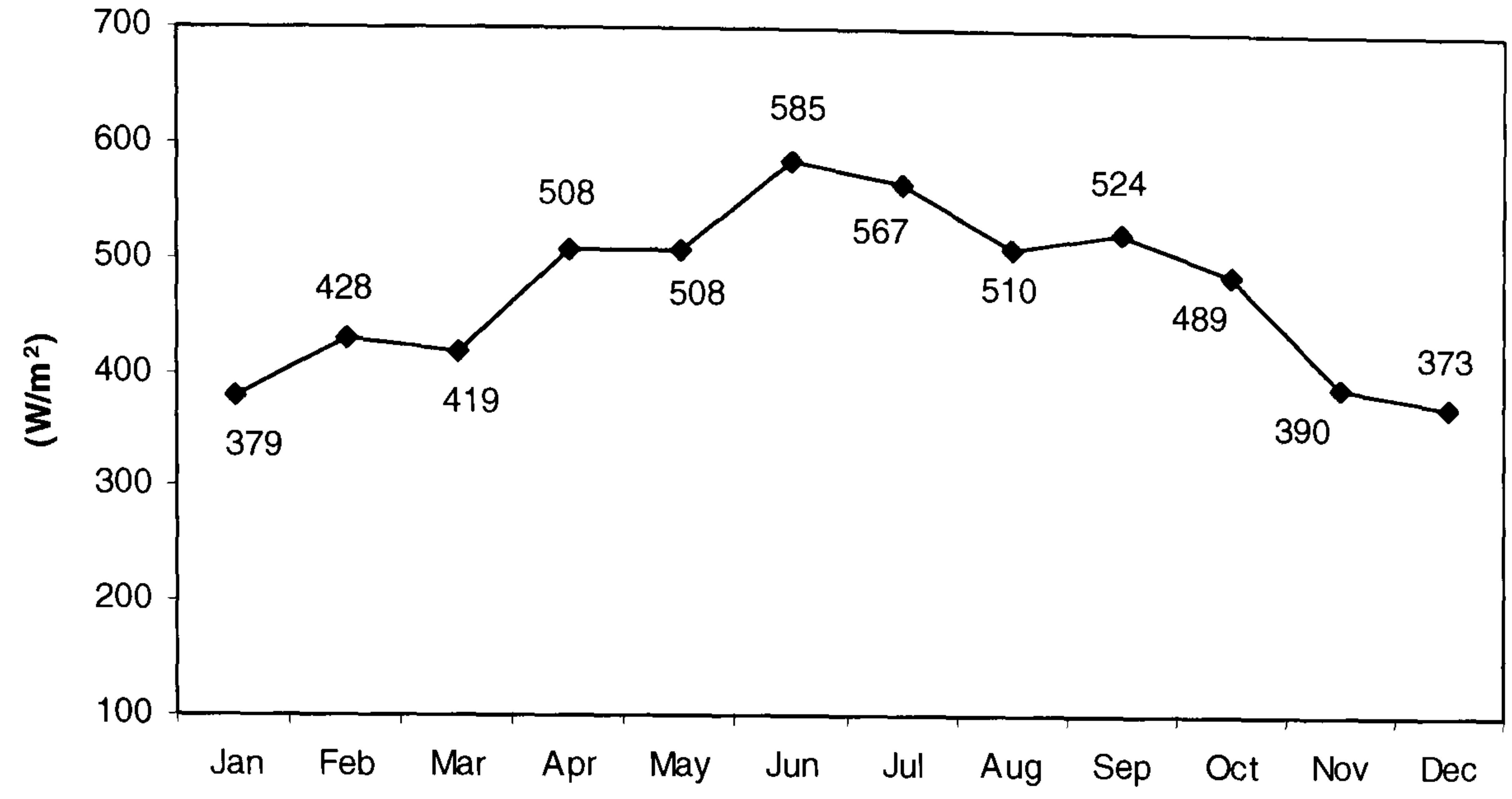

Figure 4.3 Average monthly global solar radiation on horizontal surfaces in Bahrain (Alnaser and Al-Attar, 1999)

Table 4.3 Average monthly global solar radiation on vertical surfaces in Bahrain (MeteoNorm)

Month	Horizontal (W/m^2)	East (W/m^2)	South (W/m^2)	West (W/m^2)	North (W/m^2)
Jan	379	227	462	232	95
Feb	428	259	422	255	101
Mar	419	240	283	244	96
Apr	508	278	206	287	114
May	508	275	135	280	143
Jun	585	311	122	308	181
Jul	567	475	203	445	258
Aug	510	287	178	283	127
Sep	524	287	297	289	120
Oct	489	291	420	304	118
Nov	390	232	450	234	94
Dec	373	226	480	226	99
Average	473.3	282	305	282	129

Equivalent temperature difference (TDeq)

TDeq focuses on two mechanisms: first, conduction heat gain due to the temperature difference between the indoor and second, the outdoor environment and the effect of solar radiation on opaque surfaces (e.g. external walls). It takes into account the heat storage in the mass (thermal inertia). It can be determined from:

$$Q = Uw \times Aw \times DTeq = Uw \times Aw(Teo - Tai) \tag{4.7}$$

where Q is the heat gain through opaque wall (W/m^2), Uw, U-Value of the wall (W/m^2.°C), Aw, Area of the wall (m^2), Tai, inside temperature (°C), and Teo is the sol-air temperature (°C). The sol-air temperature is the fictitious temperature of the outdoor air which, in the absence of radiative exchanges on the outer surface of the roof or wall, would give the same rate of heat transfer through the wall or roof as the actual combined heat transfer mechanism between the sun, the surface of the roof or wall, the outdoor air and the surroundings. The sol-air temperature can be calculated from:

$$Teo = Tao + (Rso \times a \times It) \tag{4.8}$$

where Tao is the outdoor temperature (°C), Rso, the outside surface resistance (m^2.°C/W), a, the absorption coefficient of the wall surface which are 0.3 for light coloured surface, 0.6 for medium coloured surface, and 0.9 for dark coloured surface, and It is the solar intensity (W/m^2).

As stated, 32.9°C is found to be the average of the outside temperature for the cooling months from May to October. 0.030 and 0.059 are the outside resistance of the roof and wall respectively and 0.6 is the absorption coefficient. Therefore, the sol-air temperature for Bahrain is:

$$TeoRoof = 32.9 + (0.030 \times 0.6 \times 473.3) = 41.4°C$$

$$TeoWall - east = 32.9 + (0.059 \times 0.6 \times 282) = 42.8°C$$

$$TeoWall - south = 32.9 + (0.059 \times 0.6 \times 305) = 43.7°C$$

$$TeoWall - north = 32.9 + (0.059 \times 0.6 \times 129) = 37.5°C$$

$$TeoWall - west = 32.9 + (0.059 \times 0.6 \times 282) = 42.8°C$$

As highlighted earlier, the TDeq is (Teo – Tai). 25.5°C is determined as the average of the indoor temperature (set point temperature). Then, the TDeq for roof is found to be15.9°C, while the TDeq for walls is found to be 17.3, 18.2, 17.3 and 12°C for the west, south, west and north walls respectively. Using the obtained results and equation (4.5) the OTTV for the roof and walls are calculated as:

$$OTTV_{Roof} = [(1-0) \times 15.9 \times 0.53] + 0 + 0$$

$$OTTV\ east = [(1-0) \times 17.3 \times 0.63] + 0 + 0$$

$$OTTV\ south = [(1-0.8) \times 18.2 \times 0.63] + [0.8 \times 7.4 \times 2.78] + [0.8 \times 0.5 \times 305]$$

$$OTTV\ west = [(1-0) \times 17.3 \times 0.63] + 0 + 0$$

$$OTTV\ north = [(1-0.8) \times 12 \times 0.63] + [0.8 \times 7.4 \times 2.78] + [0.8 \times 0.5 \times 129]$$

The OTTV for roof is 8.4 W/m^2, while the OTTV for walls ranges from 10.9, 140.8, 10.9 and 70.4 W/m^2 for eastern, southern, western and northern walls respectively. The results indicate that there is a big difference between the roof and walls' values. This difference is due to two main reasons: firstly, the thermal insulation of the roof is higher than in the walls and secondly, there is no glazing in the roof and in the eastern and western facades. The calculation shows that the impact of thermal insulation is not significant, while the glazing parameters, particularly the WWR and SC, play the major role in reducing the value of external heat transmission in such type of building (skin load dominated buildings, see section 6.3.2) and, therefore, should be given a large consideration in building thermal design. It is interesting to note that this building was subject to the benchmarking process in section 4.4.4, and the result benchmarked this building as a poor energy performer due to the large amount of external heat gain.

4.4.3 Evaluation of the OTTV with respect to Bahrain

As seen, the OTTV represents an effective tool to prevent the aggregated external heat gain when a target level for the thermal performance of building envelope is set. It must be emphasised that considering this type of standard encourages the use of thermal design parameters such as orientation, shading device, thermal mass and glazing system along with the use of thermal insulation. However, is this enough to reduce the cooling load and energy consumption of buildings?

Given the sole purpose of the OTTV is to reflect the impact of the envelope on cooling load, and hence the calculation methods of this standard often follow the traditional calculation procedure of cooling load. Recently, the calculation methods for cooling load have changed and the Radiant Time Series (RTS) – see section 2.3.3 – method has taken place instead where response factors play a significant role in these calculations (ASHRAE, 2005). The RTS method, in general, emphasises the role of zone geometry reflected by the width and depth of the zone, height, internal partitions, ceiling, floors and internal mass. Compared with this procedure, the OTTV does not consider most of these elements.

Another critical point is the ignorance of building systems and internal heat gains which are the main source of heat in office buildings. Some recent studies (Yik & Wan, 2005) assumed that the impact of the OTTV standard is not significant on the cooling load of internal load dominated buildings. This is because the envelope heat gain is relatively small compared to the internal loads from occupants, lighting and equipment. The use of the OTTV standard in the skin load dominated buildings may represent a good control tool for external heat gain due to the low level of internal heat. One last critical point is prescribing the WWR which may put some restrictions for the architectural design. To avoid such restrictions the direct logical and practical step is to move towards the energy performance standards for the building as a whole.

4.4.4 Performance standards and energy benchmarks

As indicated in section 4.1.2, the sole purpose of the performance standard is to set a target or a benchmark for the level of performance without prescribing the method to achieve that benchmark. This section attempts to establish a source of guidance for benchmarking energy performance of office buildings in Bahrain. In general, there are two types of benchmarking: internal to find that a particular aspect of energy performance is able to perform more efficiently or comparative that attempt to compare the performance of a building against established benchmarks or against those buildings which are considered to be the best practice (McCabe, 2001). Both types play a significant role in improving the energy and environmental performance of buildings. By using the first type, it is possible to assess the performance of a building and to identify positive and negative energy design features in that building. The second type helps to compare the energy performance of buildings with similar types, functions, and occupancy patterns in order to evaluate the energy efficiency in the regional and national level.

A procedure for benchmarking office buildings in Bahrain

Setting benchmarks is a complicated process. It requires a systematic procedure to be followed for its execution. In recent years, several procedures have been introduced (Barley *et al.*, 2005; CIBSE, 2004; Deru & Torcellini, 2005; Mahlia *et al.*, 2002). The procedure presented in this section outlines the different stages of benchmarking and encompasses the level of detail necessary to standardise specific aspects in buildings. Fig. 4.4 shows the hierarchy of the benchmarking procedure.

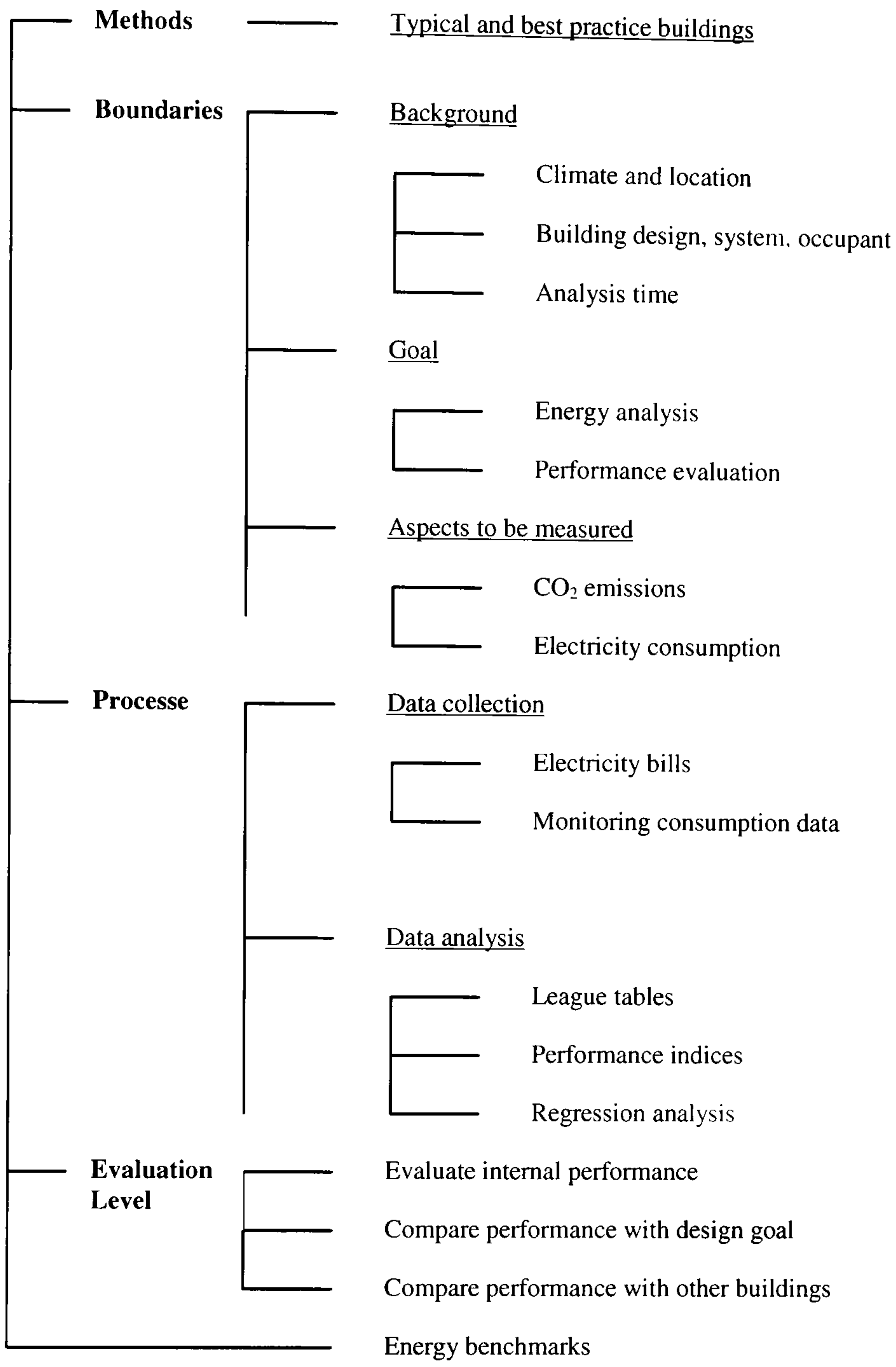

Figure 4.4 Hierarchy of benchmarking procedure

As illustrated, there are four overlapping levels. Each has its own tools and processes. These levels are briefly described below:

First level: the first level is the method which forms the foundation for the whole benchmarking process. As mentioned in section 4.1.3, there are two methods for setting energy benchmarks. In the current procedure energy benchmarks are set using the in-use standard and best practice buildings (CIBSE, 2004).

Second level: this level studies the boundaries of buildings: first, a building's background is investigated, including climate, building design and operation and the time of benchmarking. Second, the goals of the benchmarking (e.g., evaluating the energy performance or analysing the energy behaviour) are determined. Finally, the candidate aspects are specified. Examples of these aspects are energy consumption, energy cost and CO_2 emissions.

Third level: this level focuses on the process of data collection and analysis. There are many techniques that are used for data collection, namely, monitoring consumption data, calculating monthly consumption figures and calculating annual consumption figures. However, the choice of any of these techniques depends largely on the aspects to be benchmarked which are determined in the previous level. For analysing the obtained data some techniques are used such as performance indices and regression analysis. The choice of any of these techniques is subject to the desired outcome.

Fourth level: the last level is setting performance figures. These figures can be set for different purposes such as evaluating the internal performance, evaluating the building performance with respect to the design goals and comparing a building performance to other buildings and established benchmarks. These figures can be used to establish new benchmarks in different forms such as energy consumption, energy cost and CO_2 emissions. These benchmarks can be for each energy end use or for the building as a whole.

Procedure implementation

The illustrated procedure has been performed by Radhi and Sharples (2007) (see Appendix 1) to benchmark the environmental performance of office buildings in Bahrain. The following section uses this procedure to benchmark the energy performance of six representative buildings in Bahrain with respect to internal and regional levels. For the purpose of this benchmarking, detailed architectural, functional and operation data of buildings were obtained from working drawings and audit reports provided by the Electricity and Water Conservation Directorate of

Bahrain (EWCD, 2004a; EWCD, 2004b; EWCD, 2003a; EWCD, 2003b; EWCD, 2003c; EWCD, 2002a; EWCD, 2002b; EWCD, 2002c; EWCD, 1999a; EWCD, 1999b). It is important to mention that the accuracy of the obtained data was subject to the supervision of trained energy auditors.

To ensure a good representation of office buildings in Bahrain six office buildings were chosen after applying some criteria and data filters including building category, system types and operation schedules. As electricity is the only form of energy used for powering buildings in Bahrain (700 km^2), the source of energy and climate impact were given less consideration. The building category filter was applied to select only buildings with the same basic operation (office buildings). These buildings were chosen from different construction periods and different building types (high rise and low rise office buildings). The building system and operation schedules filter was applied to define the group of evaluation. For instance, the benchmarking process requires that the buildings must operate at least 60 hours per week which is normal for office buildings in Bahrain. This allows representative of the major typical class of office buildings in Bahrain to be obtained and the physical and operational characteristics of such offices to be analysed.

Performing the benchmarking

The architectural, functional, and operation characteristics of office buildings were studied in detail. The annual energy consumption were measured and analysed in each building. The technique used to assess building energy performance is the normalised performance index (NPI) in the form of kWh/m^2/yr. The NPI was multiplied by the conversion factor of electricity in Bahrain in order to estimate the CO_2 emissions index (CEI). The NPIs were first used as a technique to form a benchmarking table and then were compared to know the best and worst performing buildings.

Internal benchmarking

Table 4.4 shows the basic information of the benchmarked buildings. The consideration of local climate, occupancy patterns, the types of buildings and systems ensure the similarities between these buildings. Fig. 4.5 and Fig. 4.6 illustrate the monthly and annual electricity performance indices in the studied buildings. Although electricity consumption varies from one building to another due to the difference in size, it is clear that the electricity consumption increase in the six hottest months from May to October. August is at the top with an energy consumption ranging from 30 kWh/m^2 for the HRA-Bldg to 75 kWh/m^2 for MEW-Bldg. The lowest consumption occurs in December and January, ranging from 11 and 6 kWh/m^2 for HRA-Bldg to 64 and 67 kWh/m^2 for MEW-Bldg.

Table 4.4 Description of offices under study

Building	Status	Floor	Total floor area (m^2)	Construction date	Occupancy (m^2)/person
ST-Bldg	Private	15	585	1997	25
MEW-Bldg	Public	12	800	1984	23
AFS-Bldg	Private	9	508	1982	21
Bldg-05	Public	3	1500	1986	17
BSE-Bldg	Public	2	765	1990	32
HRA	Private	2	400	1985	25

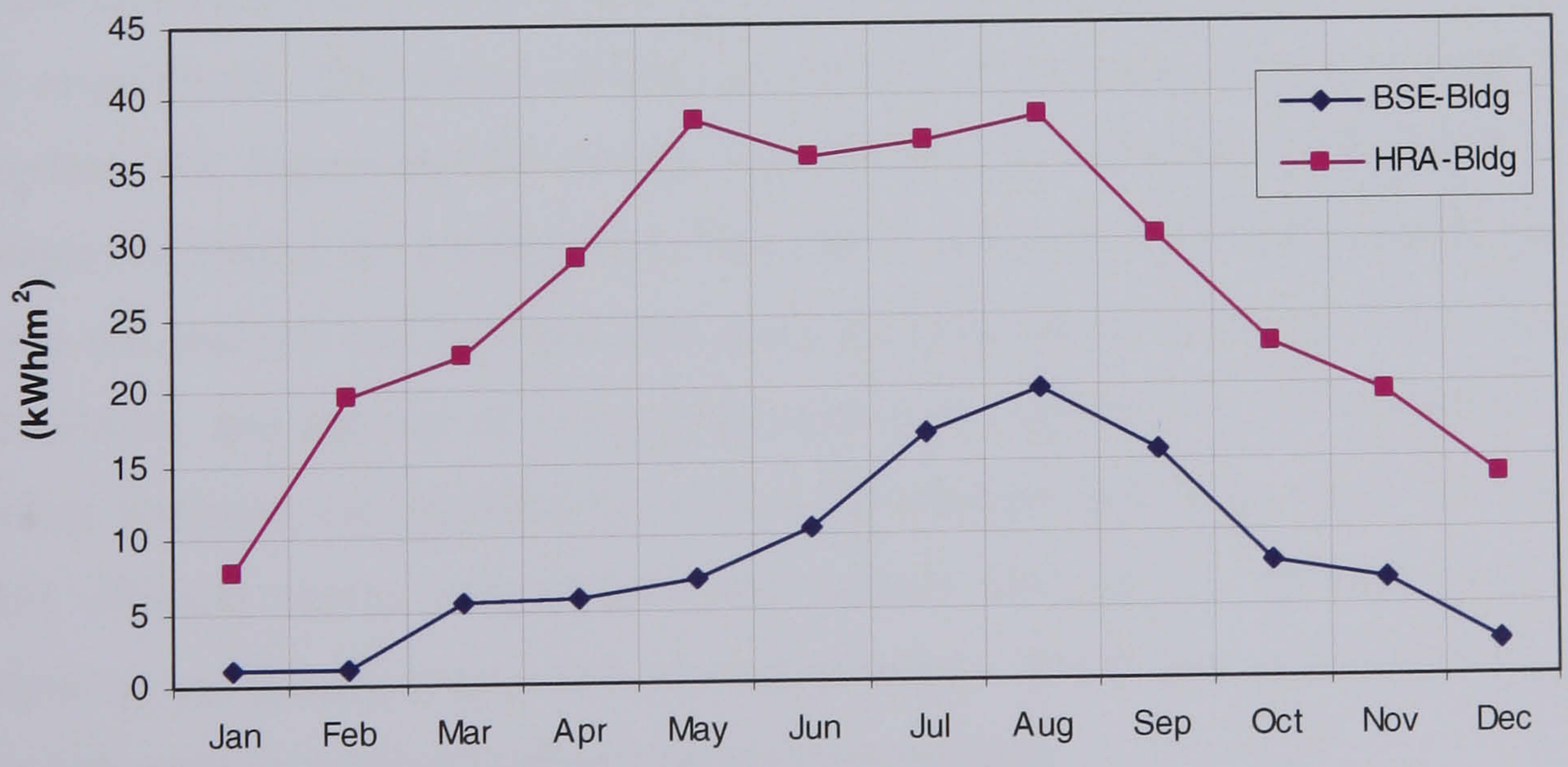

Figure 4.5 Monthly energy indices – BSE-Bldg & HRA-Bldg

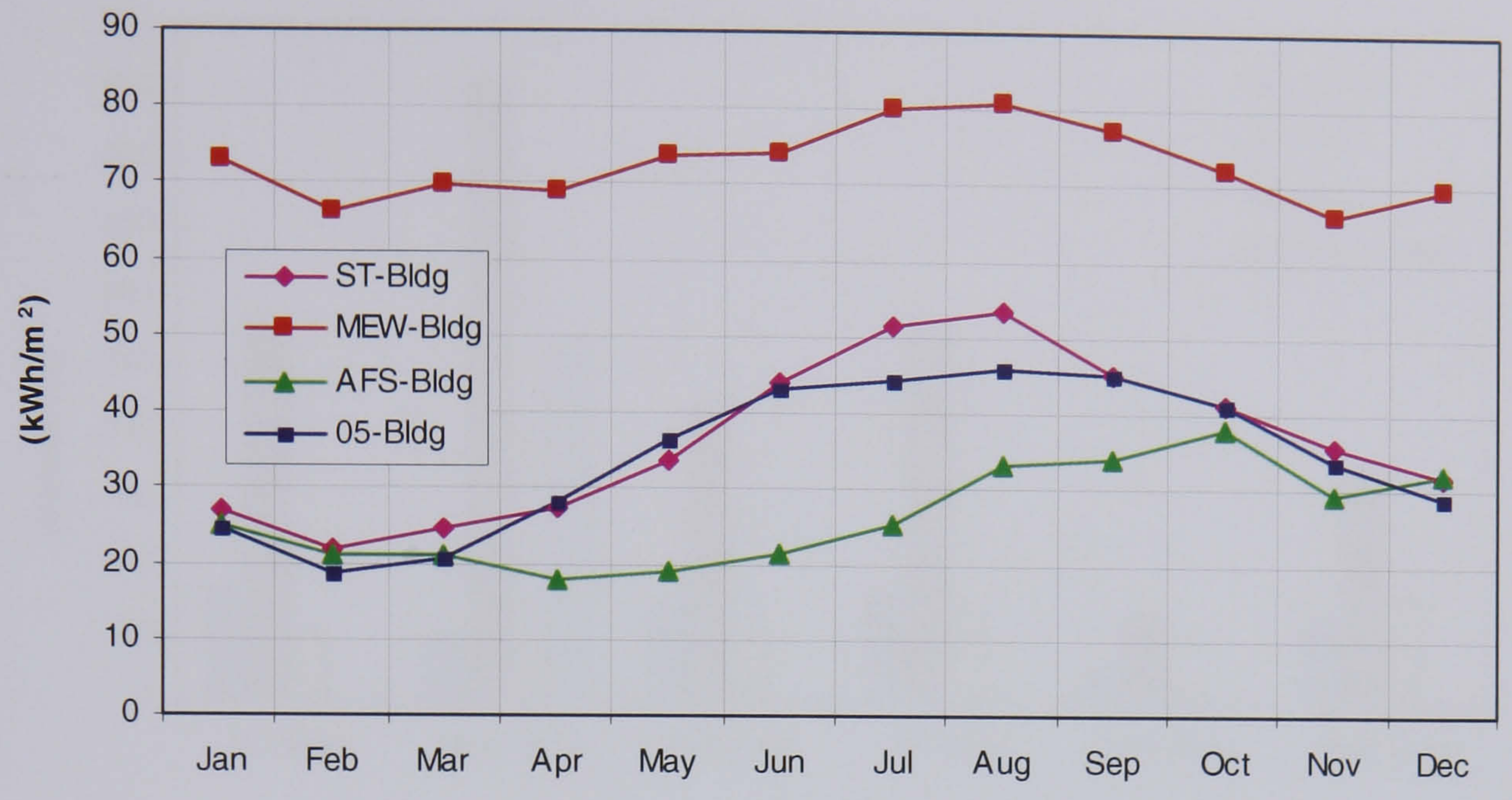

Figure 4.6 Monthly energy indices – ST-Bldg, MEW-Bldg, AFS-Bldg & 05-Bldg

Fig. 4.7 shows the breakdown of electricity consumption for each end-use of the studied buildings. It can be verified that there are three primary end-uses including HVAC system, lighting system and building equipment. The HVAC system was the main consumer of electricity. The minimum amount was consumed in BSE-Bldg with 22, 49 and 28.7 kWh/m^2/yr due to lighting, HVAC system and equipment respectively. The maximum was consumed in MEW-Bldg with 49.6, 458, 32, and 265.4 kWh/m^2/yr due to lighting, HVAC system, equipment and others end-uses respectively. The above analysis shows that the cooling load was dominant. Therefore, for improving the energy performance of buildings in Bahrain, it is necessary to reduce the cooling load. This can be achieved by eliminating the factor behind the internal and external heat gain. As mentioned in section 2.1.3, design with climate and the use of low energy standards such as thermal insulation and efficient windows can significantly reduce the external heat gain, while the use of highly efficient energy technologies and systems such as low energy lamps and equipment can greatly reduce the internal heat gain. These two strategies have the most influence on cooling load and energy consumption.

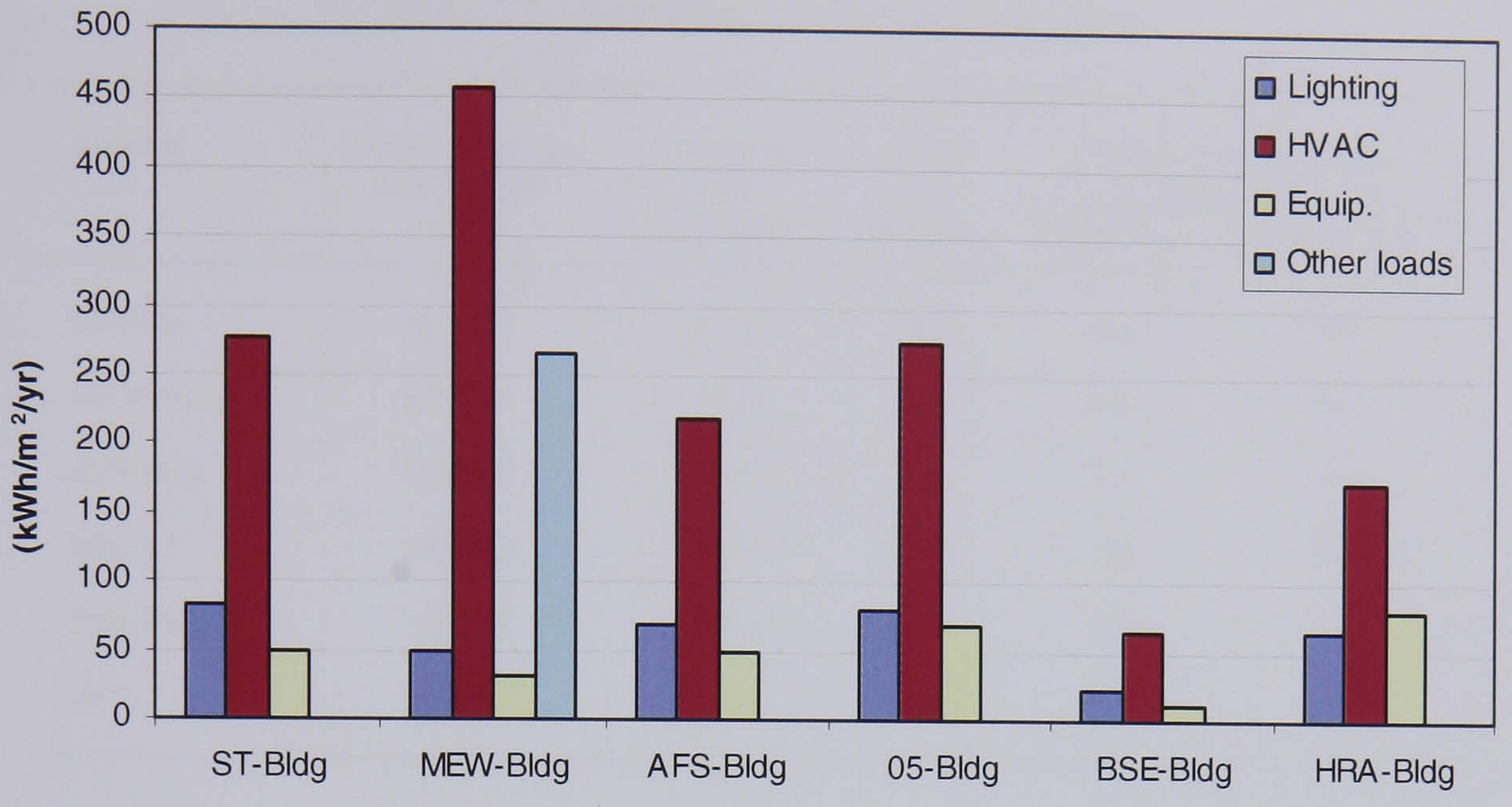

Figure 4.7 Breakdown of electricity consumption per end-uses

Regional benchmarking

To identify the worst and best energy and environmental performing buildings the total annual electricity consumption per treated area of each building was first calculated, and then multiplied by the conversation factor of electricity in Bahrain. This was done to convert the electricity consumption in kWh to kg of CO_2 emissions. From Table 4.5 it is clear that the electricity consumption per treated area per year varied from one building to another, ranging from 100 kWh/m^2/yr to 805 kWh/m^2/yr, for the BSE-Bldg and MEW-Bldg respectively. Although the MEW-Bldg had the shortest operation schedules, which is 60 hours per week, it was found to have the largest Normalisation Performance Index (NPI). The BSE-Bldg was found to have the lowest NPI in spite of its operation hours. The above process identifies the worst and best performing buildings. The result of this process shows that BSE-Bldg is the best energy performer with 100 kWh/m^2/yr and 70 kgCO_2/m^2/yr. Therefore, it is possible to say that BSE-Bldg is a low energy office building and can be used as a reference. Hence, 100 kWh/m^2/yr and 70 kgCO_2/m^2/yr can be used as a benchmark for standard practice office buildings in Bahrain.

Table 4.5 Normalised performance indices

Building	Annual electricity consumption kWh	Hours of use hours/days	Total floor Area (m^2)	Normalised performance index (NPI)	
				$kWh/m^2/yr$	$kgCO_2/m^2/yr$
ST-Bldg	3832007	12 / 6	9360	409	286
MEW-Bldg	8376088	12 / 5	10400	805	564
AFS-Bldg	1535220	12 / 6	5080	302	211
Bldg-05	1908869	10 / 5	4500	424	297
BSE-Bldg	127970	12 / 6	1280	100	70
HRA	126808	14 / 6	500	263	177

4.5 Closing Remark

This chapter was designed to provide a basic look at the state-of-the-art of BESC in Bahrain and in selected countries. It was indicated that the use of BESC is important for promoting more energy savings in buildings. This study examined the current energy codes in Bahrain and highlighted their limitations and weaknesses. It was indicated that the steady state R-value used by Bahrain building regulations is inadequate because of two reasons: first, it is a clear R-value and second, it ignores the dynamic thermal performance of complex building envelope, from which the cooling load may be negatively misrepresented. In this study, the use of envelope components codes regulated by Article-32 was discussed. It was stated that the use of these codes as the only means to improve the energy performance of buildings is insufficient. This is simply because they were developed without any consideration being paid to building type, activity, design and above all building systems. Therefore, they cannot guarantee the optimum energy design for building envelope nor are they able to ensure the efficient use of energy by the building services.

It is important to point out that the development of simple codes was important for Bahrain, which, to a large extent, did not have enough experience to apply and enforce complicated BESC. With the current economic and architectural boom, building energy standards should be developed in Bahrain. The argument is whether or not to make them building components codes or performance-based codes. On the one hand, building components codes are prescriptive codes have certain requirements to be satisfied. They are simple and easy to apply, but offer little flexibility to the building design. On the other hand, performance based codes offer a greater degree of flexibility to the building designer and architectural innovation. The review in this study shows a trend to a performance based approach. This approach can be implemented jointly with codes on specific envelope elements or system components (e.g., insulation, window area, AC system, etc) in order to ensure the dissemination of the most efficient design. The OTTV introduced in this chapter can be used as a performance standard for the building envelop, while the established energy performance benchmarks can be used as design standards for the buildings as a whole. It is important to mention that the aim of benchmarking the energy performance of office buildings is to obtain a scale for building energy design in Bahrain. This scale is to later serve as an objective for optimising the energy design of office buildings, as will be illustrated in Chapter 7.

This chapter referred to the use of simulation programs as complementary means to comply with building regulations. These programs allow trade-off between the major components of buildings in order to achieve a certain benchmark. Visual DOE and Energy-10, the simulation programs presented in Chapter 3, are ideal to do this job due to many reasons: firstly, the ease of use, accuracy and availability in Bahrain and secondly, these programs are able to measure the dynamic thermal performance of buildings using response factors techniques, and also to calculate the yearly energy consumption and estimate the CO_2 emissions on an hourly basis. These programs are useful when the whole building and performance approach are considered. However, they require an input of extensive weather data. The next chapter develops weather data for Bahrain to be used in building simulation.

Chapter 5 WEATHER DATA

Weather Data are one of the foundation stones of our [building services] industry since it is the building and its services which protect us from its extremes and create an appropriate internal environment. Without accurate weather data, we could neither design efficient of effective services nor predict energy use.

(P.G.T. Owens: CIBSE, 1984)

5.0 Introduction

The accuracy of energy analysis largely depends on the type of weather data, especially when detailed simulation programs are used to calculate building thermal response for a complete year. Chapter 2 highlighted the significant role that the types and characteristics of weather data play in building energy simulation. Chapter 6 integrates simulation programs into a systematic methodology to evaluate the impact of energy standards on building performance. This chapter develops a weather data file for Bahrain to be used with simulation programs. It starts with a discussion of the relationship between climate and buildings, in section 5.1. Section 5.2 studies the various climatic parameters that affect building energy performance and highlights some method of weather data design. Section 5.3 examines the climatic parameters of Bahrain. It then uses the studied parameters along with weather data generators to develop statistically based hourly weather data files. Section 5.4 evaluates the performance of the developed files with respect to the climate variability in Bahrain.

5.1 Climate and Buildings

Broadly speaking, buildings respond to the local environment, and therefore, different building designs are found in different regions. In any region, however, the ultimate objective of buildings is to avoid the extreme outside conditions and to provide comfortable internal environment in an economic way. The building envelope represents the connection between the internal environment and the outside conditions, and hence a key function of building envelope is to act as a climate modifier. This modifier aims to maintain a certain indoor environment which is more suitable for habitation than the outdoor (Torrance, 1991). Fig 5.1 illustrates the concept of building envelope as a climate modifier. Sometimes, this modifier fails to satisfy the comfort of the occupant due to one or more reasons such as insufficient design or due to extreme outdoor conditions which probably make it impossible for any certain level of comfortable indoor environment to be achieved. Then, it is important to rely upon mechanical means to achieve the comfort level. Practically, to avoid this situation or, at least, to reduce the reliance upon mechanical means the design of the building and its systems should be in a harmony with climate. To specify the features of such design one needs to have a reasonably accurate picture of the characteristics of the area in which the building is located (Lacy, 1977).

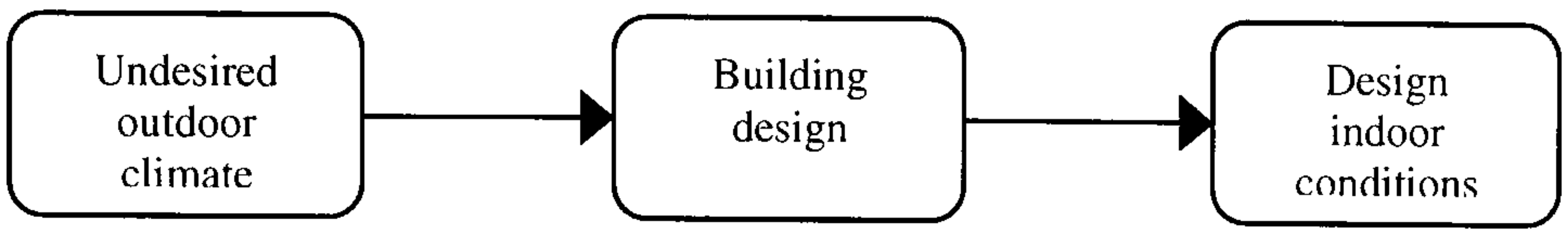

Figure 5.1 Buildings as climate modifiers (Al-Shibami, 2004)

5.1.1 Understanding the climate

Weather conditions produced by the atmosphere over a certain time form the climate of a given region. Each of these conditions represents one elements of the climate (Markus & Morris, 1980). By studying these elements, the behaviour of the climate can be understood and its impact on buildings can be evaluated (Arens *et al.*, 1980). Therefore, identifying, understanding and evaluating the impact of climate may represent the most important part of thermal design and energy analysis, and hence an accurate study of climatological elements is required. However, not all meteorological information is of value for thermal design and energy analysis. Building designers and energy analysts are often interested in those climatic elements which affect indoor comfort and heat flow through the building envelope. Since the concern here is within the thermal aspects of buildings, the elements of climate of immediate interest are thermal - primarily:

- Temperature (°C)
- Solar radiation (W/m^2)
- Relative humidity (%)
- Wind speed and direction (m/s)
- Precipitation (mm)
- Cloud cover and type (%)
- Sunshine hours (hr)

Although each of these elements impacts particular aspects of building performance, there are correlations between them. Some recent studies (Guan *et al.*,

2007) have reported a strong relationship between climatic elements such as the hourly variation of global solar radiation (GSR) and dry bulb temperature (DBT), as well as between the DBT and the relative humidity (RH). The change in any of these elements, especially the solar radiation, influences the other elements. Consequently, building performance can be influenced in direct and indirect ways. To make an effective estimation of the impact of climate on the overall energy performance the selection of climate element collection should be based on the combined integrated impacts of these elements on the overall thermal performance of buildings (Clarke, 2001; Straaten, 1967). This is of importance when weather data are designed.

5.2 Design Weather Data

5.2.1 Factors effecting the design of weather data

The diversity of sources and approaches to obtain meteorological information may offer a good help in order to generate weather data. However, the quality of these data is influenced by two main factors related to the obtained meteorological information (ASHRAE, 2005):

- Sources: the location (e.g. typology and landscape) and methods of observation.
- Length of record and climate change: the age and variation in weather conditions from year-to-year and, to some extent, from decade-to-decade due to the inherent variability in climate.

It is said that a minimum of 10 years of complete climatic information would provide a reliable weather data design (Remund & Kunz, 2003). However, having a reasonable length of continuous climatic records is not enough. The required climatic elements should be measured at small timescales. Generally, the smallest timescale of weather data is more useful. Designing hourly weather data also involves checking the missing and erroneous data. If the required data are not available at the source then some work has to be done to estimate these data using other measured data and properties. One key method is to use the basic parameters as seeds to develop detailed weather data. In practice, there are two types of weather data: actual measured data and climatic data generated through the use of mathematical time series (e.g., mathematical model, weather data generator, etc). Each has advantages and drawbacks. On the one hand, the actual measured data are more precise then the generated, but they are rarely available for long periods and, in some cases, they are difficult to obtain. On the other hand, the generated data are less accurate than the measured data. They are site independent (Remund *et al.*, 1999). Following this approach allows obtaining various types of weather data for any desired location from basic parameters. This type should be used when the actual weather data are not available.

The remaining of this chapter uses a statistical method based on basic measured data to develop hourly weather data files. The developed files, therefore, are statically based hourly weather data. In order to form the base for the development methods and process of generating weather data will be briefly explained in the next section.

5.2.2 Methods for designing weather data

In general, there are two approaches to designing detailed weather data: firstly, statistical approach and secondly, simulation approach. The former uses statistical methods to provide standard timescale data for solar radiation and other climatic elements (e.g., temperature, humidity, winds speed, etc). The latter is based on using weather data generator. Today, it is a commonplace to use the statistical methods to generate hourly weather data that permit measuring passive strategies and evaluating the performance of systems for one or more climates (Chan *et al.*, 2006; Kalogirou, 2003; Kaplanis & Kaplanis, 2007; Paassen and Dejong, 1979; Rahman & Dewsbury, 2007; Skeiker, 2007). More recently, these methods have represented the basis for weather data generators as can be seen in the TRY software (Petrakis *et al.*, 1996), RUNEOLE (Adelard *et al.*, 2000), EnerWin (Degelman, 2005) and MeteoNorm (Remund *et al.*, 1999).

5.3 Development of Weather Data

For a good development of weather data it is necessary to recognise the various patterns of climate because they are needed for the generation (Hand *et al.*, 2008). The next section studies some aspects of the climatic properties of Bahrain.

5.3.1 Climatic properties of Bahrain

Geographical characteristics

Bahrain is an island located in the Gulf region at 26.26 °N latitude and 50.35 °E longitude. Fig. 5.2 shows the location of Bahrain. In terms of area, Bahrain is the smallest country among the Gulf States, with a total land area of 700 km^2. Today, however, the land area of Bahrain is steadily increasing due to enormous reclaiming activity. The climate of Bahrain can be described as a mild winter and extremely hot summer. The characteristics of this climate resemble those of arid and semi-arid zones: rainfall is low, irregular, seasonal and variable, relative humidity is also high, especially during the rainy seasons, and temperatures are variable but high (Elagib and Abdu, 1997).

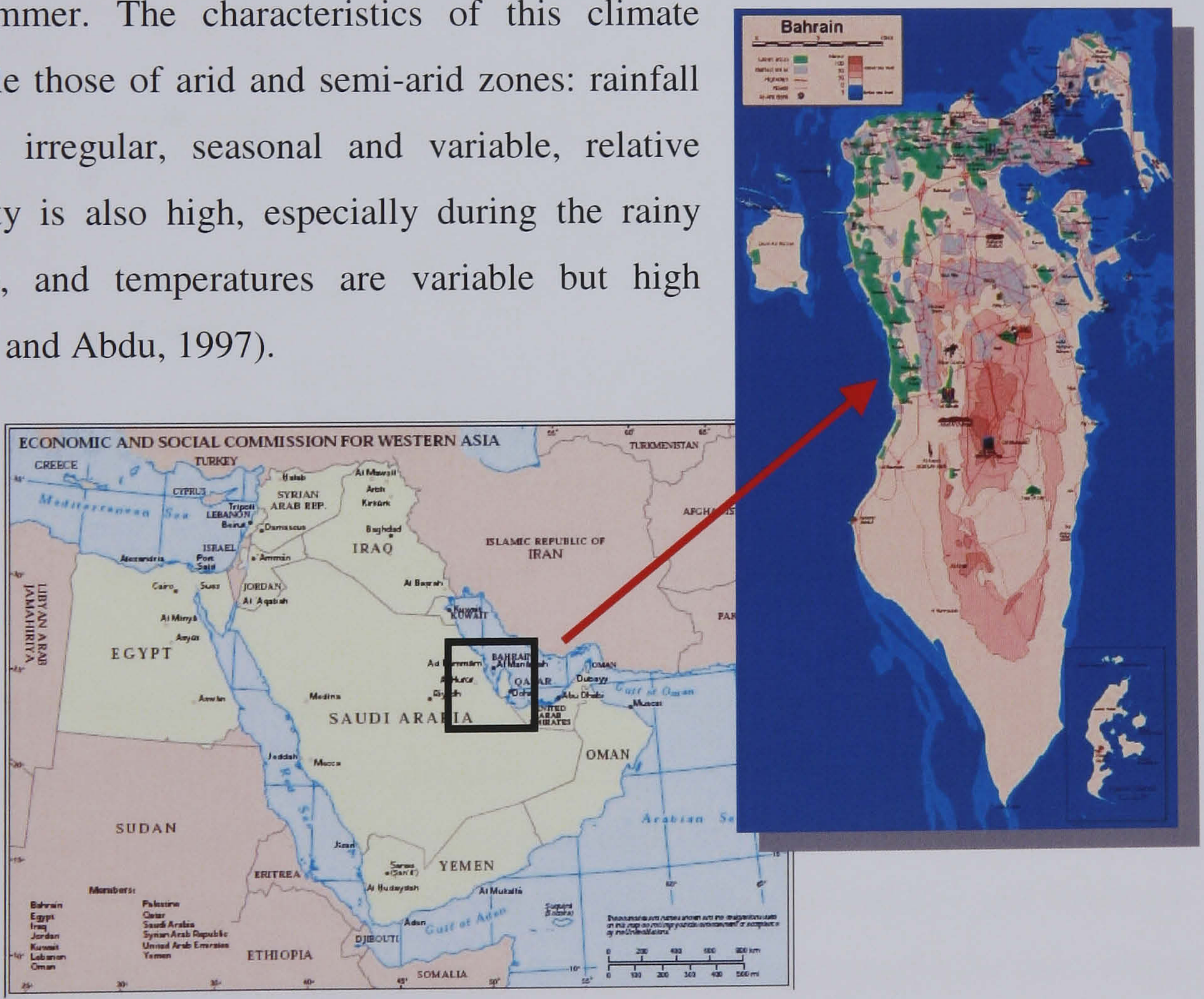

Figure 5.2 Location of Bahrain

Analysis of climatic conditions

Fig.5.3 shows a brief analysis of climatic elements in Bahrain. The meteorological data were provided by the Directorate of Meteorology located at Bahrain international airport, while the solar data were obtained from research projects conducted by the University of Bahrain (Al-Naser & Al-Attar, 1999; Muneer *et al*, 2007). One of these projects was carried out at the airport. It is important to note that the distance between the airport and the University does not exceed 35 km. An important result of these projects shows that the climatic elements, particularly solar parameters, have almost the same values at different sites in Bahrain including the airport and the University.

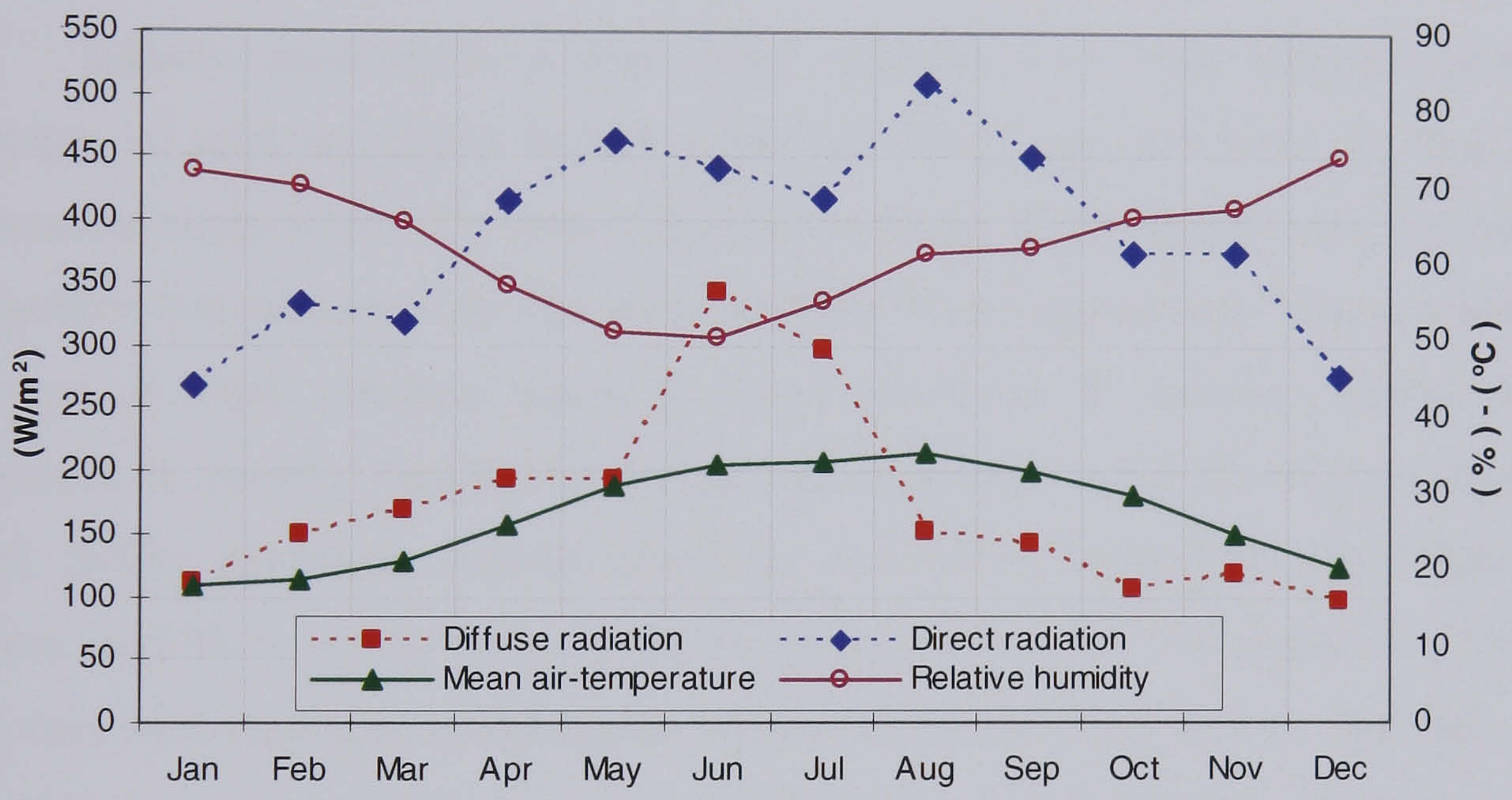

Figure 5.3 Monthly average of climatic parameters in Bahrain

The analysis of the climatic elements shows an overall yearly average temperature of 26.5°C with a monthly average maximum temperature of 41°C (August) and a monthly average minimum temperature of 14.4°C (January). The cold season in Bahrain spans from late December through January and February. March until early May is considered the transitional period between the mild winter and the hot summer. This season is characterised by sudden and daily variations of the diurnal temperature. The summer season spans from late May to September, during which the monthly mean temperature is around 30-35°C. In October and

November sunny skies are dominant with dry conditions and monthly mean temperatures between 29°C and 24°C, respectively.

The monthly average relative humidity is 62%, with a maximum monthly average of 72% (January) and a minimum monthly average of 50% (June). Wind from east north direction throughout the year is a characteristic of Bahrain. The wind speed average shows slight variation, being generally low from April to December with a monthly average of 4.2 m/s, while from January to March it is well above 5.1 m/s, reaching a monthly average of 5.2 m/s in February. On average, rainfall in Bahrain can reach up to 26 mm in January. The annual rainfall is 76 mm. The rainy season is broken up by four dry months extending from June to September.

Bahrain experiences a high solar radiation level. The highest monthly averages of total and direct radiation are 585 W/m^2 and 383 W/m^2 in June and September respectively. The lowest monthly averages of the same parameters are in December and January with 373 W/m^2 and 267 W/m^2 respectively. Bahrain has an average of 3468 sunshine hours per year (Al-Naser & Al-Attar, 1999). It is important to mention that the solar data were measured using the rotating shadow band (RSB) pyrometer manufactured by Ascension Technology, Inc., Lincoln Centre, and M.A., USA. It was installed on the roof of the University of Bahrain. The data were measured continuously and the results averaged hourly. The daily and monthly averages for direct solar parameter are calculated by subtracting the actually measured total solar radiation.

The above analysis illustrates the climate of Bahrain in the present time, which is quite different from the climate conditions in the 1960s, 1970s and even the 1980s. However, the climatic conditions of those decades still represent the base of most weather data collections in Bahrain. Today, some of these collections are still used in spite of the variation in the climatic elements, as indicated by many sources. A recent study into insolation on vertical surfaces in Bahrain indicated that in 2007 there was a reduction in diffuse solar radiation by 24.5% and an increase in direct solar radiation by 10.7% when compared with records of one decade ago (Muneer *et* *al*, 2007). Coupled with this is the increase in air-temperature. A regression analysis shows air-temperature rising trend at a rate of 1.4°C per decade (Haque, 1995).

It is of interest to highlight some of the reasons behind this variation. One possible reason is the heat island caused by the massive new construction in Bahrain. There has recently been rapid and increasing economic expenditure on huge architectural projects. The changes in atmospheric pollution and CO_2 emissions due to burning fossil fuels are other reasons for this increase. The variations in Bahrain's climate may reduce the reliability of weather data developed from previously collected climatic information. The next section examines the impact of climate variability on the performance of weather data used in energy simulation.

5.3.2 Development process

This chapter aims to investigate the impact of weather data on the accuracy of building energy analysis with respect to the climate variability in Bahrain. The investigation passed through two main stages: firstly, making weather data sets and generating two weather data files and secondly, comparing the two weather data sets to examine the climate variability along with comparing the two generated weather data files in order to assess their impact on the accuracy of building energy analysis.

First stage: making weather data

This study uses the MeteoNorm program to generate statically based hourly weather data. The MeteoNorm software is a weather data generator and database developed by the Swiss Federal Office of Energy (Swiss Federal Office of Energy, 2008). The database is a comprehensive source of weather data covering 7700 meteorological stations worldwide. These data were obtained from different organisations such as the World Meteorological Origination (WMO). A principal advantage of the MeteoNorm software is its ability to calculate the solar data based on meteorological data (air-temperature and relative humidity). It generates synthetic hourly weather data based on long term monthly averages. The generator uses statistical methods to develop synthetic weather data ranging from simplified to hourly weather data. It utilises the concept of the probabilistic transition between thresholds of the parameters to generate weather data in various formats from Markov chains (David *et al.*, 2005).

Three methods can be followed to generate detailed weather data: first, using the comprehensive database, second, inserting the climatic element values and finally, importing files of monthly and hourly averages of the key climatic elements. A statistical weather data file produced by MeteoNorm is the result of a statistically generated sequence of weather data values representing the typical weather for the site. This sequence includes almost all climatic patterns possible.

In this current stage (making weather data), two sets of measured data were formed based on long term meteorological climatic elements provided by the Directorate of Meteorology of Bahrain (air-temperature, relative humidity, precipitation and wind speed and direction) and measured solar data (total solar radiation, diffuse solar radiation and direct solar radiation) obtained from recent studies conducted in Bahrain (Al-Naser & Al-Attar, 1999; Muneer *et al*, 2007). The First Gulf War and the Kuwait oil fires of 1991 were taken as a border between the two weather data sets. The former represents the period from 1961 to 1990, and will be indicated as (climate-before-91). The latter represents the period from 1992 to 2005 and will be indicated as (climate-after-91). Year 1991 was excluded. Nevertheless, the consequences of the oil fires can be noted in the later years.

In addition, two weather data files were generated using the MeteoNorm software. The two files are for Bahrain international airport. The former is a result of using data from 1961 to 1990, and will be indicated as DATA (61-90). The latter is a result of using data from 1961 to 2005, and will be indicated as DATA (61-05). It is interesting to mention that the data of the two weather periods (1961-1990 and 1961-2005) are existed in the MeteoNorm database. This database is an option to generate these two files. However, the solar data of some countries such as Bahrain are not actual measured data; rather they are calculated based on meteorological data (air-temperature and relative humidity) monthly means. Furthermore, the computational models in the MeteoNorm only approximate the real situation.

Therefore, the development of the weather data files in this study was done by utilising the actual measured monthly means meteorological elements (air temperature, relative humidity, wind speed and direction and precipitation) in the MeteoNorm database coupled with inserting the actual measured monthly means of solar data into the software in order to ensure that all the climatic elements are real.

The obtained files, therefore, are statistically derived hourly weather data that were generated based on long terms measured monthly means using the statistical procedure in the MeteoNorm software. This was done to reflect the climate of Bahrain before and after 1991 with the aim of obtaining hourly weather data. The obtained files were converted to binary files for the use in building simulation. This conversion was done in light of the design conditions of Bahrain, as indicated by ASHRAE (ASHREA, 2005).

Second stage: evaluating weather data

The second stage of the investigation was carried out in a two-part sequence: first, the climate variability was studied through a comparison of the climatic elements of the two sets (climate-before-91 and climate-after-91) formed in the previous stage. Since the concern in this study is within the thermal aspects of buildings, the elements of climate of immediate interest are thermal. Therefore, the comparison was carried out on four key thermal elements including air-temperature, relative humidity, solar radiation and wind speed. These parameters were chosen due to their impact on the thermal performance of buildings. Wind speed was included due to its impact on cooling and heating loads.

Second, the impact of this variation on the accuracy of building energy analysis was evaluated through a comparison of the thermal performance of the two weather data files (DATA 61-90 and DATA 61-05) developed earlier. This comparison was to examine the reliability of the developed weather data files to give the closest result to the actual consumption when used with simulation programs. The Visual DOE program was used in this case. Two case studies were simulated using the Visual DOE program. The output of the simulation programs was first plotted graphically and then compared using a well-known statistical test namely, the *t*-test. This methodology was used by Radhi (2008b) to compare the accuracy of building energy analysis in Bahrain using data from different weather periods (see Appendix 3).

Building characteristics considered in this evaluation

For a sufficient comparison two case buildings were used: the Ministry of Electricity and Water building (MEW-Bldg) and the Bahrain Society of Engineers building (BSE-Bldg). Detailed description of the former building is available in Chapter 6, while the latter is described below. It has a rectangular shape oriented north to south. The building consists of two storeys (24 m x18 m) with a total floor area of 1280 m^2. Fig. 5.4 shows the ground floor plan and the front elevation of the building. The floor-to-floor height is 4.0 m. The walls consist of 200 mm concrete block, and 50 mm polystyrene expanded insulation. The building has multi-thermal zones with central HVAC system; each of the air-conditioned zones has set point temperature between 24 and 25.5°C for summer and between 21 to 22°C for winter. Detailed description of the building physical and operation characteristics are illustrated in Table 5.1.

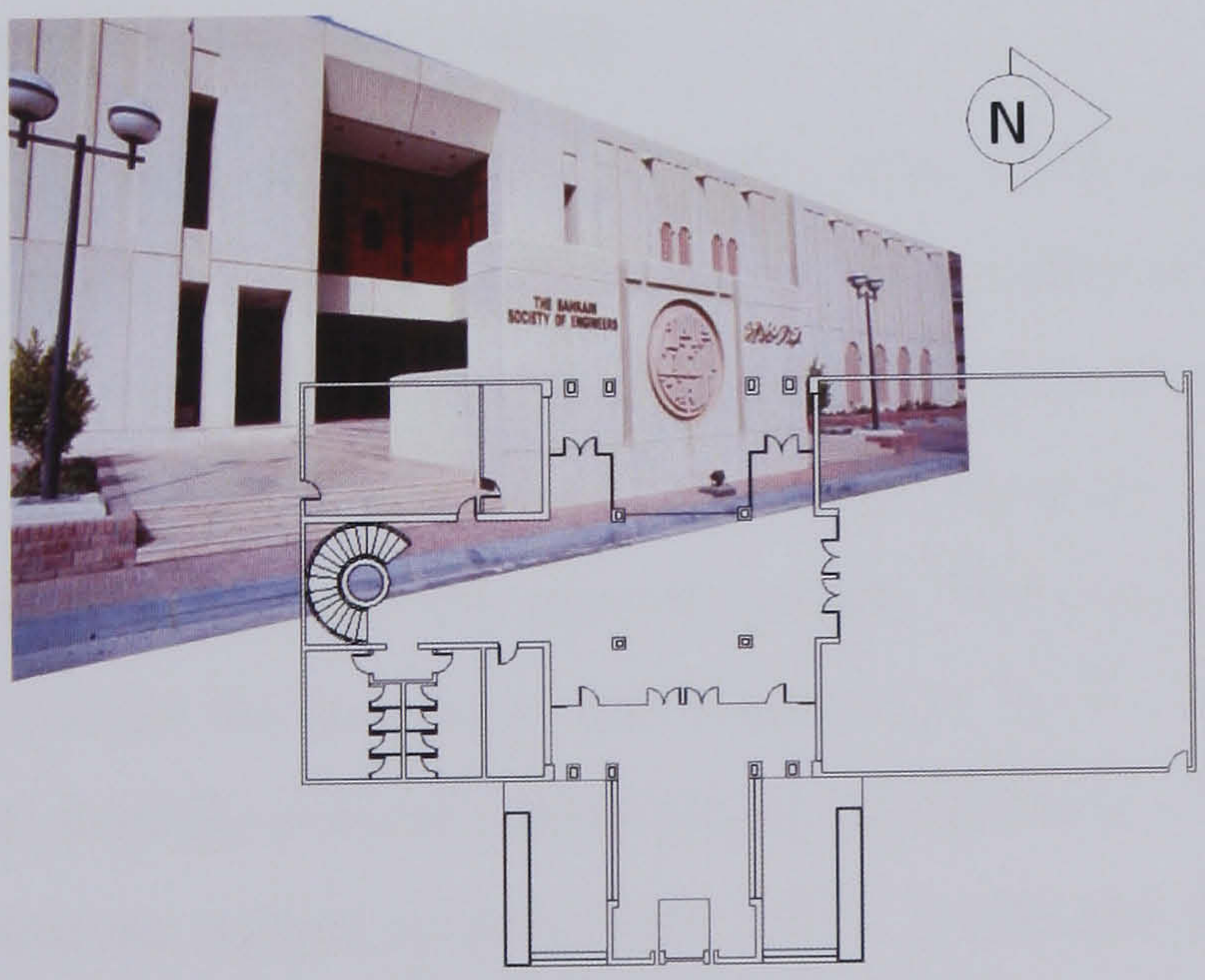

Figure 5.4 Plan and front view of BSE-Bldg

Table 5.1 Description of the BES-Bldg

Parameters			
Building form			
No. of floor	2		
Total area	1280 m^2		
Floor height	4.0 m		
Orientation	North to South		
Building skin			
	Construction	Thickness (mm)	U-Value (W/m^2.°C)
Wall	Concrete block	200	0.5
Roof	Concrete slab	200	0.33
Opening	Low-energy glazing	6mm	1.6
	SC		0.5
	Shading device		yes
Infiltration rate	3.0 m^3/h/m^2		
Ventilation rate	7.5 L/s/person		
Building body			
Thermal zones	Multi-zones (e.g., offices, auditorium, library, lectures hall, etc)		
Building system			
Equipment	35 W/m^2		
Lighting	20 W/m^2		
HVAC	Central HVAC system		
Set point temperature	Summer (24-25.5°C) Winter (20-22°C)		
Building operation			
Schedules	60 hours/week		
Occupancy	30m^2/person		

5.4 Evaluation of Weather Data

5.4.1 Comparison of weather parameters

Figs. 5.5-5.10 show the monthly average values of the key elements of the two sets of measured data (climate-before-91 and climate-after-91), including mean air-temperature, maximum air-temperature, relative humidity, wind speed and solar radiation. In Fig. 5.5, a variation of monthly average mean air-temperature of the two periods appears especially in the summer month. The maximum increase was found to be 1.4°C, while the minimum was found to be 0.1°C. The same situation can be noted in the monthly average maximum air-temperature, as shown in Fig.5.6. The maximum increase occurs in July with 2.6°C, while the minimum increase occurs in January with 1.2°C. The distribution of the two curves with respect to relative humidity shows a different scenario. Fig. 5.7 illustrates a drop in the recent values of relative humidity. The curve of climate-before-91 has relatively higher values from the curve of climate-after-91, especially in the summer months from May to August. The maximum reduction was found to be in May with an approximate 8.2%. For wind speed, as shown in Fig. 5.8, it is clear that there is a considerable difference between the two curves. The illustration shows a drop in the wind speed with respect to climate-after-91. Considering the small area of Bahrain and the recent constructional boom, this reduction seems logical due to the massive architectural projects and local influence.

The same scenario can be noted in the solar radiation distribution. When the direct and diffuse solar radiation of climate-before-91 and climate-after-91 plotted against each others, as shown in Figs.5.9-5.10, a deviation appears between the two curves. Fig. 5.9 shows a declination in the diffuse radiation especially in the summer months. Unlike the diffuse solar radiation, there is an increase in the direct solar radiation, as illustrated in Fig.5.10. It is worth mentioning that the share of direct radiation in the total solar radiation reaches 69.4%, while the share of diffuse radiation is only 30.6%. A recent study (Muneer *et al.*, 2007) suggested that the reason behind this difference is the reduction in the atmospheric pollution.

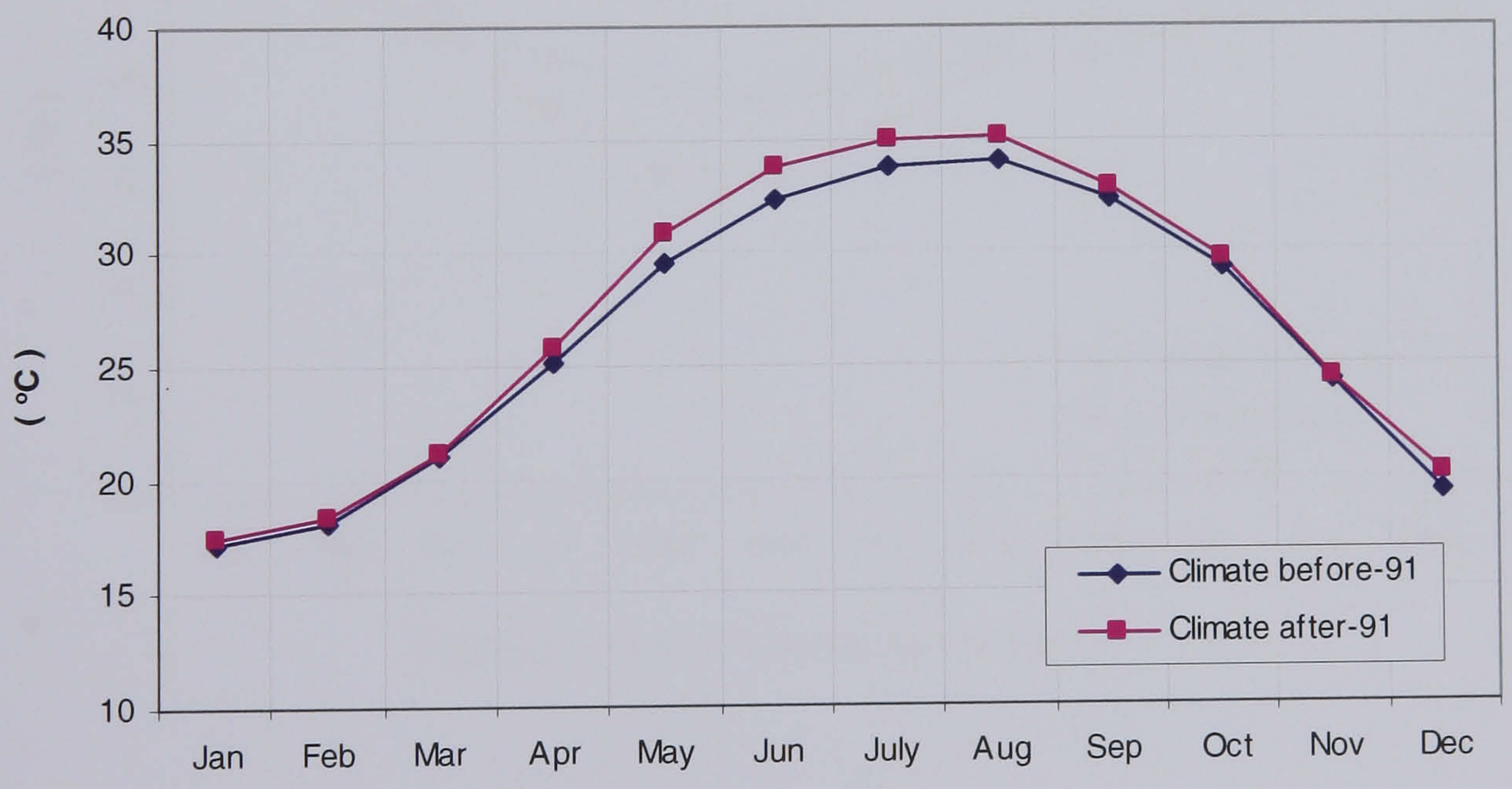

Figure 5.5 Mean air-temperature (Airport)

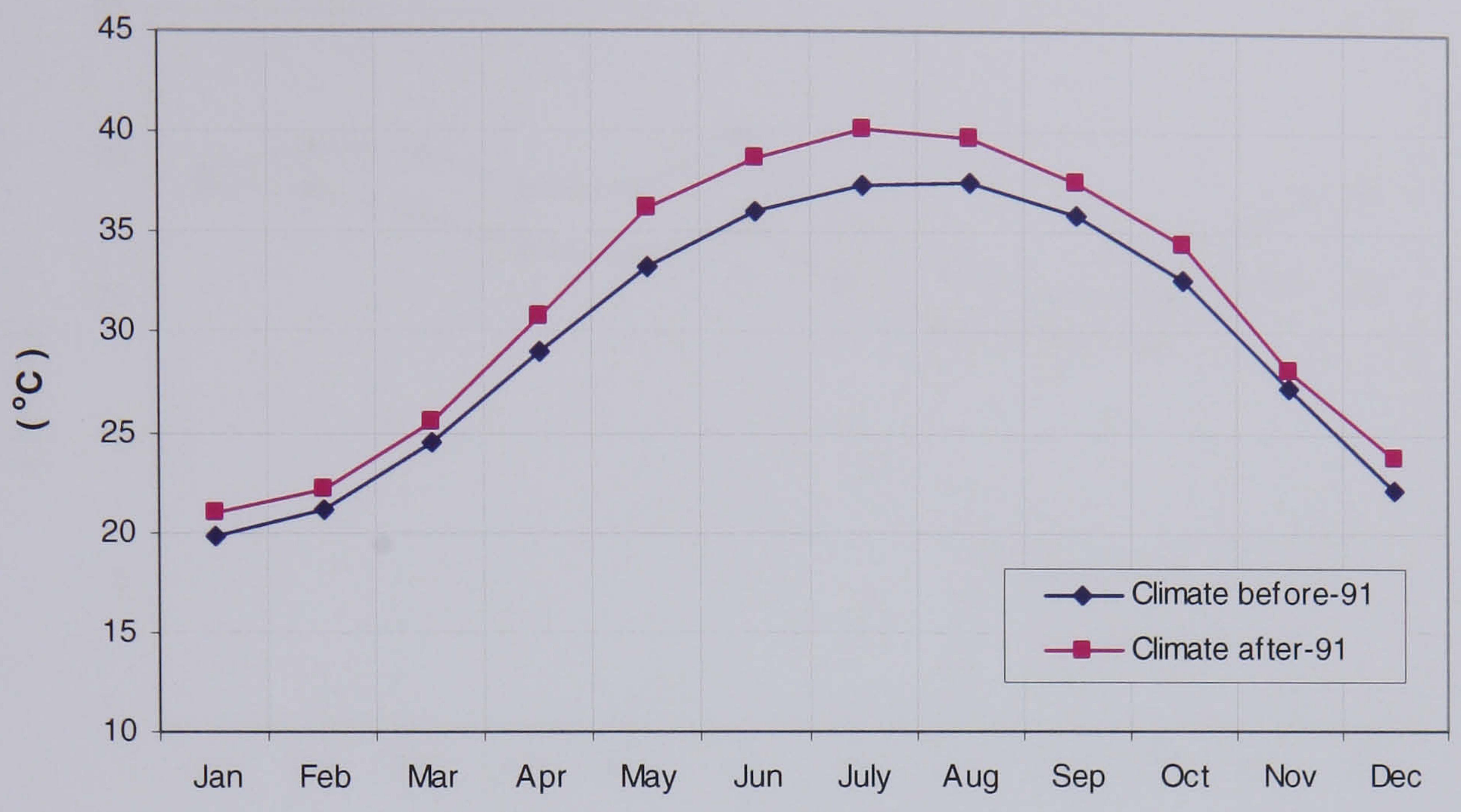

Figure 5.6 Maximum air-temperature (Airport)

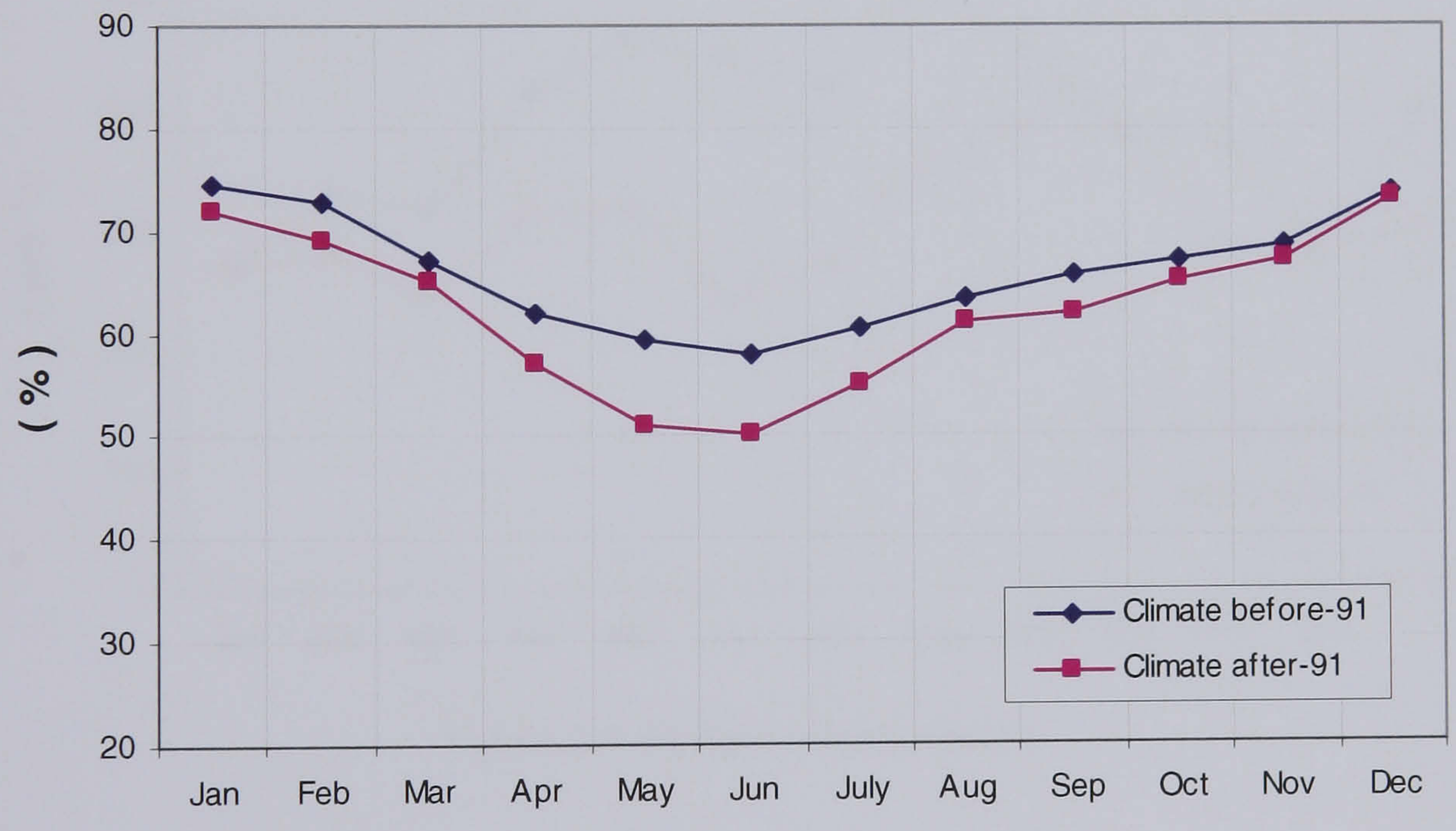

Figure 5.7 Relative humidity (Airport)

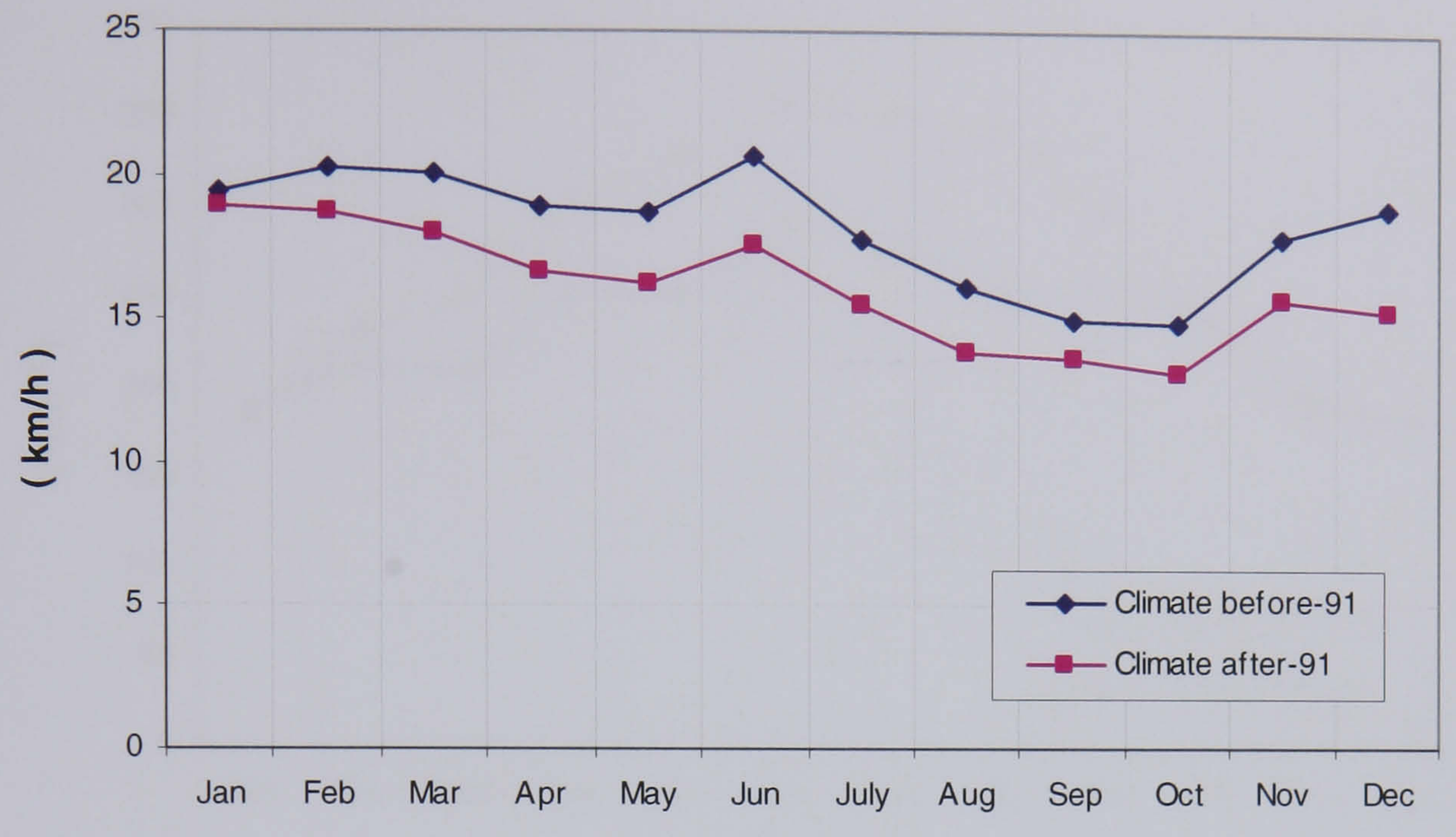

Figure 5.8 Wind speed (Airport)

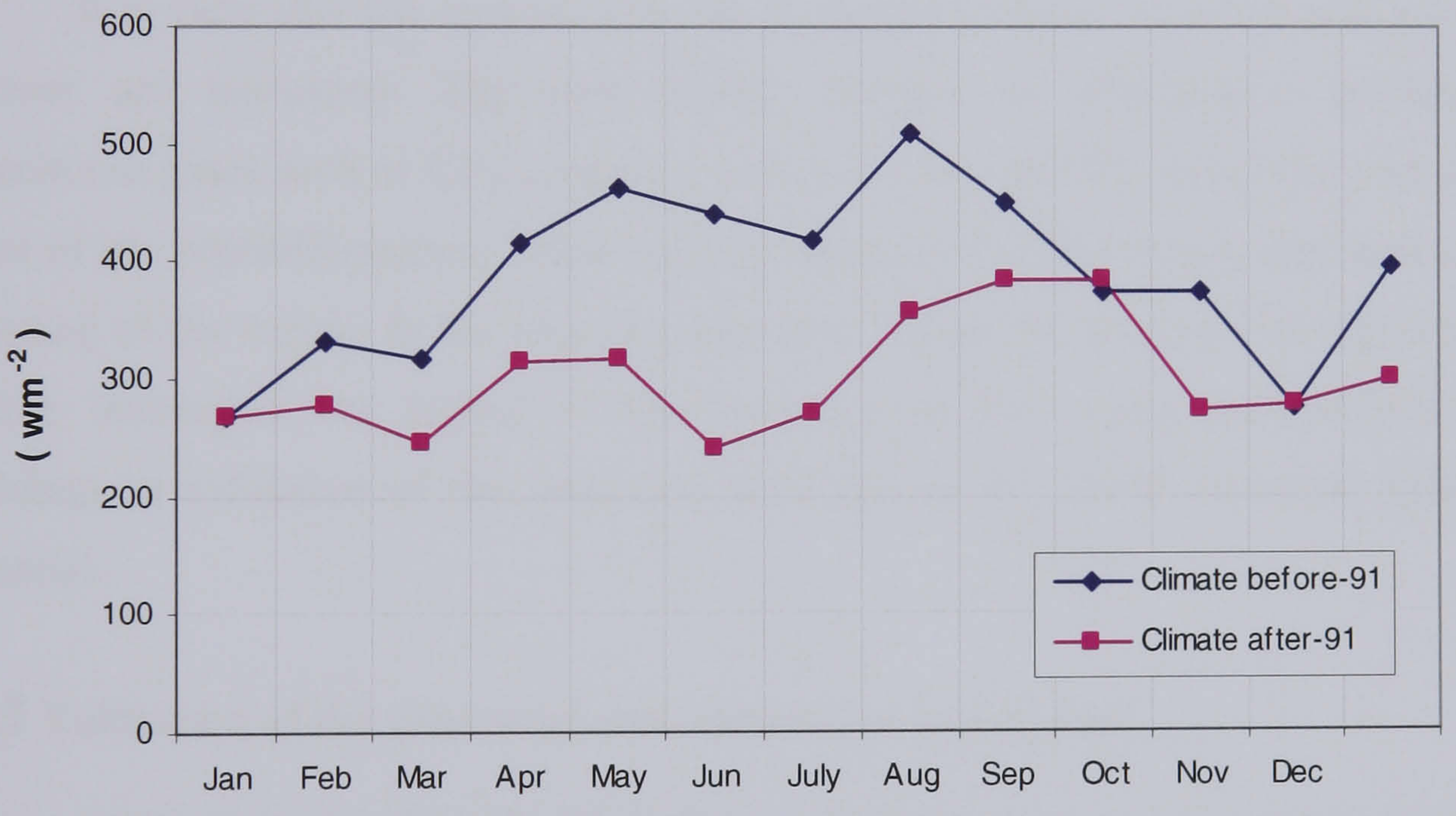

Figure 5.9 Diffuse solar radiation

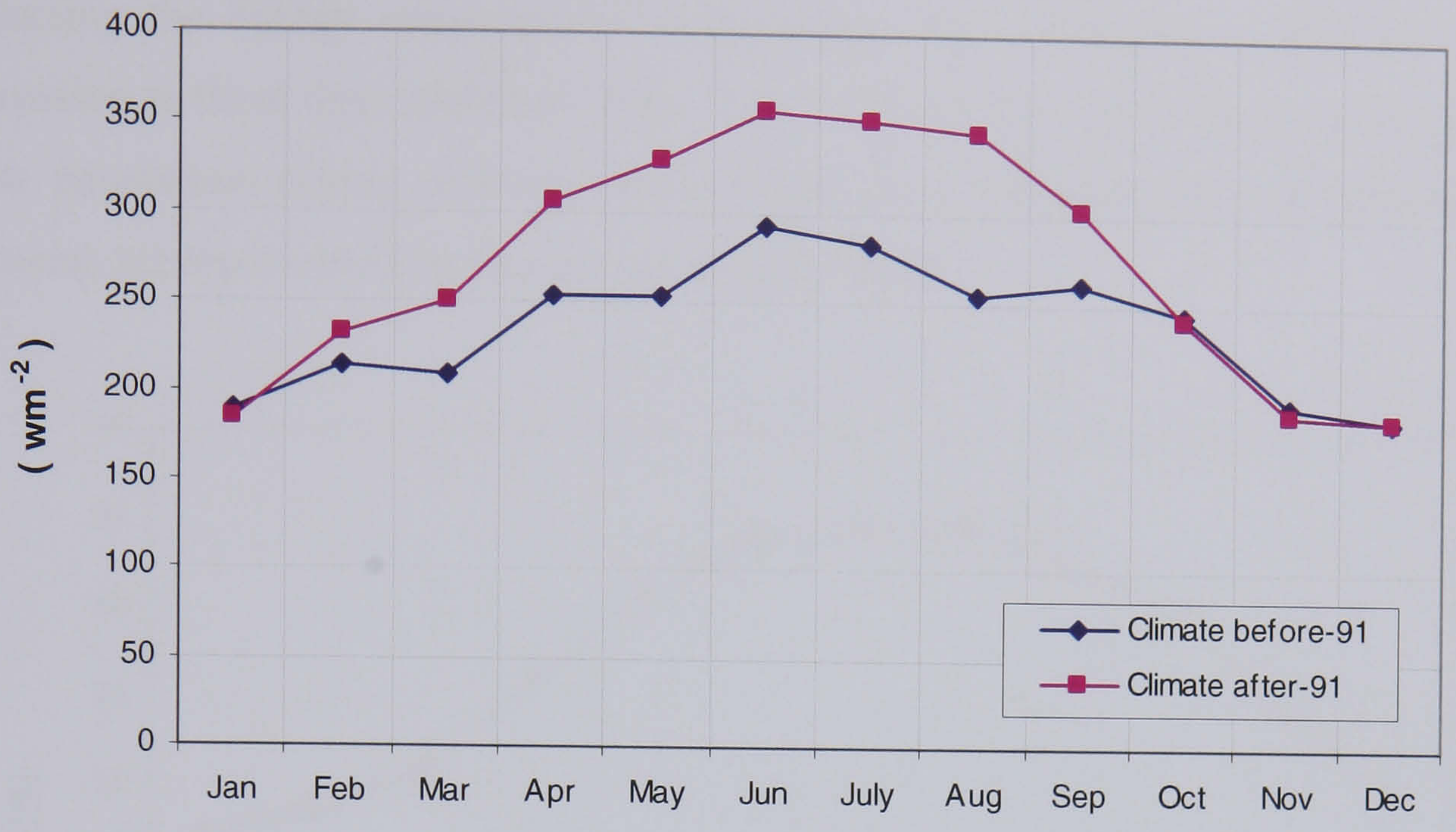

Figure 5.10 Direct solar radiation

It is clear that the reasons why the examined climatic elements tend to get warmer are numerous. The heat island, changes in atmospheric pollution, greenhouse gases such as CO_2 caused by energy use and burning fossil fuels are just some of the possible reasons. These reasons, along with many others may lead to a warming of the region. In the long run they may change the climate characteristics. Before investigate the impact of this tendency on the energy performance of buildings, a validation of the generated data against the actual measured data is essential.

5.4.2 Validation of the generated data against measured data

As mentioned earlier, the MeteoNorm generator was used to generate hourly weather data based on actual long term monthly means. To examine the accuracy of the generated data to represent the actual climate of Bahrain the measured climatic elements of one of the aforementioned periods was used (96-05) as a base to generate a weather data file. This was done in the basis that a10 years of climatic information would provide a reliable weather data design (see Section 5.2.1). A comparison was then carried out between the actual measured elements of this weather period (96-05) against the same elements in the weather data file. As the air-temperature, relative humidity and total solar radiation are the major factors impacting the energy consumption in buildings. This comparison will limit the discussion to these three elements. Figs. 5.11, 5.12 and 5.13 show the comparison of these parameters during different times of the year. The measured and generated elements are represented by two curves in each figure.

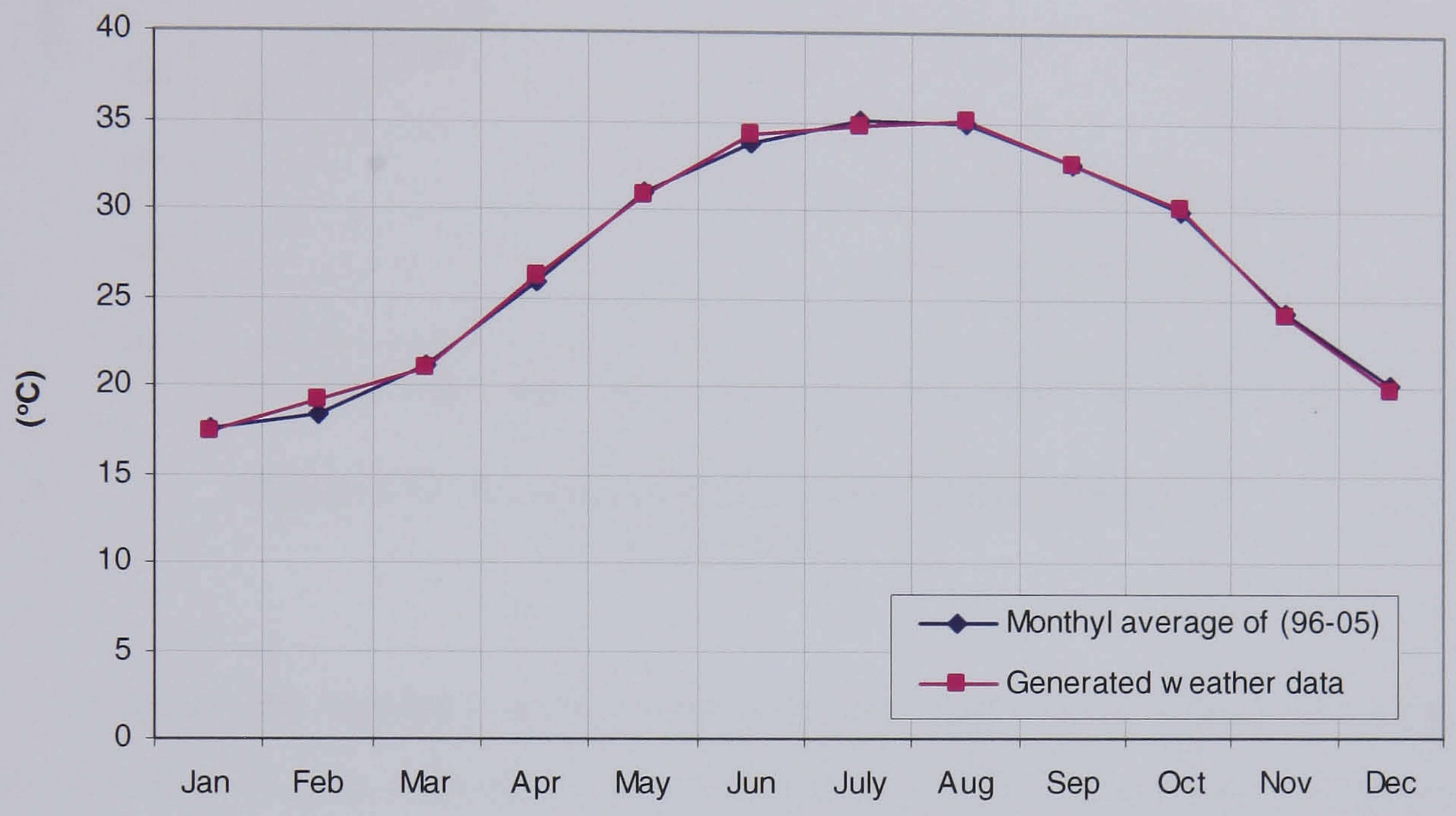

Figure 5.11 A comparison of monthly average mean temperature

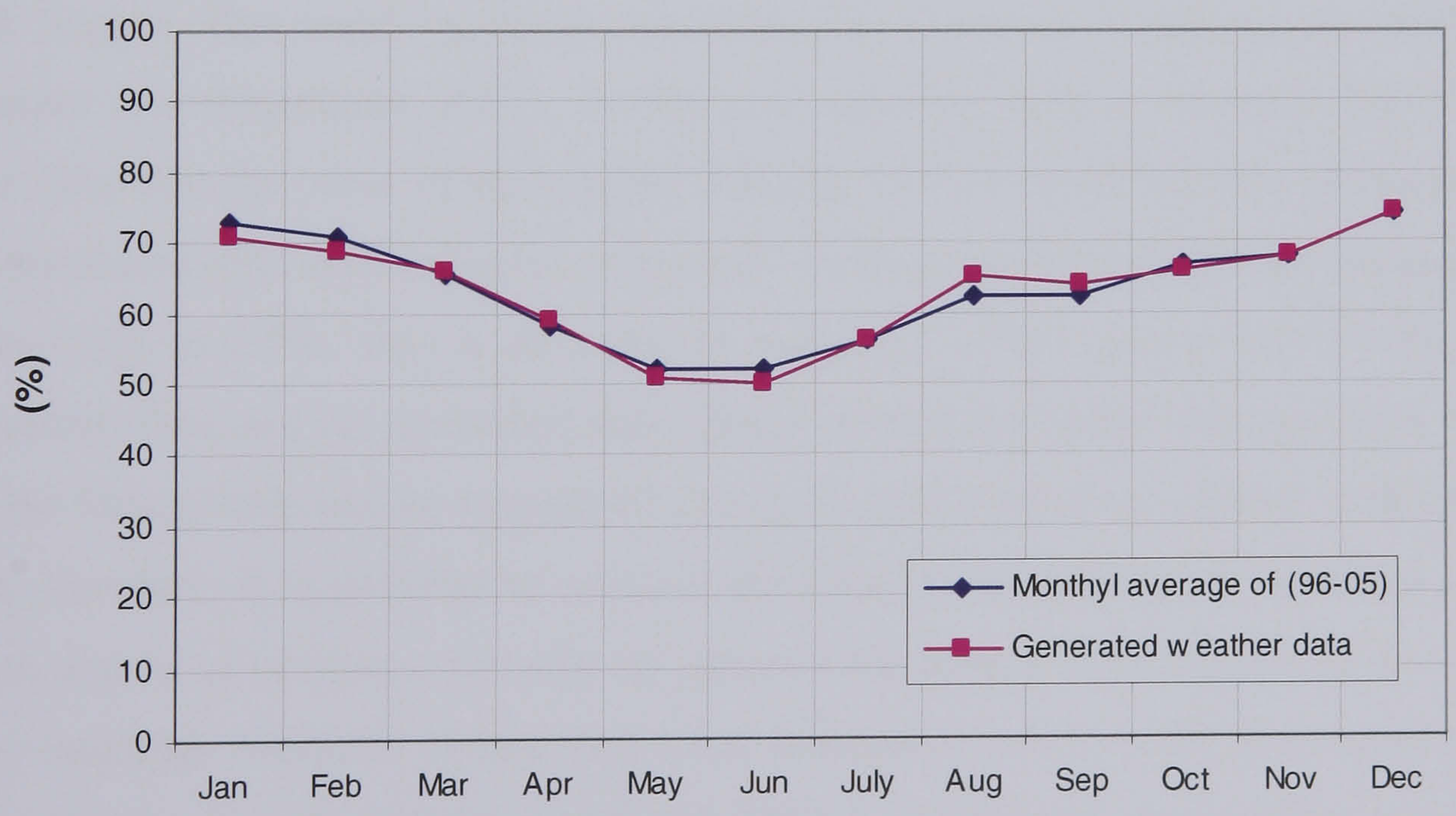

Figure 5.12 A comparison of monthly average mean relative humidity

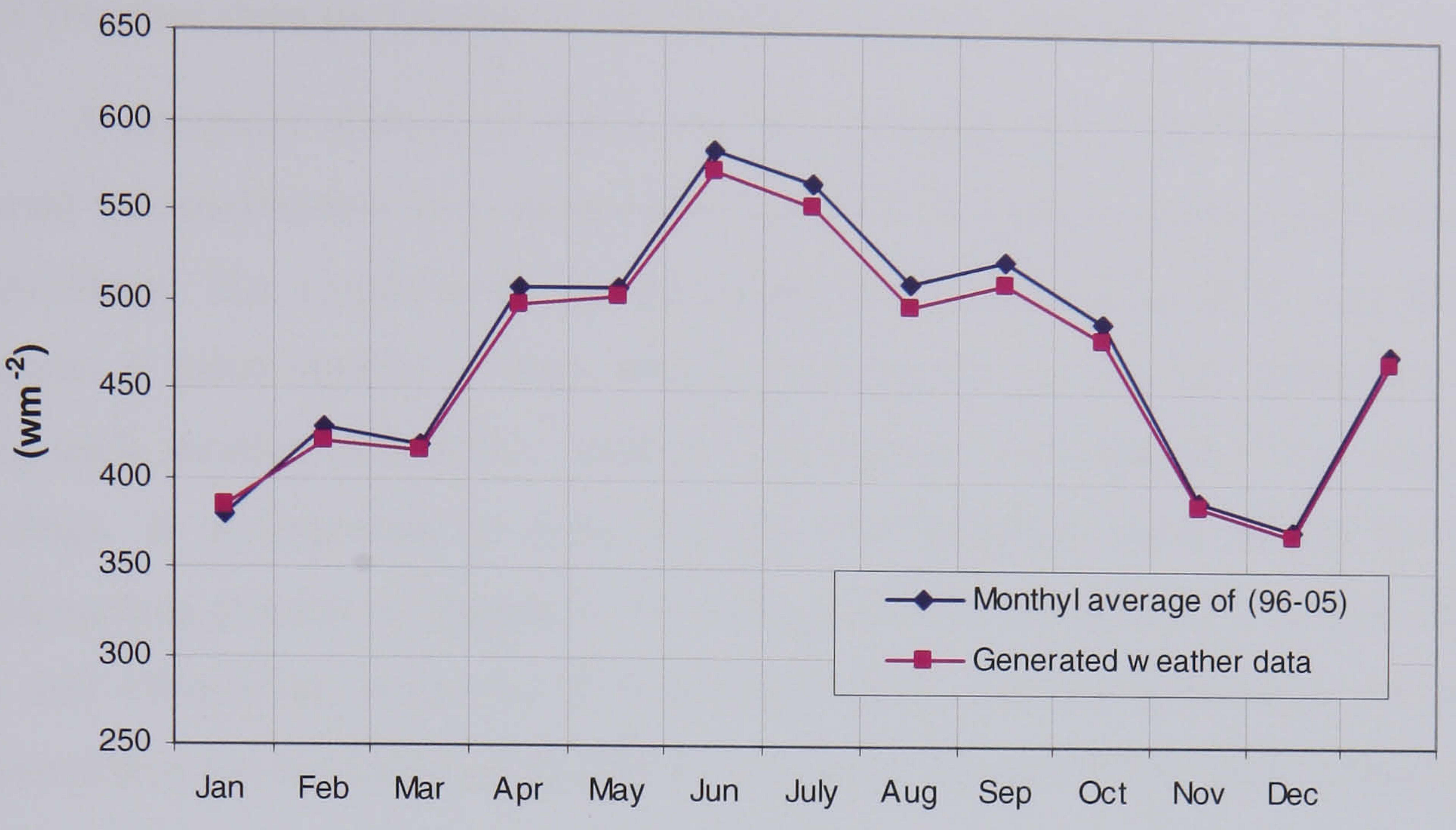

Figure 5.13 A comparison of monthly average mean total solar radiation

Clearly, the monthly averages mean temperature of the weather data file are fairly distributed with respect to the corresponding monthly averages mean of the measured temperature of the ten years with a small deviation in February and June. The same scenario can be noted in Fig. 5.12, which shows the two curves with respect to the relative humidity. The variation, in this case, is in January, May, June and August. This small variation (less than 1%) is normal in statistically derived weather data (Degelman, 2004). For the total solar radiation as shown in Fig. 5.13, it is clear that the curve of the weather data file is close to the ten year averages of the measured total solar radiation with small variations in the summer months ranges from 0.5% to 2.5%. This is an accepted indication of the agreement between the measured data and the generated data. Based on this indication, the generated data by the MeteoNorm can be considered as a good reflection of the climate in Bahrain and, therefore, it is possible to estimate the energy consumption of buildings to a good degree of accuracy. In order to estimate the energy consumption of the two case buildings computer binary files were developed based on the aforementioned two weather periods (DATA 61-90 and DATA 61-05) and incorporated into the Visual DOE program.

5.4.3 Weather data performance and building energy simulation

A computer simulation based on the developed files and buildings from Bahrain was undertaken as a comparative study of the electric energy performance of buildings. The comparison was performed using the Visual DOE simulation program. A great number of runs were carried out to examine the sufficiency of using each weather data file to estimate the energy consumption of the studied buildings. It is important to note that the two buildings were subject to the benchmarking process in Chapter 4. The energy utilisation index (EUI) of BSE-Bldg was 100 kWh/m^2/yr, while the EUI of MEW-Bldg was 805 kWh/m^2/yr. It was indicated that the electricity of the HVAC system is the most significant. Therefore, the calculation of cooling load and the total electricity consumption was taken as criteria. In this comparison, three types of simulation output were of interest: monthly profile of electricity, annual profile of electricity and cooling load profile.

Monthly and annual profile of electricity consumption

For the purposes of this comparison, electricity consumption due to DATA (61-90), electricity consumption data due to DATA (61-05) and the consumption data from electricity bills are represented by three curves in Fig. 5.14 and Fig. 5.15. The consumption values were obtained by simulating the BSE-Bldg using Visual DOE based on the DATA (61-05) and DATA (61-90). As for BSE-Bldg, as shown in Fig. 5.14, it is clear that during the summer months there is a large deviation between the curve of DATA (61-90) and the electricity bills, while DATA (61-05) is quite normally distributed with respect to the corresponding monthly consumption of the electricity bills. For MEW-Bldg, as shown in Fig. 5.15, the curve of DATA (61-05) is closer to the electricity bills, while the curve of DATA (61-90) has relatively larger deviation from the actual monthly consumption distribution, especially in the summer months from May to September.

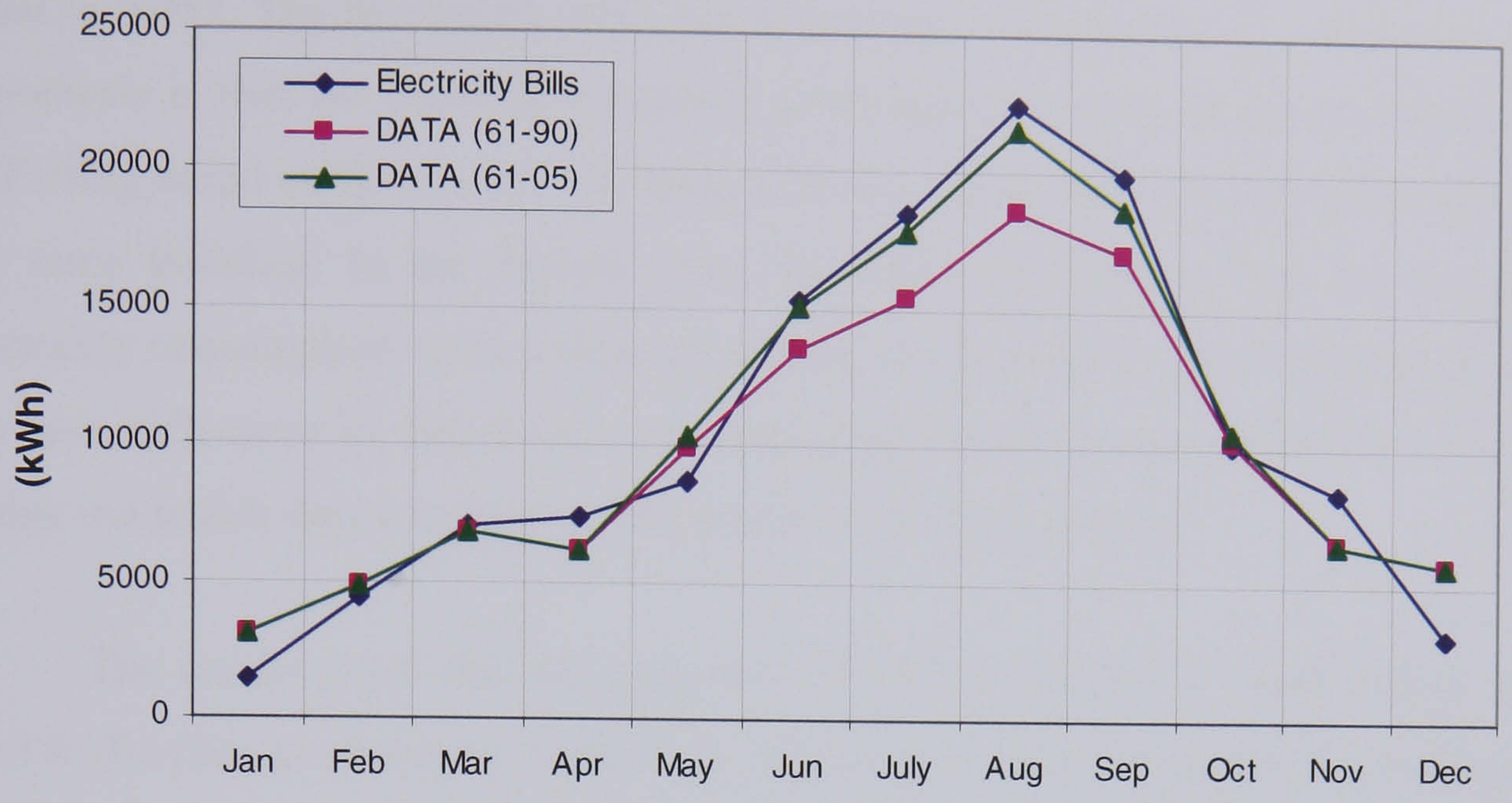

Figure 5.14 Electricity consumption of the BSE-Bldg

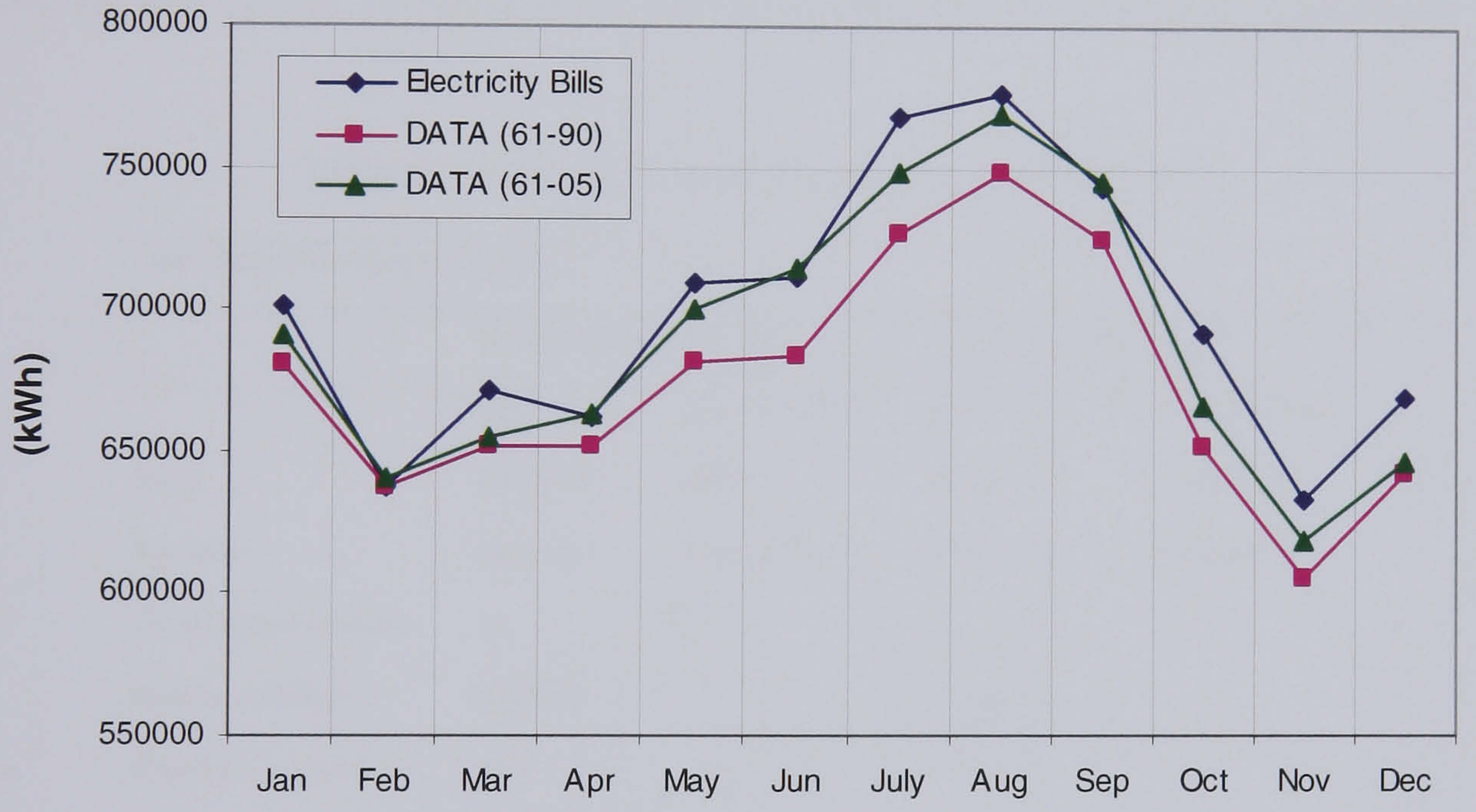

Figure 5.15 Electricity consumption of the MEW-Bldg

Clearly, DATA (61-05) is more representative for the actual building's situation. It can be used to estimate the monthly electricity performance more accurately. To confirm this result a *t*-test was performed on the monthly electricity consumption of the BSE-Bldg and the estimated data of consumption. In this test, the aim is to answers the following questions: is there a sufficient reason to conclude that the difference between the means of two populations (electricity consumption values based on generated weather data value and actual consumption values) is not equal to 0.05? The two-tailed *t*-test was performed twice. In the first time, the null hypothesis is that the monthly electricity consumption results from simulating the BSE-Bldg based on DATA (61-90) have different values from the electricity bills of the same building. In the second time, the null hypothesis is that the monthly electricity consumption results from simulating the BSE-Bldg based on DATA (61-05) have difference in values from the electricity bills of the same building. This is to fine out which data are closer to the actual consumption values.

The results show that the *t*-statistic of DATA (61-90) is much higher than DATA (61-05), as shown in Table 5.2, and hence is less similar to the electricity bills. Also, the probability of DATA (61-90) occurring during those years was 23%, while the probability of DATA (61-05) occurring was 80%, where the lower the *p*-value, the less chance of occurrence, and hence the difference is more significant.

Table 5.2 *t*-test of monthly electricity consumption

t-test: Paired two sample for means				
	Bills and DATA (61-90)		Bills and DATA (61-05)	
	Bills	DATA (61-90)	Bills	DATA (61-05)
Mean	10564.17	9835	47463059	40133891.06
Variance	47463059	27013470	47463059	40133891.06
Observations (months)	12	12	12	12
Pearson correlation	0.983655		0.988405	
Hypothesized mean	0.05		0.05	
df	11		11	
t statistic	1.257774		0.257357	
P (T<=t) two-tail	0.234519		0.801654	

Another important point to note is that the level of accuracy of each file in representing the weather and its impact on the electricity consumption was found to be the same in both case buildings. It was found that there was as much difference as 14.5% between the actual annual consumption and consumption related to DATA (61-90), while this difference becomes only 1.4% in the case of DATA (61-05). It was also noted that DATA (61-90) tends to underestimate the monthly electricity consumption. The underestimation ranged from 7.7% in February to 21% in July.

Cooling load profile

To investigate how climate variability alters electricity consumption the cooling degree–days were first calculated, as they represent the key impact on cooling and heating loads. When the cooling degree–days of each file are compared, as shown in Fig. 5.16, the result shows a 5.5% annual difference between DATA (61-05) and DATA (61-90). In the summer months, the amount of cooling degree–days in DATA (61-90) is less than DATA (61-05) by 6.6%. In the winter months, the amount of heating degree–days in DATA (61-05) is 0.75% less. The increase in cooling degree–days can be related to the increase in the air-temperature and direct solar radiation in the months from May to October. The drop in the wind speed may represent a negative impact on cooling loads, as speedy wind reduces the impact of temperature and solar radiation on the outer surface of buildings.

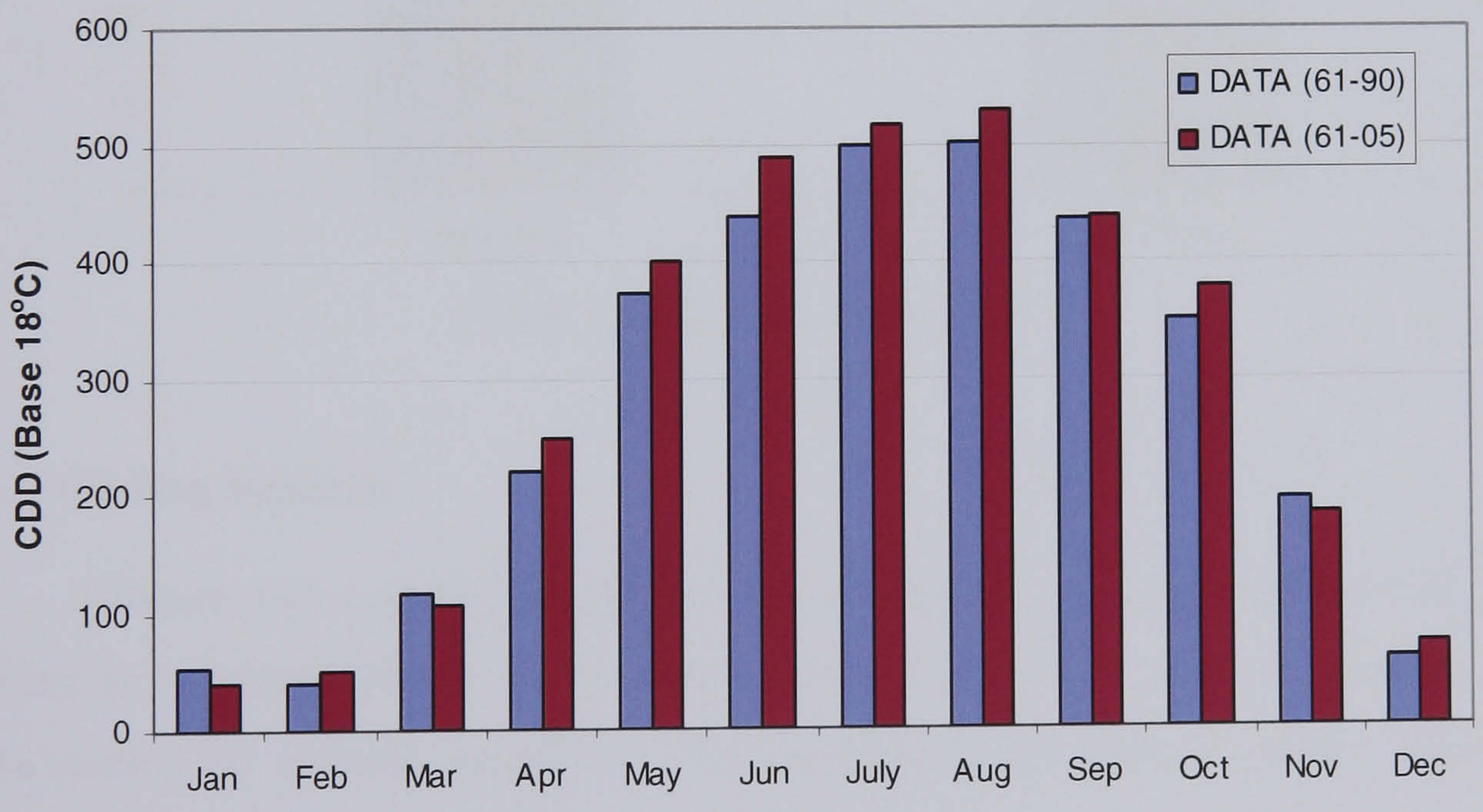

Figure 5.16 Monthly cooling degree-days (base 18°C)

Fig. 5.17 shows the annual cooling energy, as indicated by the benchmarking result and as obtained from Visual DOE using DATA (61-90) and DATA (61-05). It is clear that DATA (61-05) estimates the annual cooling load more accurately than the DATA (61-90) in both buildings. The percentage differences between DATA (61-05) and the benchmarked cooling load in BSE-Bldg and MEW-Bldg are 1.5% and 2.4% respectively. These differences become 5.9% and 8.9% when DATA (61-90) are used. As illustrated earlier, there is an increase in the direct solar radiation and air temperature as a result of heat island and population. This increase is assumed to be the most possible reason for the difference in cooling energy between the benchmarking results, simulation results based on DATA (61-05) and simulation results based on DATA (61-90).

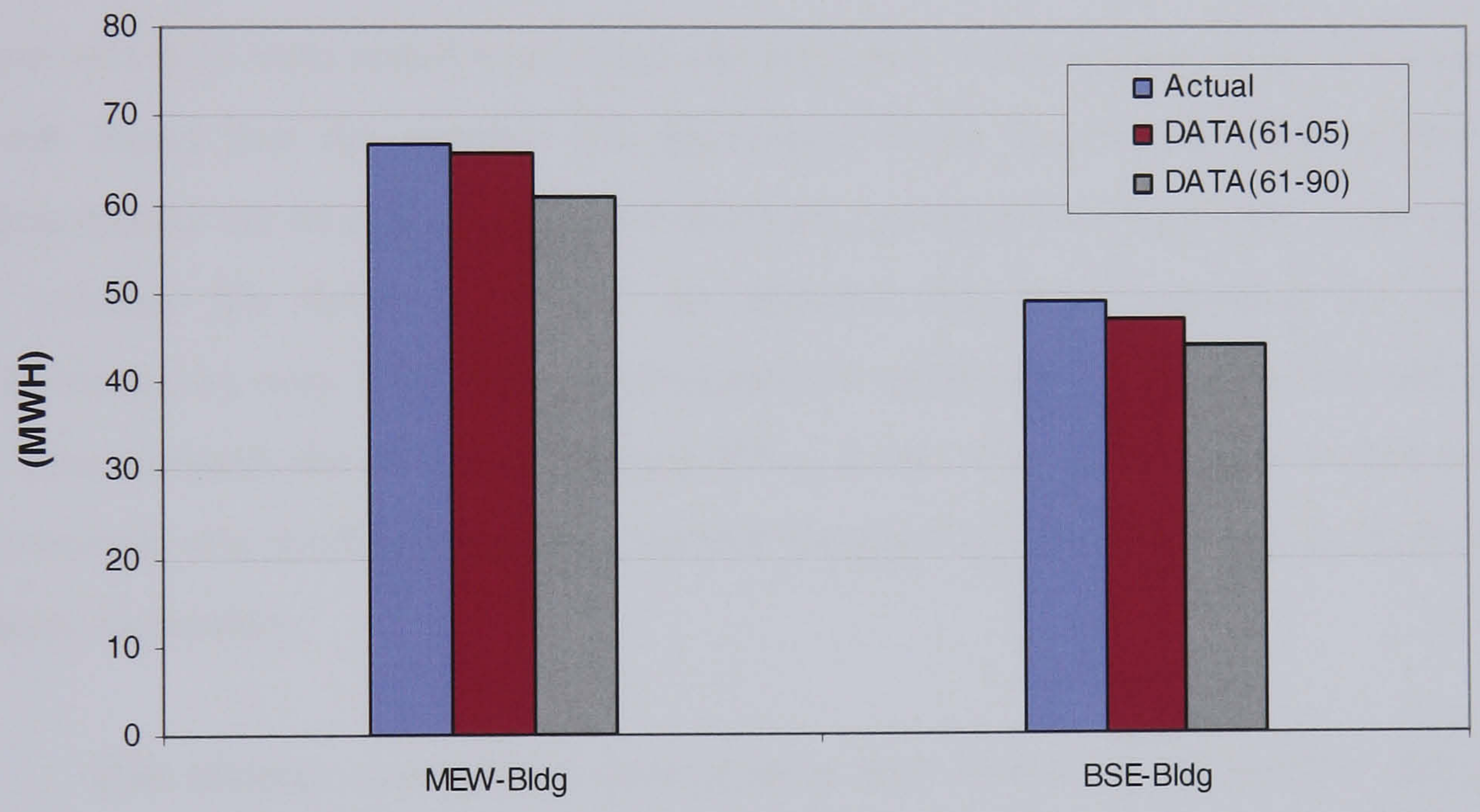

Figure 5.17 Annual cooling load

5.5 Closing Remark

Climate has a major impact on the energy use of most commercial and residential buildings. However, its impact differs from one location to another and with respect to climate variability. The estimation of climate impact requires representation of weather parameters, especially when simulation programs are used. However, the variation in weather conditions may affect the accuracy of this representation. For a reliable representation the inherent variability in climate should be taken into account when developing weather data for energy analysis. In this study, a comparative evaluation of Bahrain's climate shows variation in the climatic parameters. It was found that these parameters tend to get warmer. The temperature is rising at a rate of 1.4°C per decade, while the relative humidity is decreasing by approximately 8.2% for the same period. Wind speed tends to be slower than before due to building and local influences. Direct solar radiation is increasing, especially in the cooling months. However, there is a drop in diffuse solar radiation.

Weather data used in Bahrain were developed based on far past climatic information, a reason why the variations in climatic elements during the last few decades has been neglected. This puts the reliability of those data in question. In this study, two weather data files were developed. The first is based on data from far past. The second is based on updated data to reflect all patterns of Bahrain's climate. These two files were tested to estimate the electricity consumption of two buildings. It was found that the weather file developed based on far past data tended to underestimate the monthly and annual electricity performance by 14.5%. Conversely, the weather file developed based on updated data underestimated the actual performance by only 1.4%. Due to ignorance of variation in solar radiation, the first file misrepresents the cooling load by 5.9% to 8.9%. The set of results in this study demonstrate the need to update the current weather data in Bahrain with respect to climate variability.

This chapter covered the development and evaluation of weather data for Bahrain. It first generated statistically based hourly weather data and then developed computer files. These files were incorporated into a simulation program in order to evaluate their performance with respect to the actual energy consumption of office buildings. The next chapter integrates building simulation into a systematic methodology in order to evaluate the energy performance of office buildings in Bahrain.

Chapter 6 A METHODOLOGY FOR PERFORMANCE EVALUATION

> *A building's energy performance is determined by a complex and unique set of variables. The most valuable road to improvement usually results from detailed analysis combined with creative problem solving.*
>
> *(Sizemore et al., 1979: 25)*

6.0 Introduction

Chapter 1 described computer modelling as one of three major strategies for promoting building energy efficiency in Bahrain. Chapter 4 identified various types of building energy standards and highlighted their impact on energy performance, while Chapter 5 developed a recent weather data file to use with simulation programs. These programs can be a potentially powerful analysis system. The implementation of such system, however, requires a general methodology. The main research objective of this chapter is to introduce a simple but reliable methodology for evaluating the impact of energy standards on building performance using a state-of-the-art building simulation. This chapter begins with a discussion on the process of improving building energy performance and the need for evaluation methodologies, in section 6.1. Section 6.2 then introduces the methodology and highlights the various effects of energy performance. Section 6.3 implements the introduced methodology to a case building from Bahrain.

6.1 Energy Performance of Buildings

6.1.1 Improving energy performance

Any attempt to improve the energy performance of buildings should go through four logical steps, as illustrated in Fig. 6.1. These steps should be considered under the whole building performance and can be summarised as:

Evaluation of the current performance: this step seems to be the most important ones. It gives a complete picture about the current situation of building performance and provides a basis for identifying measures for optimising the energy performance.

Search for optimisation measures: the second step reviews the measures already identified during the previous step and search for additional measures.

Assessment of optimisation measures: the third step is the assessment of the identified and proposed measures in order to find the most rewarding ones.

Targeting future performance: in the last step, a realistic and achievable target for the future performance is set.

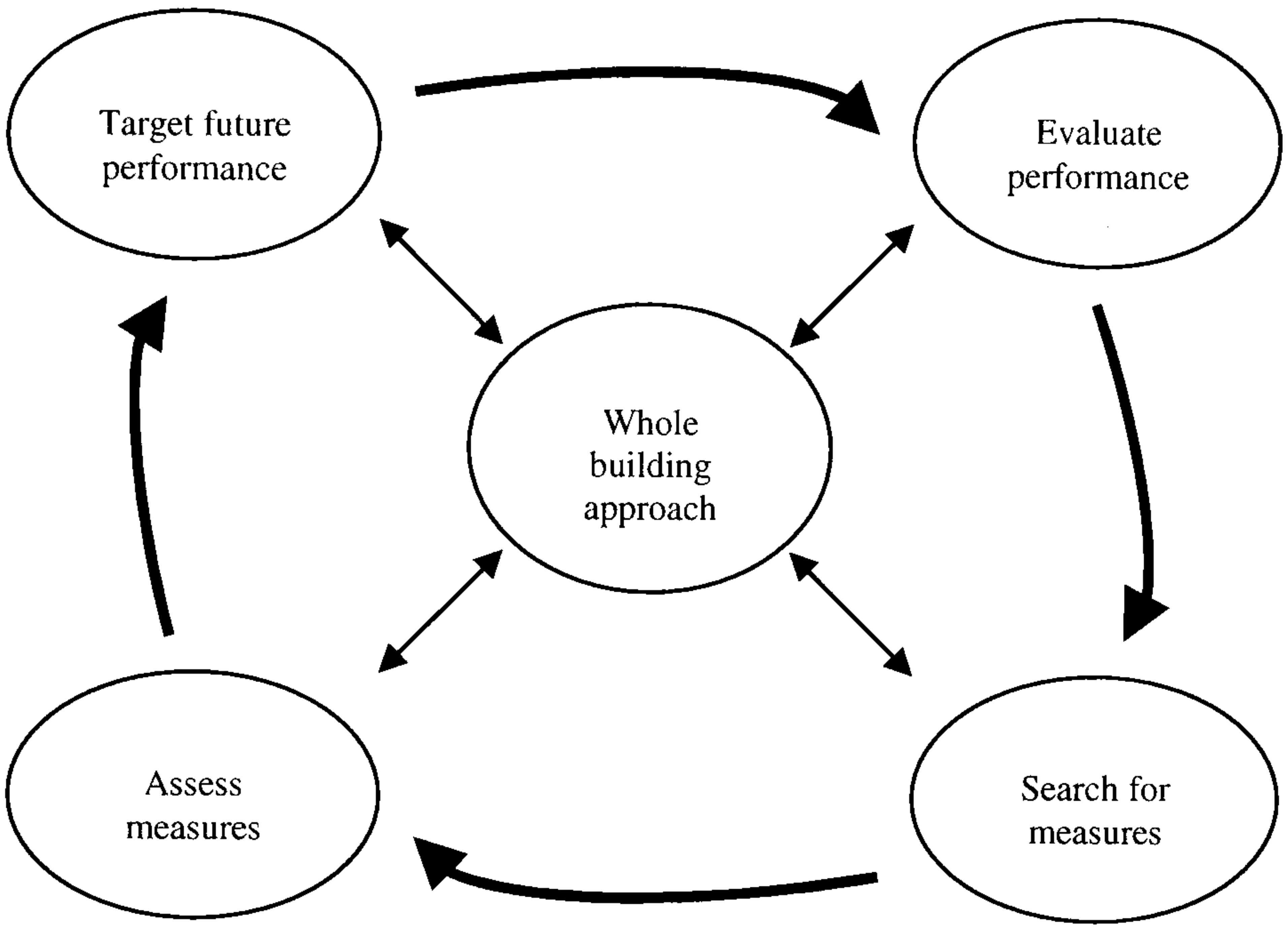

Figure 6.1 Steps for improving energy performance

6.1.2 Need for evaluation methodologies

Modern buildings are complicated energy systems, where the interaction of different variables plays the major role in the energy consumption, CO_2 emissions and the level of internal conditions. Analysing this interaction requires a reliable procedure and tools, especially with the high degree of complication and diversity. Today, a great deal of effort is ongoing to find methods to evaluate the performance and introduce tools for energy analysis. The European Energy Performance of Building Directive (EPBD) is such an attempt. This directive aims to ensure energy saving and CO_2 emission reduction without compromising the local conditions and people's comfort. To achieve this aim the EPBD focuses on developing methodologies to evaluate the energy performance of buildings. In the Gulf States, particularly in Bahrain, there is a need for such methodologies due to their economic and environmental benefits.

6.2 A Methodology for Energy Performance Evaluation

The principle of any successful methodology for performance evaluation is the consideration of all impacting parameters such climate, building design, building occupants and the indoor environment. Fig. 6.2 shows a simple methodology for evaluating the energy performance of buildings. This methodology consists of three steps:

- o Studying the effect parameters
- o Analysing energy behaviour
- o Evaluating building performance

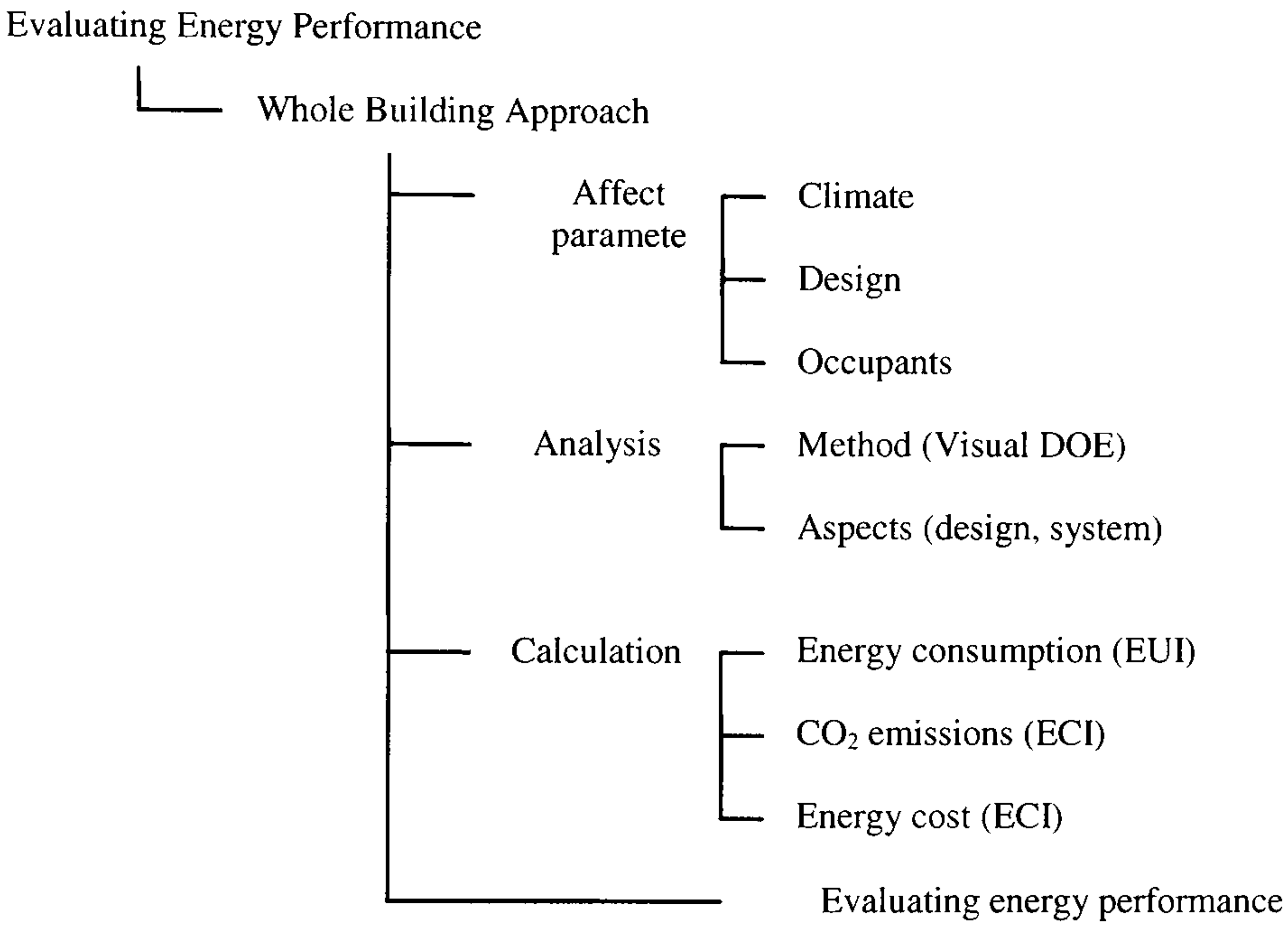

Figure 6.2 A methodology for energy performance evaluation

These steps are applicable to all buildings, with special emphasis on office buildings. The aim is to introduce a methodology that integrates simulation programs in the process of evaluating the impact of energy standards on building performance. The principal advantage of this methodology is that less specialised skill is required and only a microcomputer is needed to perform the evaluation. Therefore, evaluating how to improving the energy performance can be done cheaply and quickly. The following sections briefly study each of the above steps

6.2.1 Effect parameters

The effect parameters can be divided into three categories: climatic effects, design effects and people effects. The climatic effects relate to the micro-climate and location of the building. The design effects focus on the building design and systems operation, while the people effects are concerned with the occupant's needs and behaviour. Because each building is unique the impact of these effects varies from context to another. However, the climate seems to be the first and most important motivation for energy use and, therefore, no analysis can be done without studying the climate.

Climate

Climate has a major impact on the energy performance of buildings. Such impact can be seen in the impact of temperature on heating, cooling and ventilation loads, wind speed and direction on space heating and ventilation, solar radiation on cooling and lighting loads, hours of day-lighting on lighting load and the cloud layer on space heating. To estimate these impacts on the overall energy performance of any given building, a representation of weather parameters is required. This is of importance when the simulation programs are used in the performance evaluation. The climate of Bahrain and weather data generation were studied in Chapter 5.

Design

Buildings are complex products composed of a large number of materials and components, each constituting of various design variables. These variables are interacting with each another and with the climate. A variation of every variable may impact the energy behaviour, the internal conditions and the external environment. Design variables impacting the energy performance are:

- o Envelope parameters
- o Thermal properties elements
- o Building System – HVAC, Lighting and Equipment

The envelope parameters are an important factor that impacts the energy consumption and the internal conditions. Each of these parameters has different effect on the thermal performance of buildings. The design of the opaque wall, for example, impacts the ventilation and building thermal loads, while the design of glazing impacts the cooling and lighting loads. Furthermore, the way the building system (HVAC and non-HVAC systems) set up to respond to the demand of lighting, cooling, and ventilation is another major factor impacts the amount of energy consumption. Above all, how these system are performing to maintain comfortable internal conditions. Therefore, the complex and dynamic interactions the building's parameters and materials have with each other and with the environment need to be considered for a sufficient evaluation.

People

It follow from the above that the efficient operation of building systems is a key factor in the amount of energy consumption. These systems and their operation schedules are often related to the people and influenced by the way of using the building (Depecker *et al.*, 2001). The people impact is noted in the working times, cleaning schedules, maintenance, thermostat setting and above all the way the people are interacting with the building systems (attitude and culture) (Pedersen, 2007). The people impacts may represent the most influential factor on the amount of energy consumption. The share of this factor can reach 50% of the total energy consumption. However, this amount varies from one building to another depending largely on building type (e.g., residential or commercial), building system (e.g., passive, air-conditioned) and control system (e.g., manual, automatic) (Andersson *et al.*, 1987). Moreover, people themselves constitute a source of heat within a building. This means that for estimating the energy consumption of a building it is important to obtain information about the people occupying the building along with information about building location and physical design.

6.2.2 Energy analysis

Analysis procedure

Energy analysis may be performed for new building design, energy-end-use monitoring or for energy audit calculations. In other words, it can be used to predict future performance, to estimate present performance or to investigate past performance. Each type has its own methods and techniques. For example, the estimation of the past performance can be made through using some audit and analysis techniques. They are based on energy invoices (bills) for the past few years including some aspects of energy use (e.g., energy peak, energy consumption and energy costs). This type of evaluation is illustrated in the benchmarking process in Chapter 4. The present and future performance can be estimated using a multitude of methods, which are, most of the time, subject to technical developments.

Nowadays, performance evaluation is closely linked with the use of computer. Energy simulation programs are becoming the most popular and flexible tools for building energy analysis. Their advance has significantly changed the way the energy analyst performs the analysis, especially with complexity of modern buildings. Since computer modelling is concerned, this chapter limits the discussion on the analysis process used by the Visual DOE program. This is because Visual DOE can be used by different disciplines involve in building design and operation to provide energy performance assessment that is as close as possible to the real performance of the building throughout its life-cycle. Another point is that Visual DOE is able to estimate building performance using different criteria such as energy, cost and environment indicators.

Analysis process

Fig. 6.3 illustrates the structure of the analysis procedure adopted for this study where the simulation program represents the main tool. In this procedure, the assessment of energy performance is a move from the load calculation level to the energy estimation level. Between these two levels, there are three general steps:

Building description: the first step is the description of the building and all factors affecting its energy consumption.

Load calculation: the second step is the dynamic calculation of building loads. It is useful to separate the end-uses: HVAC and non-HVAC systems. This is because the HVAC load calculation is a complicated process due to its sensitivity to more dependent variables than any other components of the building. Thereby, most of the analysis is centred on the HVAC system.

Energy estimation: the last step is a totalling for the HVAC and non-HVAC system energy needs including the efficiency of these systems. This allows the estimation of the energy consumption for the whole buildings.

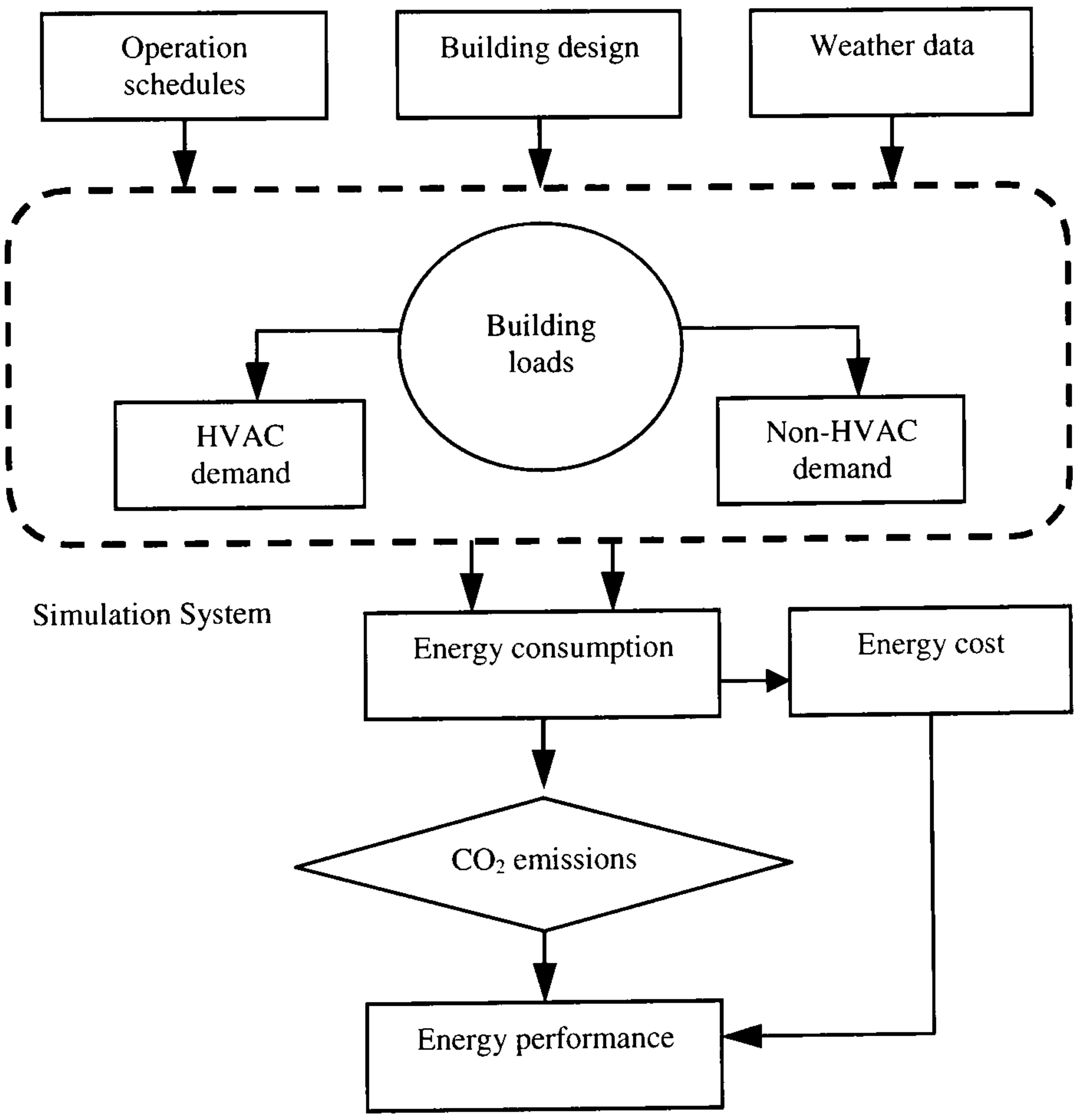

Figure 6.3 Structure of energy analysis

The above steps are realised in the Visual DOE program which is essentially based on the transfer function method. In Visual DOE, the consideration of the impact parameters and their interactions comes first following by the Load, System, Plant, and Economic (LSPE) procedure (Visual DOE Manual, 2004). This helps to develop different outputs and profiles of loads, energy consumption and CO_2 emissions.

6.2.3 Evaluation of building performance

Before performing the evaluation, criteria for evaluating building performance should be defined. Various criteria are used to performer this evaluation, including energy indicators, thermal comfort, day-lighting level, visual comfort, and acoustic comfort. Each of these criteria measures one or more requirements of building performance. However, improving some performance requirements may deteriorate other aspects. Therefore, it is important to evaluate the performance of the building as a whole. The amount of energy consumption, energy cost, and CO_2 emissions of the whole building may represent sufficient indicators for the whole building energy performance. To evaluate the energy performance in light of the simulation program outputs it is necessary to translate this output to useful data such as an energy utilisation index (EUI), energy cost index (ECI) and CO_2 emissions index (CEI). These indices can be certified and used as indications for the current performance.

6.2.4 Optimisation measures and targets for future performance

Optimisation is the search for the best possible solution to a particular problem (Bouchlaghem, 2000; Nielsen, 2002). This search can be for minimising the energy consumption, reducing the CO_2 emissions or for any other aspect of building performance. The search for optimisation measures can be identified in a two-part sequence: measures already identified and proposed measures based on the result of energy analysis. As will be discussed in the next chapter, one method of searching for optimisation solutions is to test several measures by computing the energy performance of each one with respect to a base-line. Varying one measure at a time and keeping the others fixed or following what the so-called sensitivity analysis enables one to obtain a great number of optimisation solutions. This will not only show the impact of different energy standards on energy consumption and CO_2 emissions, but will also show the impact of these standards on various building loads. These results and other assessment methods are then used as a target for future performance, for which building management is stimulated to make improvements (CIBSE, 2004).

6.3 Implementation

For the purpose of this implementation, the current methodology was applied to evaluate and optimise the performance of an existing office building in Bahrain. The energy behaviour of this building was first analysed in order to know the negative and positive design features. The procedure introduced earlier was followed based on the weather data file developed in Chapter 5 and the Visual DOE program presented in Chapter 3. The most efficient measures were then identified. Finally, an attempt was made to drive a target for electricity consumption that serves as a benchmark for future performance.

6.3.1 Building characteristics considered in this implementation

As six office buildings were benchmarked in Chapter 4, this section examines the worst energy performer among them. The Ministry of Electricity and Water office building (MEW-Bldg) is constructed on a rectangular footing. It has a ground floor and 11 more storeys as shown in Fig. 6.4. The surface area of each floor is 800 m^2, and its floor to floor height is 3.8 m. The walls consist of mainly 200 mm concrete block, 24 mm inside and outside plaster, and 50 mm polystyrene insulation. The roof consists of 50 mm screed, 35 mm polyurethane and 200 mm concrete slab. The glazing type is 6 mm double glass with an approximate 80% glazing (0.8 window-to-wall ratio). The building has multi-thermal zones with a central constant HVAC system. Complete details of the building's physical and operational characteristics are illustrated in Table 6.1.

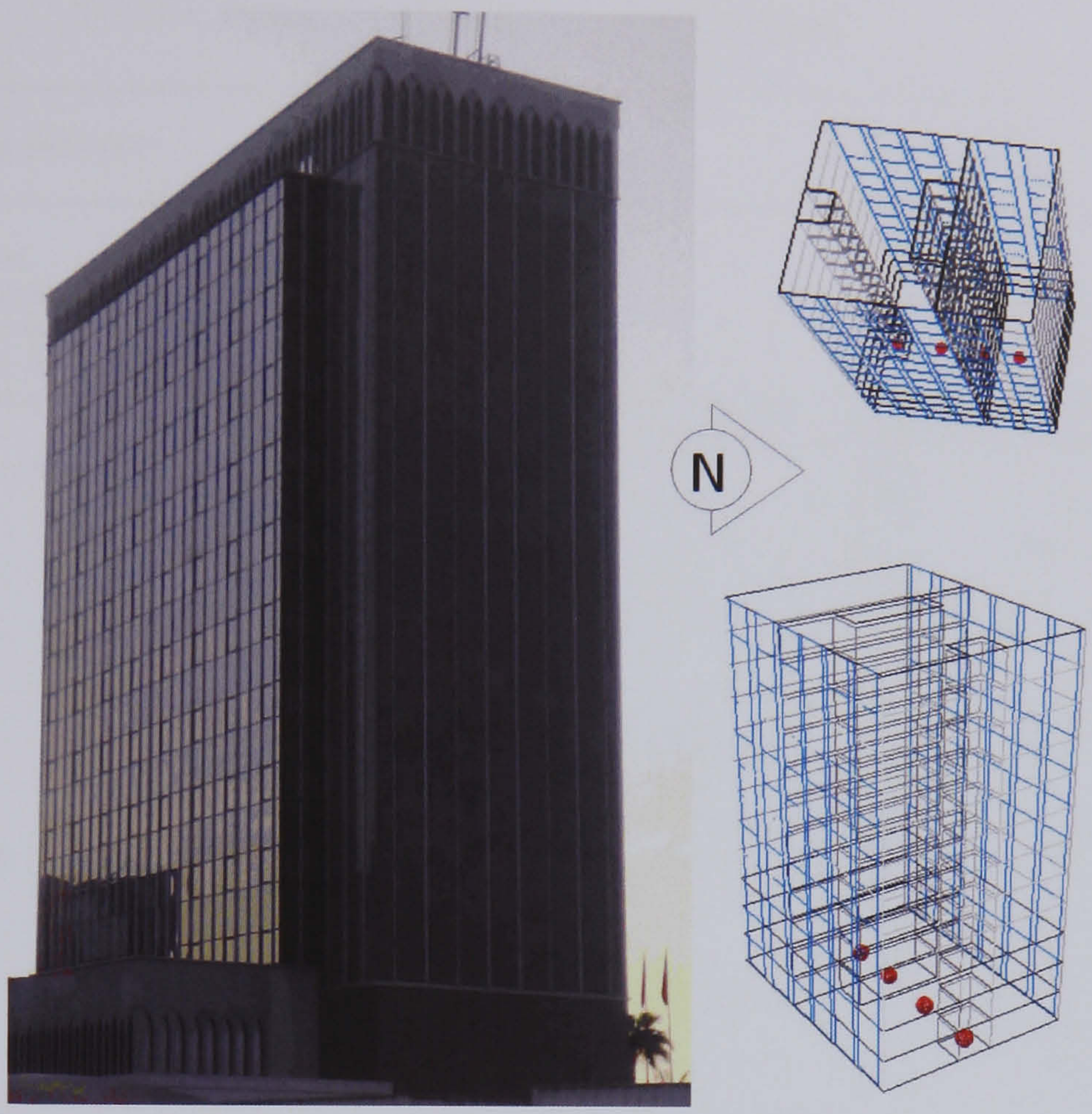

Figure 6.4 View of MEW-Bldg

As tabled the temperature is set on 22°C in winter and 24°C in summer. The operation schedule of the building is from 7.00am to 2.00pm, and sometimes extends to 6.00pm of approximately 60 hours per week, which is normal for the public sector in Bahrain. The lighting is divided into two categories, i.e. the common area and the office area. Both use different types of lighting fixtures with an average load of 18.5 W/m^2. This building uses different types of equipment including personal computers, small and large printers, scanners and various types of office equipment. There are three lifts and two domestic water pumps for sprinkler system and two hose reel pumps.

Table 6.1 Description of MEW-Bldg

Building parameters					
Total area	9600 m^2				
Floor height	3.5 – 40 m				
Orientation	East to West				
Building skin					
Components	Construction	Thickness (mm)	Conductivity (W/m.°C)	R-Value (m^2/W.°C)	U-Value (W/m^2.°C)
Opaque wall	Outside surface	-	-	0.059	
	Outside plaster	12	0.75	0.016	
	Concrete block	200	-	0.2	0.63
	Insulation	50	0.03	1.17	
	Inside plaster	12	0.75	0.016	
	Inside surface	-	-	0.121	
Roof	Screed	50	1.45	0.03	
	Insulation	35	0.033	1.52	0.5
	Concrete	200	1.83	0.11	
Opening	Double glazing	6 mm	16.6	0.3597	2.72
	SC	0.57			
	Transmittance	0.81			
	Shading device	No			
WWR	0.8 north and south facades – 0 east and west facades				
	Infiltration rate	5.0 m^3/h/m^2			
	Ventilation rate	7.5 l/s/person			
Building body					
Thermal zone	Floor 1	Reception and managers offices			
	Floor 2	A canteen and offices			
	Floor 3	IT centre			
	Floor 4 -12	Office cubical			
Building system					
Equipment	56.4 W/m^2				
	3 lifts rated 15 kW / 2 water pumps each rated 18 kW				
	1 sprinkler system 37 kW / hose reel pumps each rated 18.5 kW				
Lighting	Florescent / spot light 18.5 W/m^2				
HVAC system	Constant centralised System				
Set point	Winter	22°C			
	Summer	24°C			
Building operation					
Schedules	7am – 2 pm	60 hours/week			
Occupancy	25 m^2/person				

Calibrating to the case building's past performance

As stated earlier that the estimation of the past performance can be made by studying the energy bills of the past few years. Information obtained from previous bills can be used to investigate the level of efficiency of the building comparing to similar buildings or to standard benchmarks. In the building under study, the electricity bills of one year were collected on request from the Electricity and Water Conservation Directorate. These bills provided sufficient information about the previous annual and monthly electricity consumption and also helped in calibrating the base case of the simulation program. Table 6.2 illustrates the annual and monthly electricity consumption from electricity bills and consumptions obtained from the Visual DOE program.

As tabled, the electricity bills are represented by MEW-Bldg, while the simulation model is represented by the base case building. Initially, the model was defined using the actual building data obtained from the audit report. The weather data file (DATA 61-05) developed in Chapter 5 was used as a climate input. It is clear that there was as much as 4.0% difference between the actual annual consumption of the MEW-Bldg and the base case building. The most possible reason behind the over-prediction in such a high rise building is the occupant behaviour (cleaning times, maintenance, operating some office equipment) which may affect the operation schedules. This behaviour is difficult to be predicted by simulation programs even when accurate audit reports are used. Although the simulation result (less than 5%) is accepted in building simulation (Visual DOE Manual, 2004), trials were made to manipulate the estimated input performance parameters such as schedule of use rate and set point temperature to closely match the electricity consumption of the base case with electricity bills. For the final trials as shown in Fig 6.5, schedules of occupancy, lighting, and equipment were adjusted and different infiltration rates were tried.

Table 6.2 Monthly and annual electricity bills

Month	Days	MEW-Bldg (actual) (kWh)	Base case building (a simulation model) (kWh)	Difference (%)
Jan	31	701140	728653	-3.9
Feb	28	637081	674527	-5.9
Mar	31	671294	692402	-3.1
Apr	30	661928	700999	-5.9
May	31	709799	735630	-3.6
Jun	30	711580	741294	-4.2
Jul	31	768412	787171	-2.4
Aug	31	776343	810122	-4.4
Sep	30	743842	783264	-5.3
Oct	31	691548	700386	-1.3
Nov	30	633745	659173	-4
Dec	31	669376	687332	2.7
Average				-3.4
Annual (kWh/yr)	365	8376088	8710971	-4.0
EUI (kWh/m2/yr)		805	837	-4.0

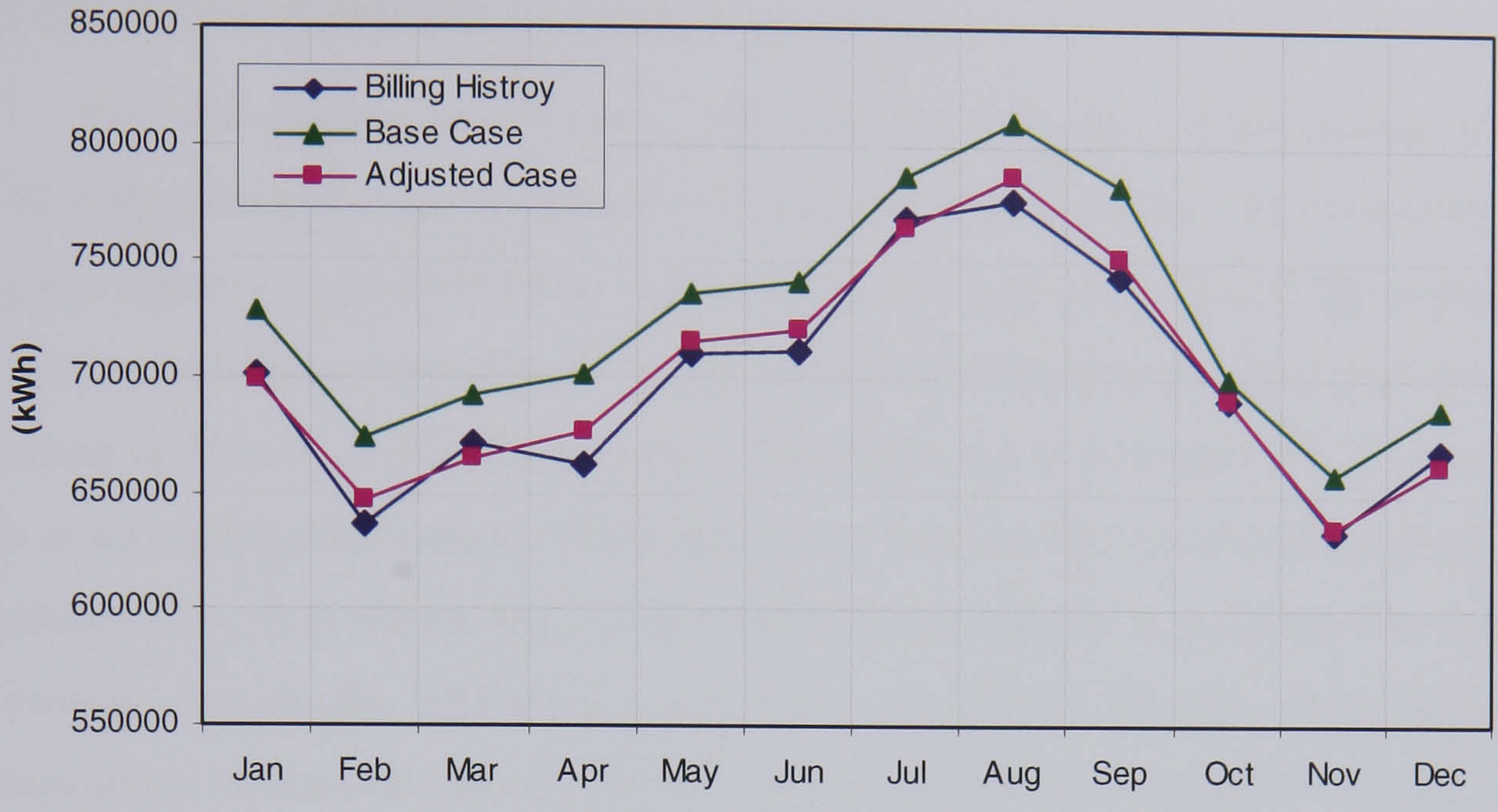

Figure 6.5 Comparison of monthly billing history and simulation results

Based on the above illustration, it is clear that Visual DOE predicted the monthly electricity consumption fairly well during different times of the year. When the actual consumption for heating season from November to April was compared with the simulation results, the difference ranged from 2.3% to 0.3%, while the difference of cooling season from May to October ranged from 2.7% to 0.5%. The final results show a 1.4% difference between the actual annual consumption and the estimated one. This can be considered an accepted result. The remainder of this chapter first analyses the energy use patterns of the studied building and then proposes the best possible measures for the performance optimisation and finally sets a target for its energy performance which had an 805 kWh/m^2/yr performance index.

6.3.2 Performing the analysis

A great number of runs were made to evaluate the energy use patterns of the MEW-Bldg. Three types of simulation output were of interest:

- Monthly profiles of building electricity consumption
- Annual electricity consumption
- Cooling peak load components

Monthly profiles of building electricity consumption

Fig. 6.6 graphically illustrates the monthly electricity consumption of the MEW-Bldg obtained from electricity bills and simulation results. As illustrated, the monthly figures of simulating the case building are fairly distributed with respect to the corresponding monthly figures of the actual electricity consumption with a small deviation in March, June and December. The difference is less than 3% in all cases. This is an accepted indication of the agreement between the simulated data and the electricity bills. It is shown that the electricity consumption varies from one month to another due to the difference in weather conditions. Clearly, the electricity consumption increase in the six hottest months from May to October. August is at the top, while the lowest consumption occurs in November and February.

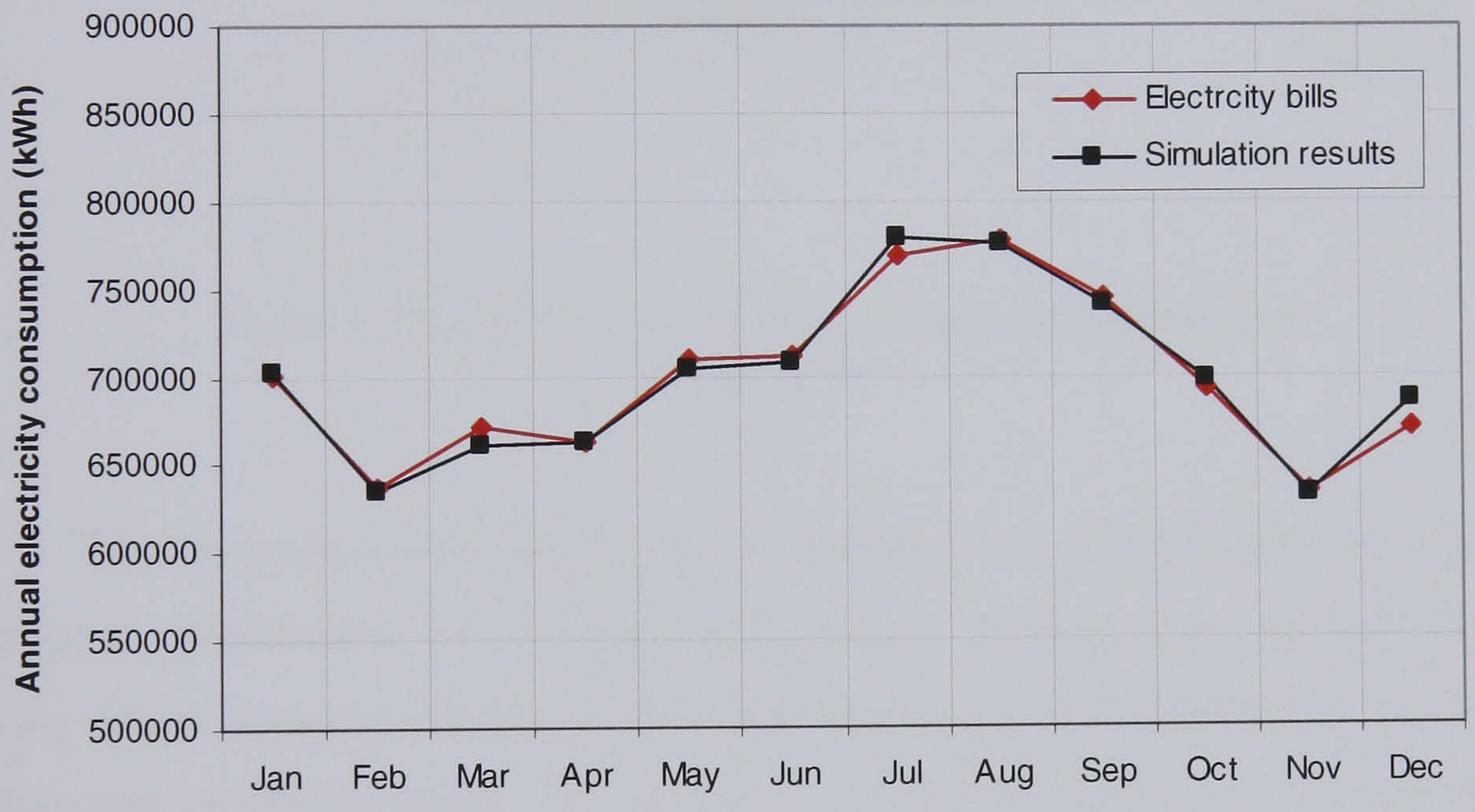

Figure 6.6 Monthly consumption

Annual electricity consumption

The annual electricity consumption of the MEW-Bldg was found to be influenced by a number of performance parameters as shown in Fig 6.7. These parameters are broken down into nine components according to the Visual DOE program:

- Lights
- Equipment
- Space heat
- Space cool
- Heat reject
- Pumps
- Ventilation fan
- Domestic hot water
- Exterior-lighting

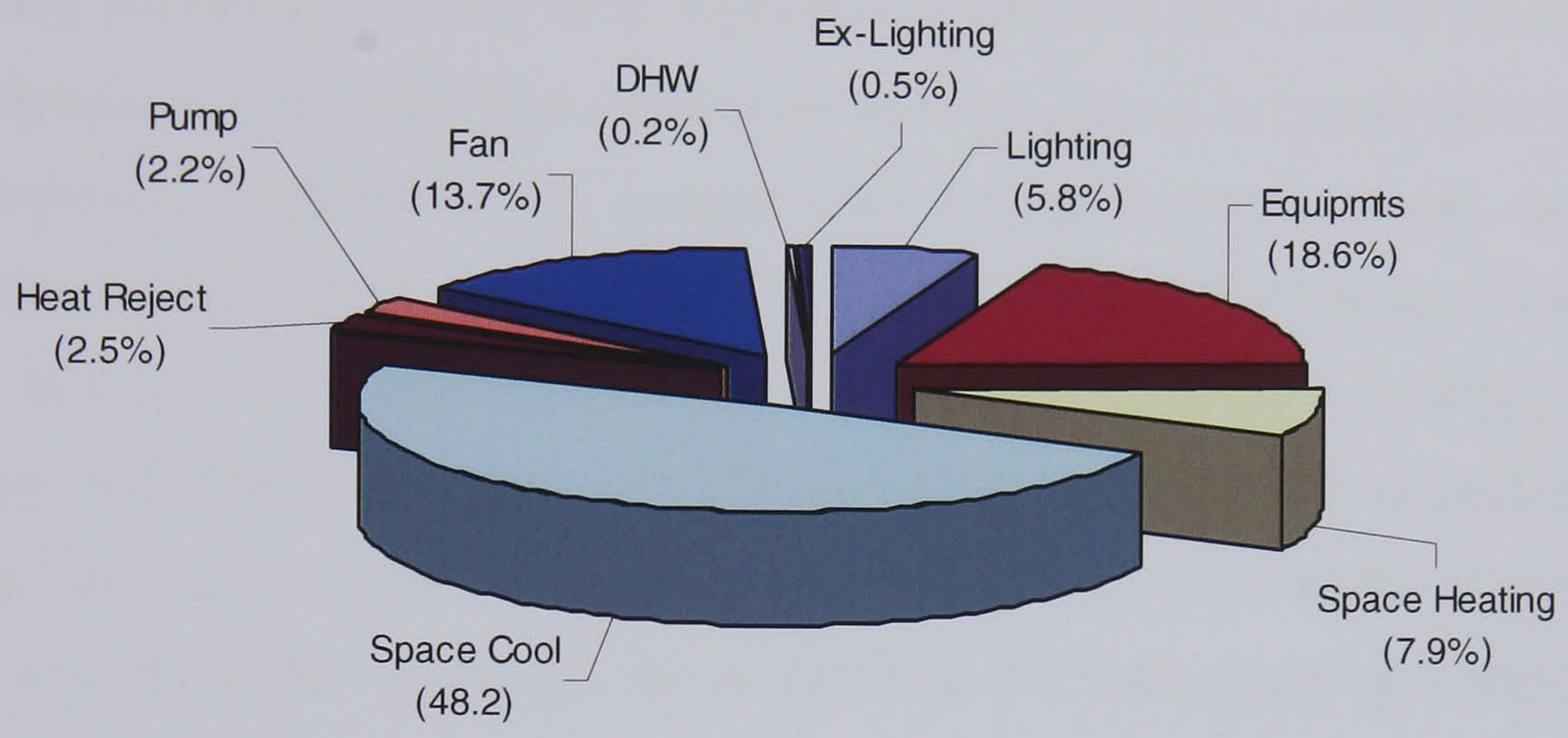

Figure 6.7 Breakdown of annual electricity consumption per components

The illustration indicates that the electricity of the HVAC system is the most significant, particularly for cooling energy (space cooling, fans, pumps and heat reject), which requires 66.9% of the total electricity consumption to satisfy the cooling and ventilation loads. This percentage is normal for commercial buildings in Bahrain. Heating the same building consumes only 7.9%, which is relatively small compared to the cooling energy. This is due to the hot climate of Bahrain and the short period that the building needed to be heated up. At the same time, domestic hot water consumes only 0.2% for the whole year. As the building is equipped with various electricity devices, the equipment has a major share of electricity consumption which reached to 18.6%. Lighting consumes 5.8% which is fairly low in these types of buildings. The reason behind this is the huge glass façade with an approximate 0.8 window-to-wall ratio. As shown the huge glazing area positively impacts the lighting load. However, it negatively impacts the cooling loads.

Cooling peak load components

As indicated earlier the cooling energy has the major share of electricity consumption. Fig. 6.8 breaks down the cooling peak loads according to the sources of the load in the building under study. These sources include wall conduction, roof conduction, glazing conduction, glazing solar radiation, occupant, lighting, equipment and infiltration. Clearly, the external heat gain particularly that related to the glazing parameters are the most significant impact on the cooling loads. Solar gain is dominant (40%) and heat conduction through glazing is significant (12.8%). Other parameters impacting the cooling load are the infiltration rate and heat conduction through opaque part at approximately 4.3% and 3.2% respectively. The internal heat gain also plays an important role in the amount of cooling energy, especially that of the equipment and lighting with 27.7% and 9.7% respectively. In addition, are the occupants themselves. They generate heat which impacts the cooling load by 2.8%. Although office buildings are categorised as internal load dominated, it is clear that the external load in this building has the largest share of heat gain with an approximate value of 60.1%.

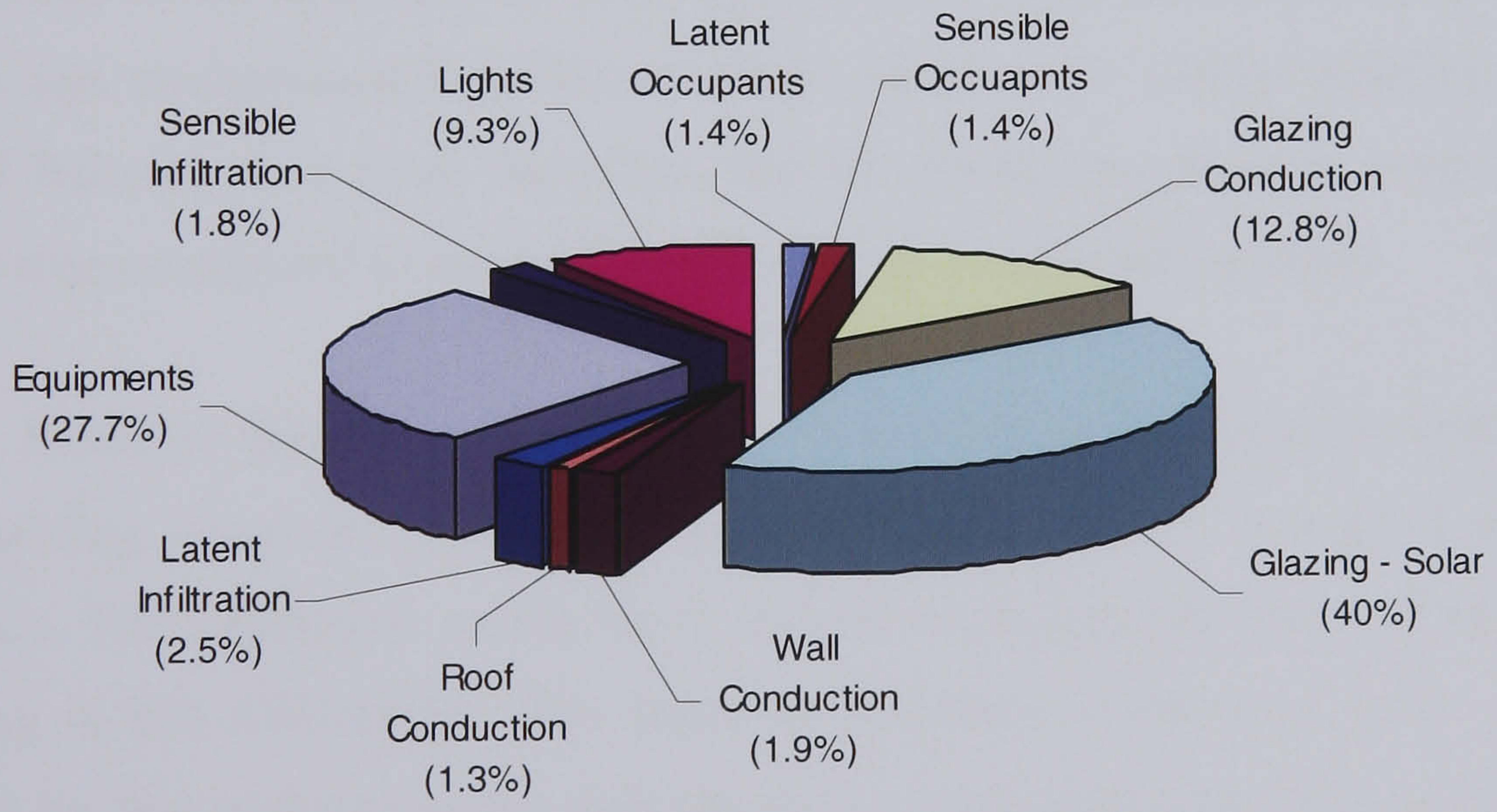

Figure 6.8 Breakdown of cooling load per components

Based on the above analysis, the cooling load is dominant in this building due to the high external and internal heat gains. The reason behind the former heat gain is the design of envelope components and how these components interacted with the climate, as can be seen in the large amount of solar heat gains through the southern facade. This facade has 0.8 window-to-wall ratio without protection against overheating and sun glare in the hot months. The latter heat gain is due to the system design and how this system is operated by the occupants. The design and operation of this system has led to a large amount of electricity consumption and considerable amount of heat, especially from equipment and artificial lighting.

6.3.3 Evaluating the performance of the MEW-Bldg

The evaluation is based on the energy performance indices. Table 6.3 illustrates the energy consumption of the studied building, and relates its performance indices, which obtained from the building simulation, to the indices of the other benchmarked buildings in Chapter 4 and the indices of the typical building from Saudi Arabia reviewed in Chapter 2 (see Table 2.1) in terms of electricity use, electricity cost and CO_2 emissions. It is important to note that the reviewed building is located in Damamm (50 km from Bahrain). The climate of Damamm is similar to that of Bahrain and the type and operation schedules of the reviewed building are also similar to the benchmarked buildings. As shown, the studied building is a poor energy and environmental performer when compared to similar buildings in and around Bahrain. It is clear, therefore, that the simulation program gives accurate results when compared to those obtained from the benchmarking study.

Based on the above, one can predict and estimate the energy consumption of any building using the procedure presented in this chapter to a good degree of accuracy. The simulation results show that the electricity use index of the studied building is 805 kWh/m^2/yr. This index is converted to the cost index (Bahraini Dinars) by first multiplying the total electricity consumption by the cost of demand and peak units, and then dividing the outcome on the treated floor area of the building. The result show 12.8 BD/m^2/yr. As the electricity is the only form of energy used for powering the MEW-Bldg, the carbon emissions index is directly estimated through multiplying the total electricity use by the conversion factor for electricity. The obtained result is 565 $kgCO_2/m^2/yr$. In this way, other performance indices for any given performance objective can be identified and tracked.

Table 6.3 MEW-Bldg performance indices

Building	Annual electricity consumption kWh	Cost index BD/m2/yr	Normalised performance index (NPI)	
			kWh/m2/yr	kgC/m2/yr
ST-Bldg	3832007	6.4	409	286
MEW-Bldg	8376088	12.5	805	564
AFS-Bldg	1535220	4.7	302	211
Bldg-05	1908869	6.6	424	297
BSE-Bldg	127970	1.6	100	70
HRA	126808	4.1	263	177
Atypical office from Damamm Saudi Arabia (2003)	4333016	4.9	315	220*

*This was done with an assumption that the conversion factor is 0.7
BD, Bahraini Dinar ($ = 0 .378 Dinar)
The distance between Damamm and Bahrain is approximately 50 km and have same climate as Bahrain

6.3.4 Search for optimisation measures

The analysis of the energy use patterns and the determination of the relationship between these patterns and the drivers that impact them indicated that the cooling load was significant because of the high internal and external heat gains. In light of these results, a number of measures to optimise the energy performance of the building under study were identified. They were classified into two categories: envelope measures to reduce external heat gain and system measures to reduce internal heat gain. Altering the set point temperature was added as an operation measure. Measures relating to the HVAC system and operation schedules could be effective in optimising the energy performance. However, replacing the HVAC system with more efficient one was not considered in this study.

6.3.5 Assessing optimisation measures using Visual DOE

It must be stated that each building is unique and what is considered cost-effective in one building may not be efficient in another building, even though they have much in common such as climate, construction characteristics, system, occupancy patterns, and operation schedules. This is simply because of the differences in building design and occupant behaviour. The proposed measures were evaluated and examined using the sensitivity analysis. To know the most rewarding once these measures were first applied individually. However, to show the importance of the whole building approach, the optimisation measures were then applied together. Finally, the results of both simulations were compared and analysed.

Envelope measures

These are measures that can be implemented in the opaque and transparent parts of the building skin. Envelope measures were highlighted with respect to the OTTV standard in Chapter 4 and will be discussed in more detail in Chapter 7. This chapter briefly examines two envelope measures to reduce the external heat gain, including thermal insulation and glazing systems.

Thermal insulation

In the MEW-Bldg, 50 mm thickness polystyrene insulation (0.63 $W/m^2.^oC$) was used in the walls and 35 mm thickness polyutherene insulation (0.50 $W/m^2.^oC$) in the roof. To examine the impact of using an additional layer of insulation to reduce heat conduction through the opaque part different U-Values for walls and the roof were tried. Fig. 6.9 illustrates the reduction in cooling load and electricity consumption due to various U-Values. Clearly, there is a linear relationship between the U-Value and the cooling load and electricity consumption. However, the reduction is relatively small. The maximum reduction is 1%. This is simply due to the dominance of the glass on the overall wall formation of the building. This has consequently led to a small percentage of heat conduction through the opaque part of the building. Therefore, using thermal insulation measures in this building is not cost effective.

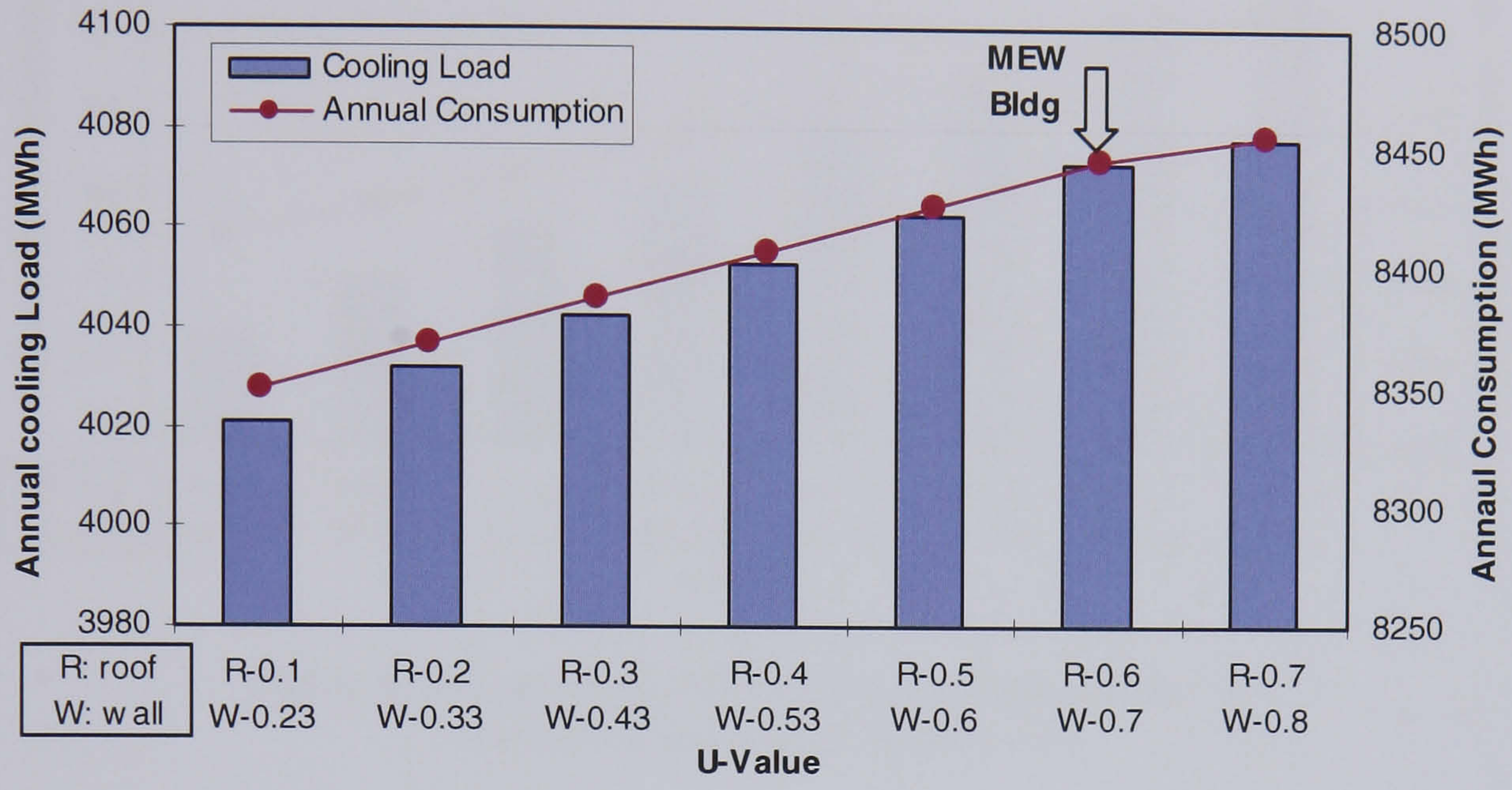

Figure 6.9 Impact of U-Value on cooling load and electricity consumption

In fact, reducing the thermal transmittance for walls and the roof may require additional energy for cooling the building down, especially after long breaks. The reason behind this is that reducing the U-Value of the building skin of offices leads to trapping more amount of the heat generated inside the building by equipment, lighting and occupant or heat transferred to the interior through the glazing. Fig. 6.10 shows that more amount of cooling energy due to the walls and roof conduction is decreased as the U-Value of walls and the roof is reduced. In contrast, more amount of cooling energy due to heat gain through window and from internal sources is consumed when the U-Value is reduced, as illustrated in Fig. 6.11. It is important to note that the extra cooling energy is consumed not because gaining more heat from the window and the internal sources; rather it is a result of trapping more heat gained from those sources. This is simply because the use of high U-Value helps to heat loss, and vice versa.

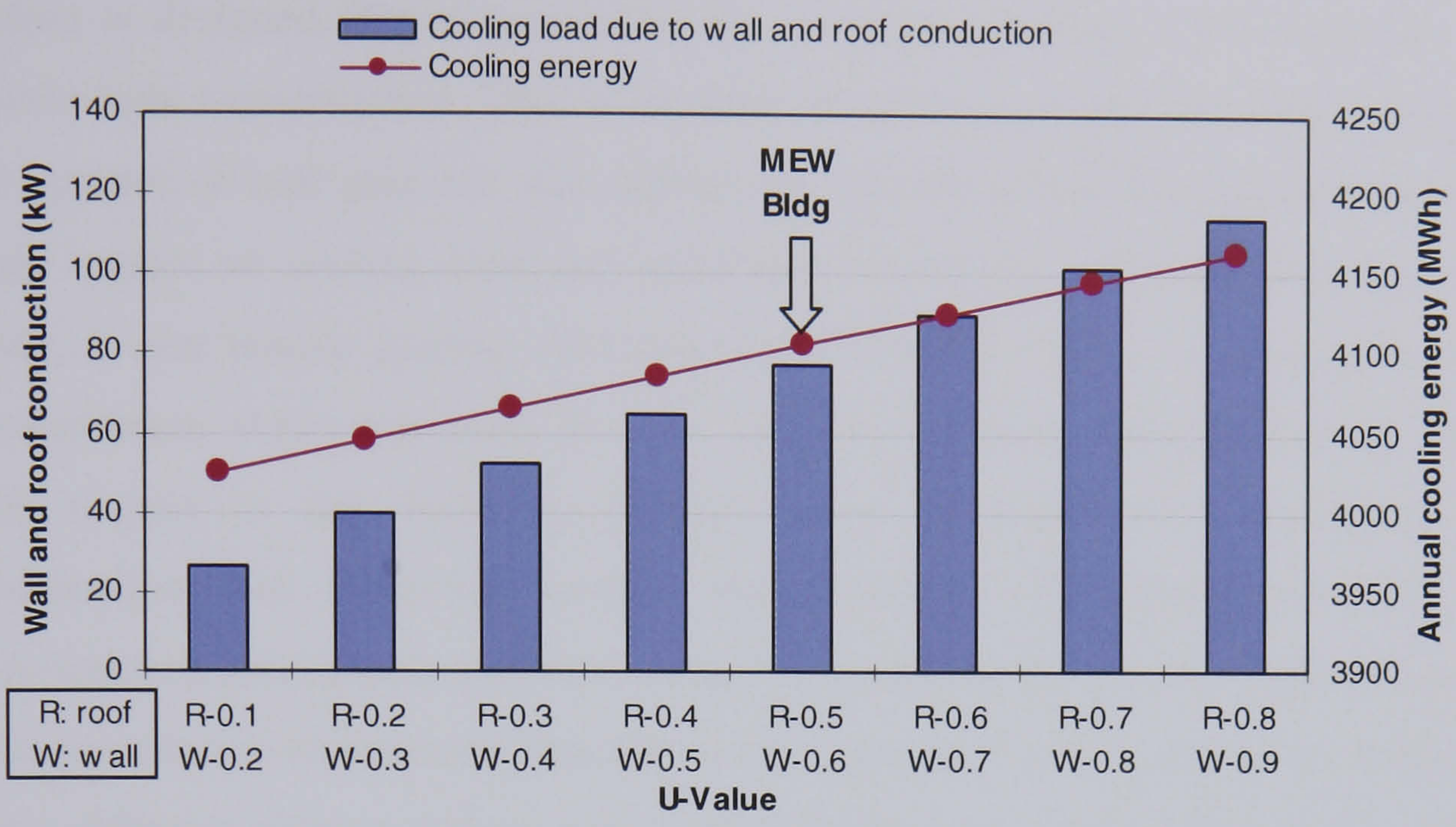

Figure 6.10 Impact of wall U-Value on walls and the roof conduction and annual cooling load

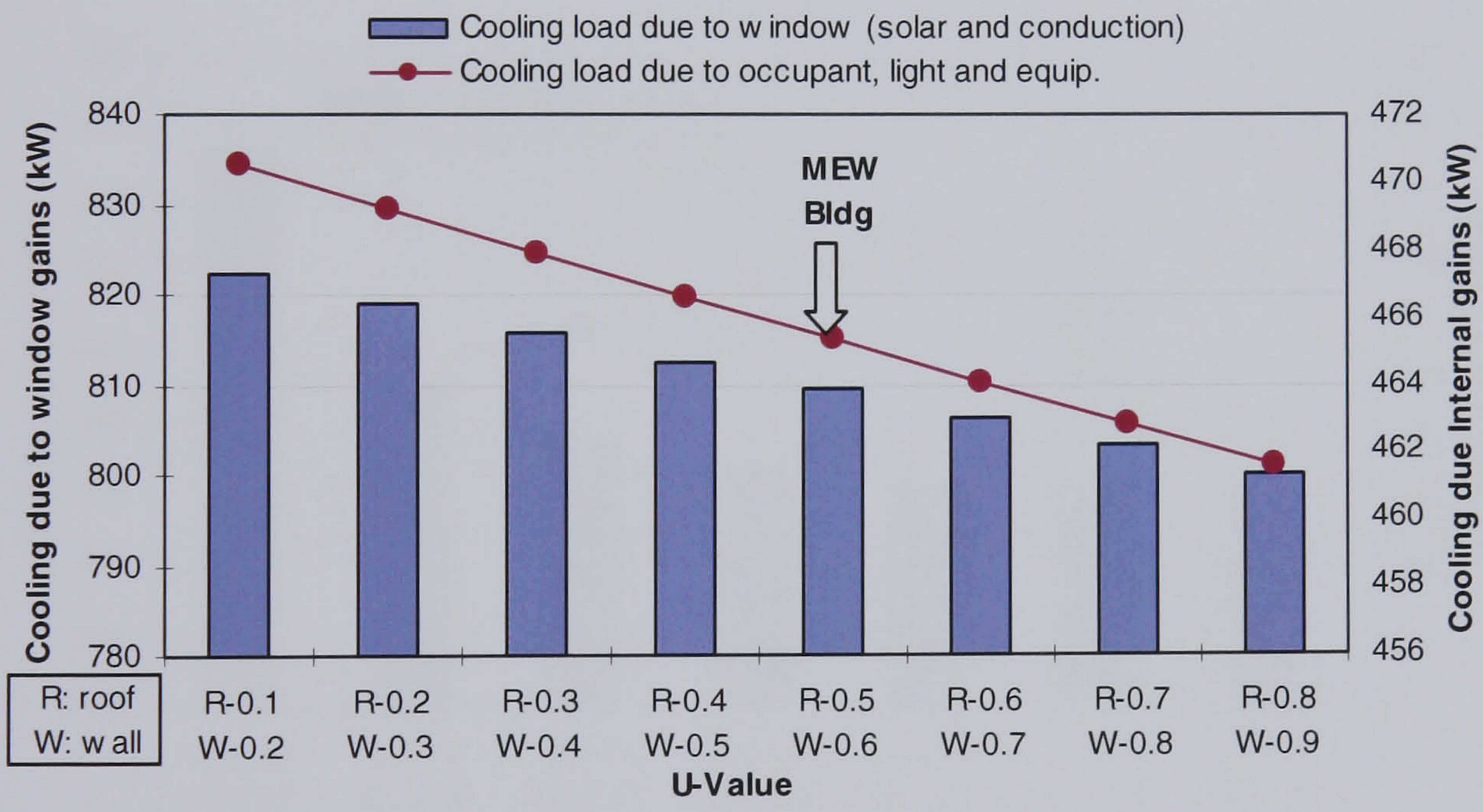

Figure 6.11 Impact of wall U-Value on cooling energy due to internal and window heat gains

Glazing system

The above analysis showed that the large amount of external heat transfer through the glazing, representing approximately 52.8% of the total heat gain. Therefore, using efficient glazing systems to reduce this amount represents an important measure. Three key parameters must be appreciated when the glazing system is designed. These parameters are: U-Value, shading coefficient (SC) and visible light transmittance. This is because the glazing system not only influences the amount of heat gain but also affects the amount of day-lighting, which has a large impact on cooling load and electricity consumption. In the building under study, 6 mm double glazing (U-value: 2.27 W/m^2.^{o}C, SC: 0.5, and visible light transmittance: 0.81) was used. In order to know the most efficient glazing system with respect to this building, different types of glass were examined. The examination was done by varying the U-values and keeping the SC and transmittance level fixed, and vice versa. For rounding the picture, lighting sensors were provided to measure the benefits of day-lighting. Fig. 6.12 shows the impact of using different glazing system with same U-Value and various SC on the cooling and lighting loads. It is clear that there is a reciprocal relationship between the cooling and lighting load.

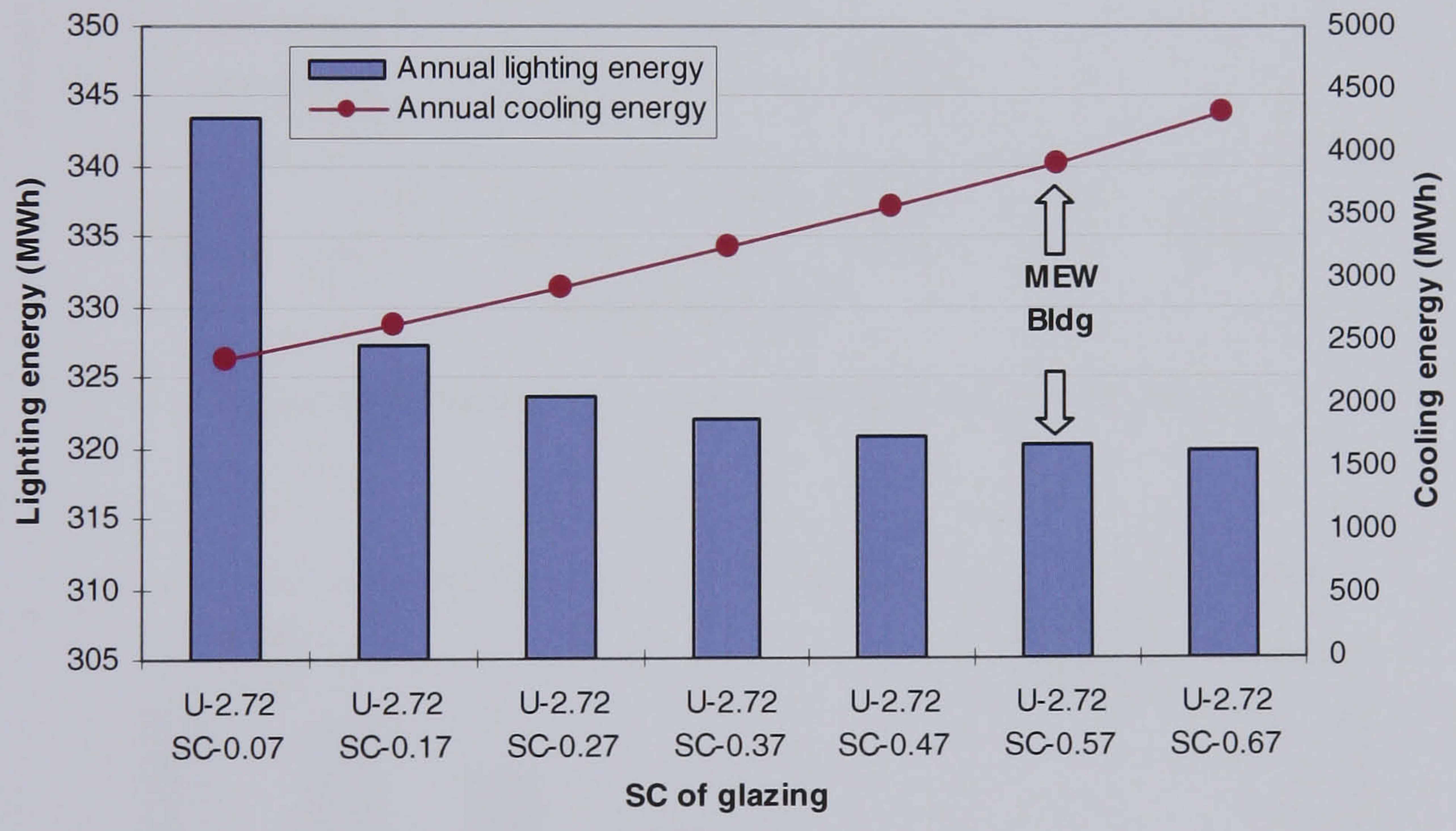

Figure 6.12 Impact of SC on cooling and lighting loads

When different U-Values of glazing were tried with fixed SC as shown in Fig. 6.13, the result shows a different scenario. There is a steady drop in the cooling load till it reaches 1.50 W/m^2.^{o}C, and then is a brief increase. 1.50 W/m^2.^{o}C may represent an optimum point for this building. When the U-Value exceeds the optimum point, the building switches from pro-insulation to anti-insulation. As illustrated, the impact of U-Value of glazing is significant when it is applied to the heating energy, while this impact becomes moderate when cooling energy is concerned. A calculation to the annual electricity consumption and annual heating and cooling energy shows that a 136 MWh reduction in annual heating energy can be achieved due to the 0.2 W/m^2.^{o}C (U-Value) of glazing coupled with an 8 MWh reduction in annual cooling energy. When these two figures are summed the total is a 144 MWh reduction in the annual electricity consumption as shown in Fig. 6.14.

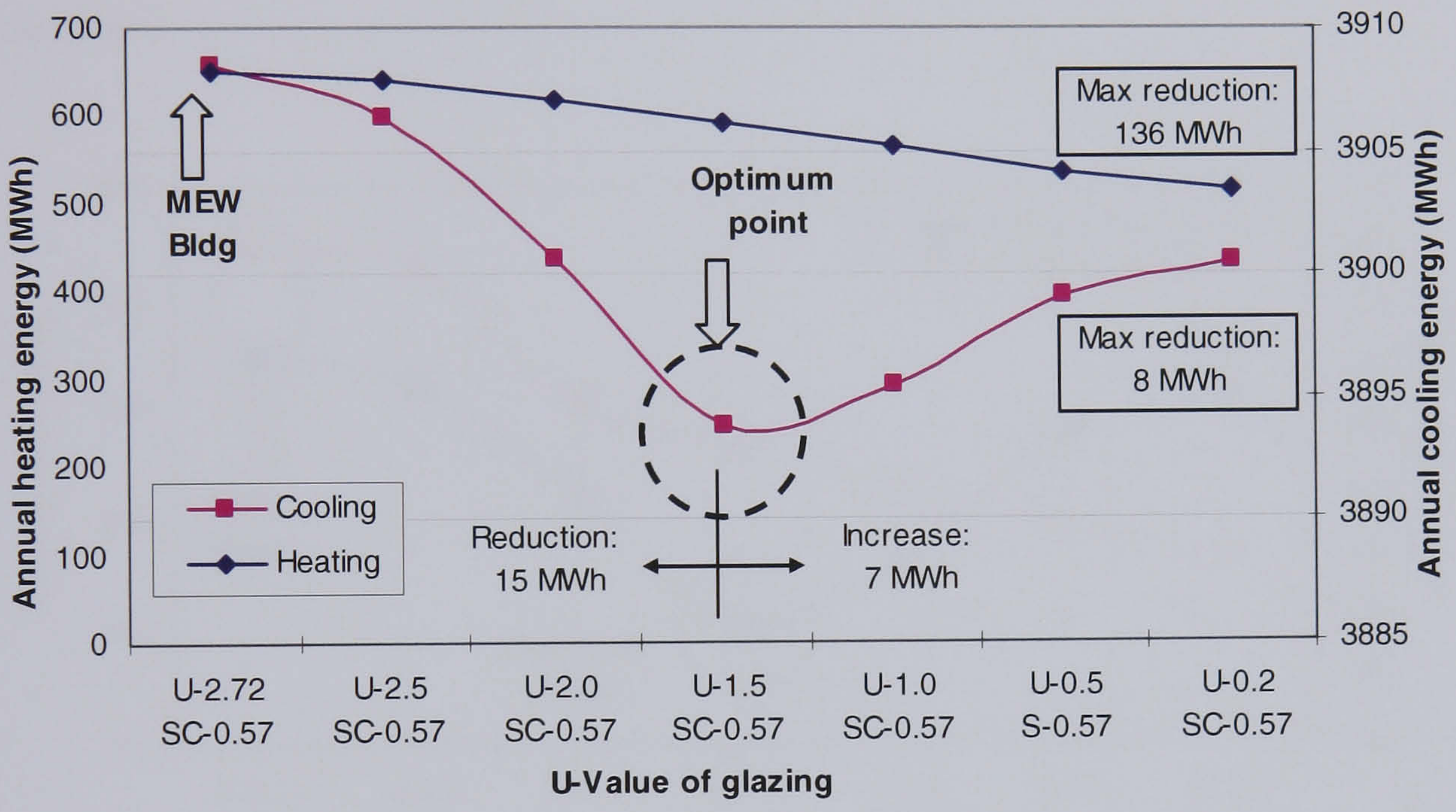

Figure 6.13 Impact of U-value on cooling and heating energy

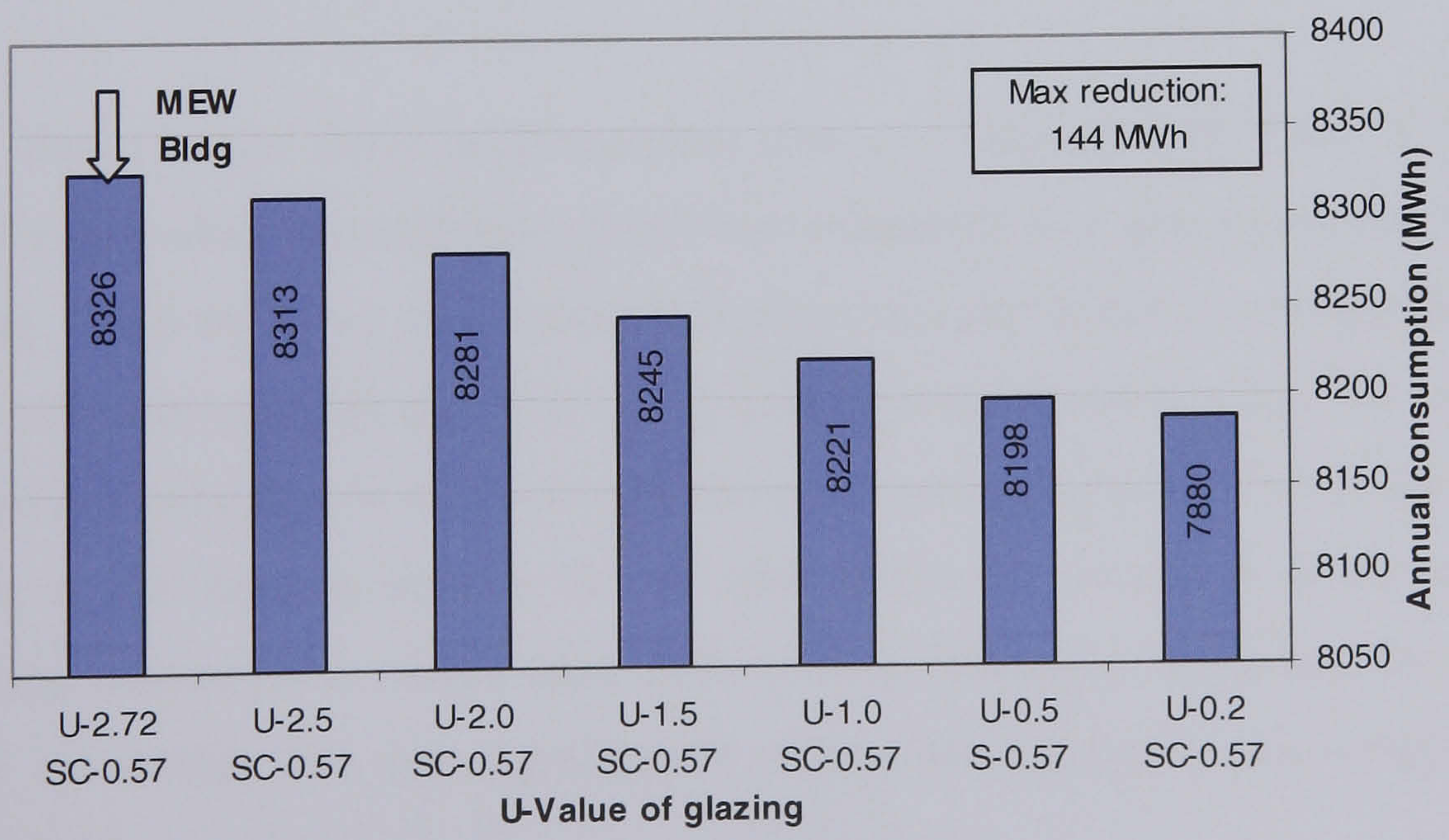

Figure 6.14 Impact of U-Value on electricity consumption

The optimum point is seen not only in the annual electricity consumption and cooling load as illustrated above, but also in the cooling peak demand as shown in Fig.6.15. At this point the building switches from pre-insulation to anti-insulation. The most possible reason behind this switch was the trapped internal heat as in the case of using high thermal insulation. To strengthen this assumption the curve of heating load is included in the graph. As can be seen there is no optimum point in heating peak load, rather there is a steady drop that can reach 15%. Therefore, reducing the SC and keeping the U-value in a range of 1.50 W/m^2.°C can save more electricity.

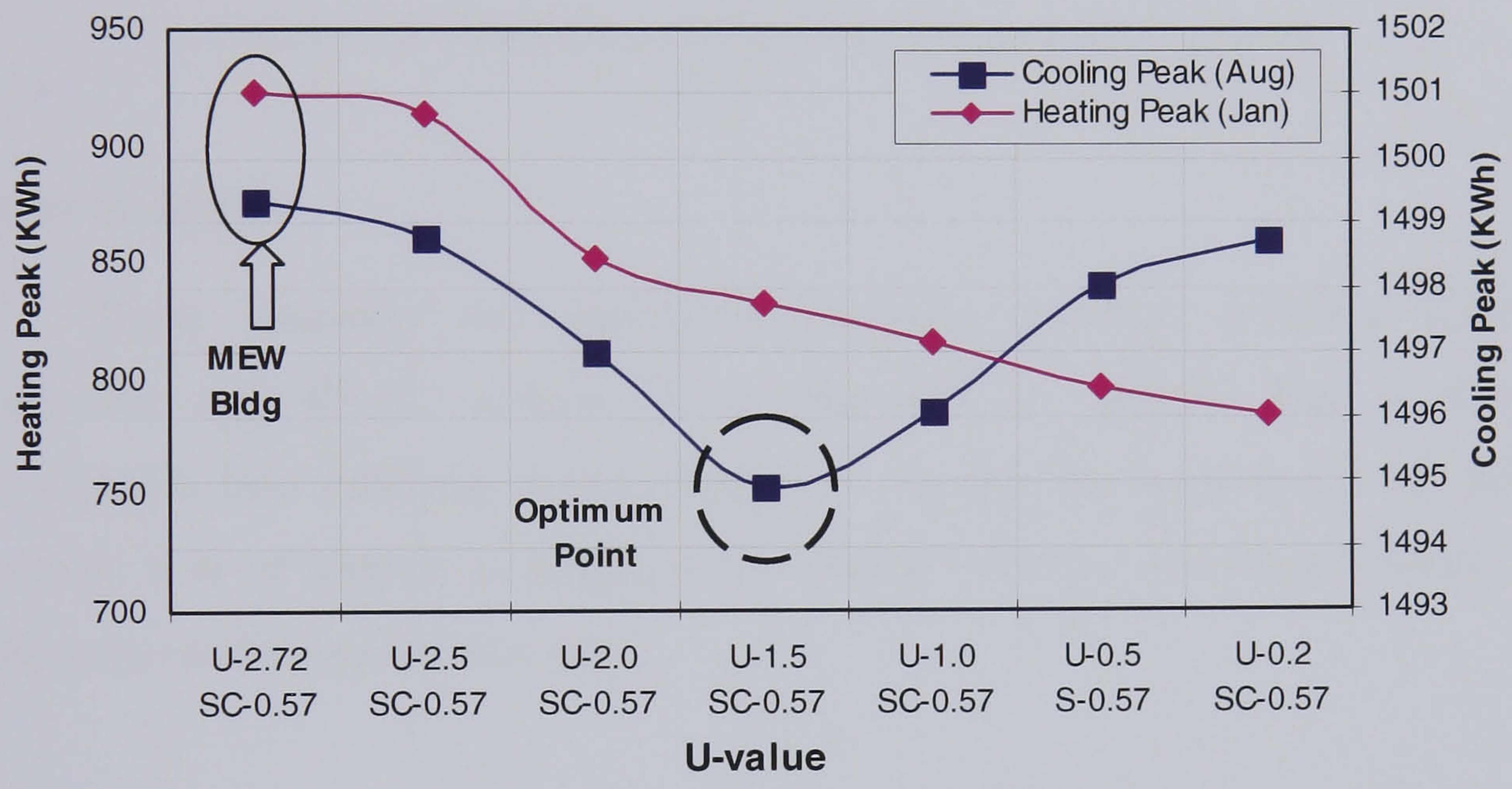

Figure 6.15 Impact of U-Value on cooling and heating peaks

Based on the above analysis, glass with a U-value of 1.48 W/m^2.°C and SC of 0.20 and visible transmittance of 0.5 was examined as a glazing system for this building. Fig. 6.16 shows a comparison of electricity end-uses between the base case before and after applying the identified glazing system. It can be seen that there is a considerable reduction in all electricity end-uses even in lighting. This is because of the use of the lighting sensors. At the same time, the reduction of the monthly electricity consumption ranges from 28% to 30%. Therefore, replacing the glazing system to another one can significantly reduce the electricity consumption and cooling load.

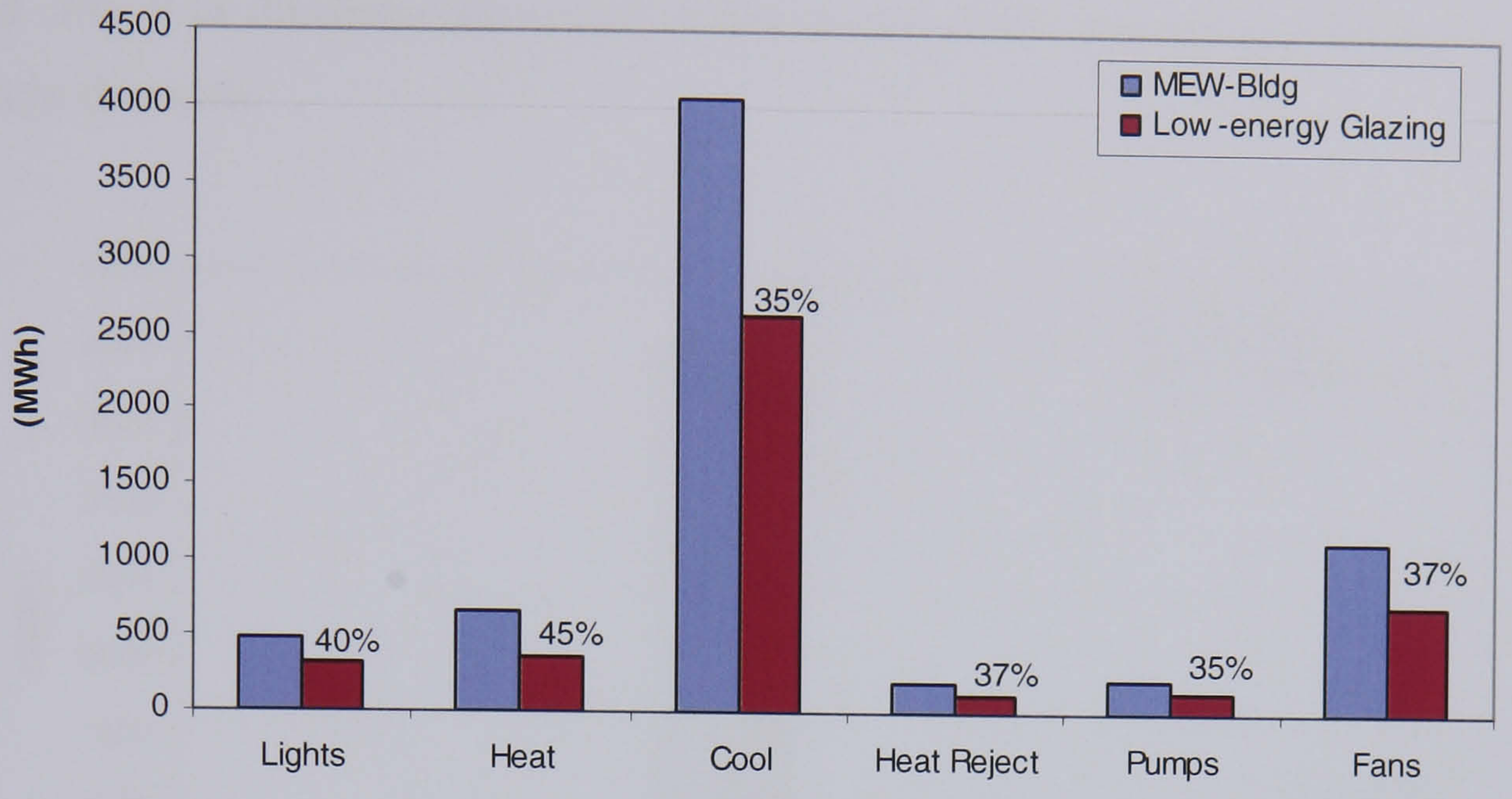

Figure 6.16 Comparison of electricity end-uses due to glazing

System measures

These measures are applied to building services including lighting, equipment, and HVAC system. It is important to mention that a detailed investigation into building system design is beyond the purpose of this study, however, it is of interest to highlight the impact of using low-energy lamps and equipment on the internal heat gain.

Lamps

In Bahrain lighting systems consume about 20% of the total electricity of commercial buildings. In the building under study, 4.0% of the total electricity consumption was consumed by the lighting system. Although this amount is small, there is an opportunity to improve the efficiency of the lighting system by using low-energy lamps for the interior spaces. As a result, two loads were influenced: the lighting and cooling loads, as shown in Fig.6.17. The internal lighting load was reduced by 25%. Another benefit of using low-energy lamps was the reduction in the internal heat gain which led to a 2.2% drop in the cooling load. Coupled with this was the drop in the cooling peak due to the reduction in the sensible heat gain. Similarly, using low-energy equipment can make a significant impact on the cooling load. Fig. 6.18 illustrates the impact of low-energy lamps and equipment on cooling energy demands.

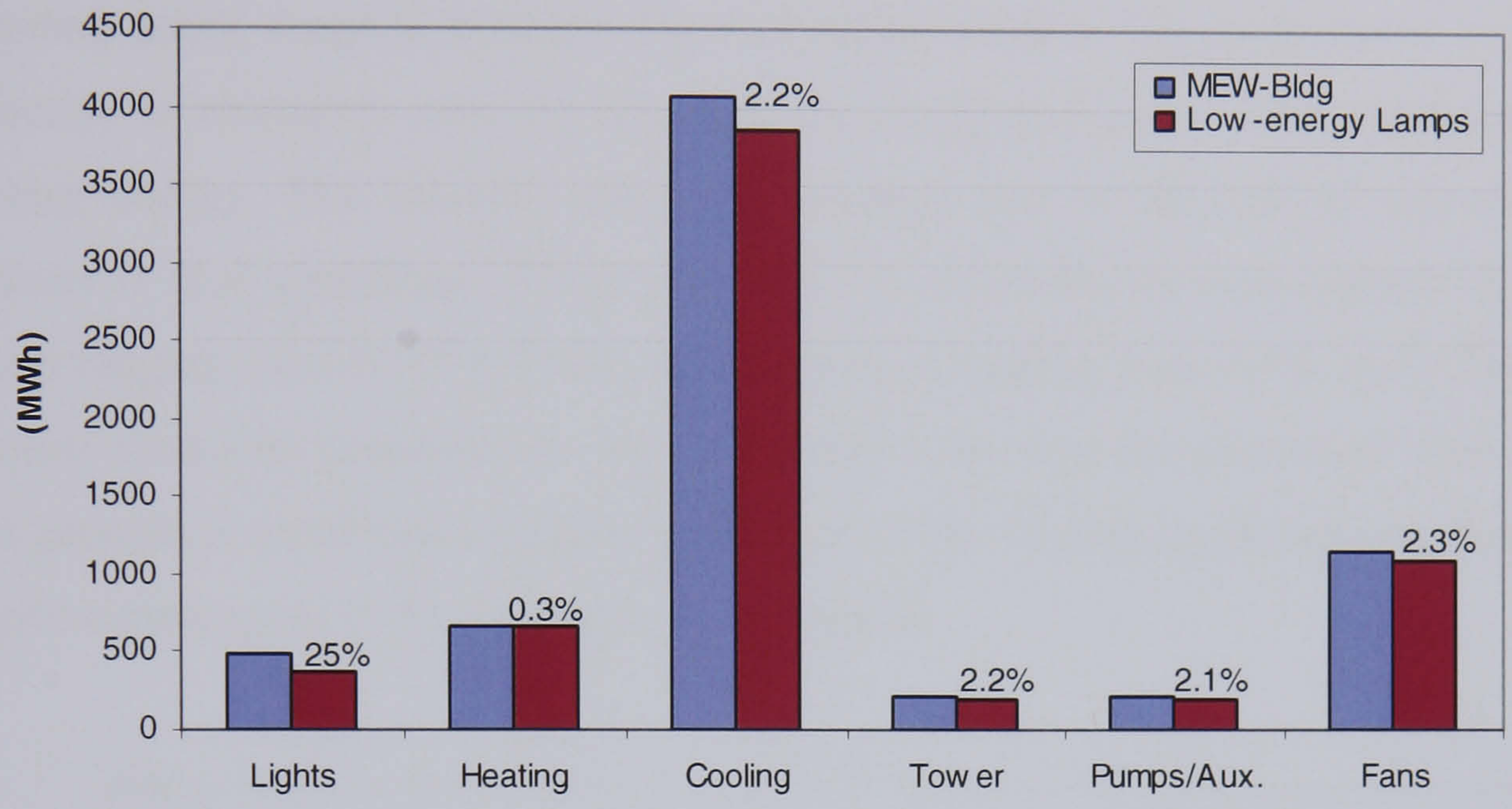

Figure 6.17 Impact of low-energy lamps on cooling loads

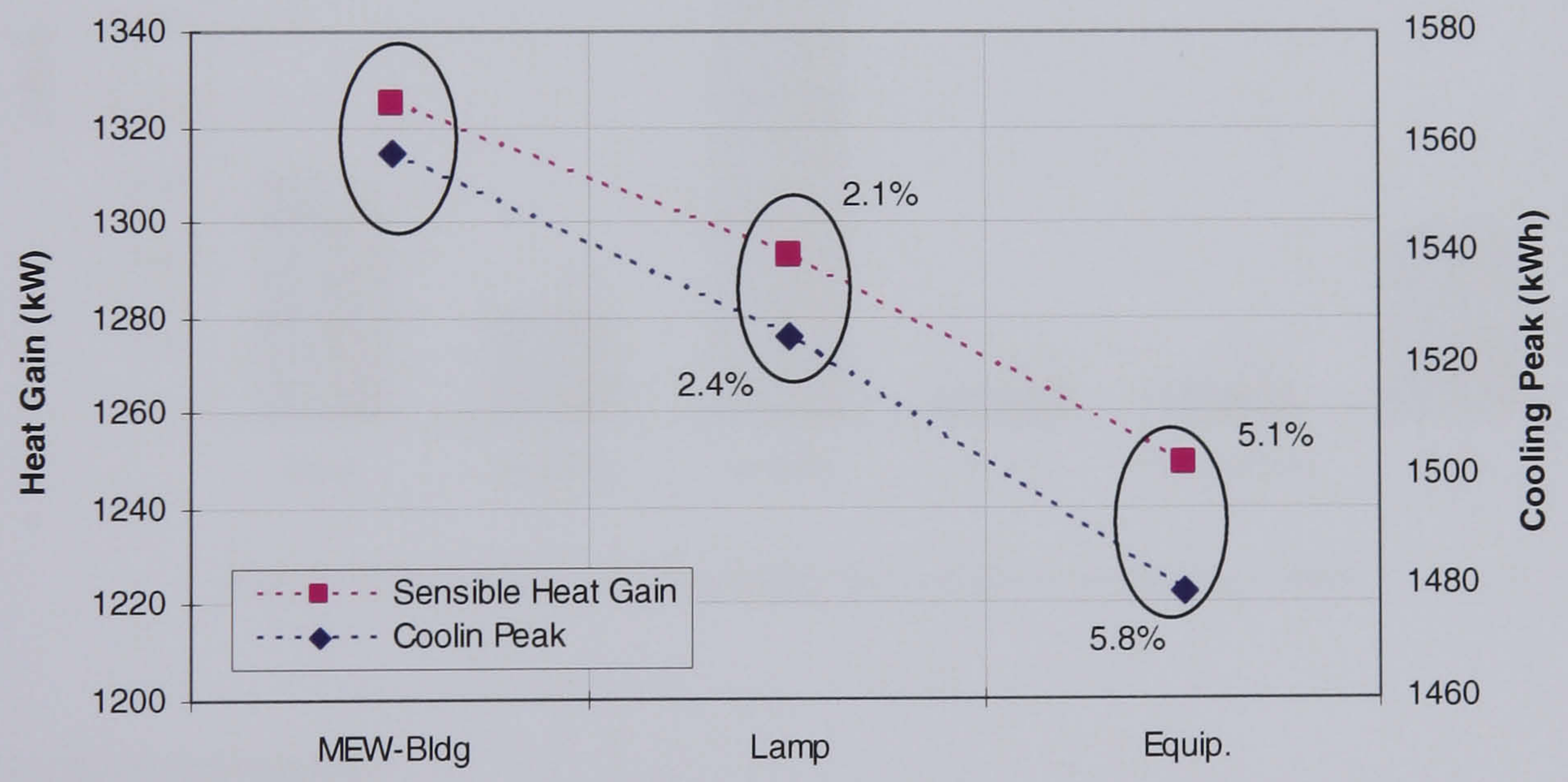

Figure 6.18 Reduction in sensible heat gain and cooling load

Equipment

As illustrated, using low-energy equipment reduces the cooling load peak and internal heat gain by 5.1% and 5.8% respectively. In the building under study there is a variety of office equipment such as computers and printers. Two strategies can be effective: firstly, using low-energy equipment, and secondly, controlling the operation by "power monitor saving". According to the audit reports, these computers remain on for an average of 10 hours per day. In spite of that, the expected actual usage is 6 hours. The simulation result in Fig. 6.19 shows a 20% reduction in electricity used for powering the equipment and a 5.2% reduction in cooling energy. The monthly electricity savings due to the use of equipment measure is also significant. There is a reduction in electricity consumption during winter ranging from 6.7% to 7.0% and a reduction ranging from 7.4% and 7.8% for summer electricity consumption. This difference is because the equipment with high heat generation represents a positive participant in the heating loads (winter), but is a negative participant in the cooling loads (summer).

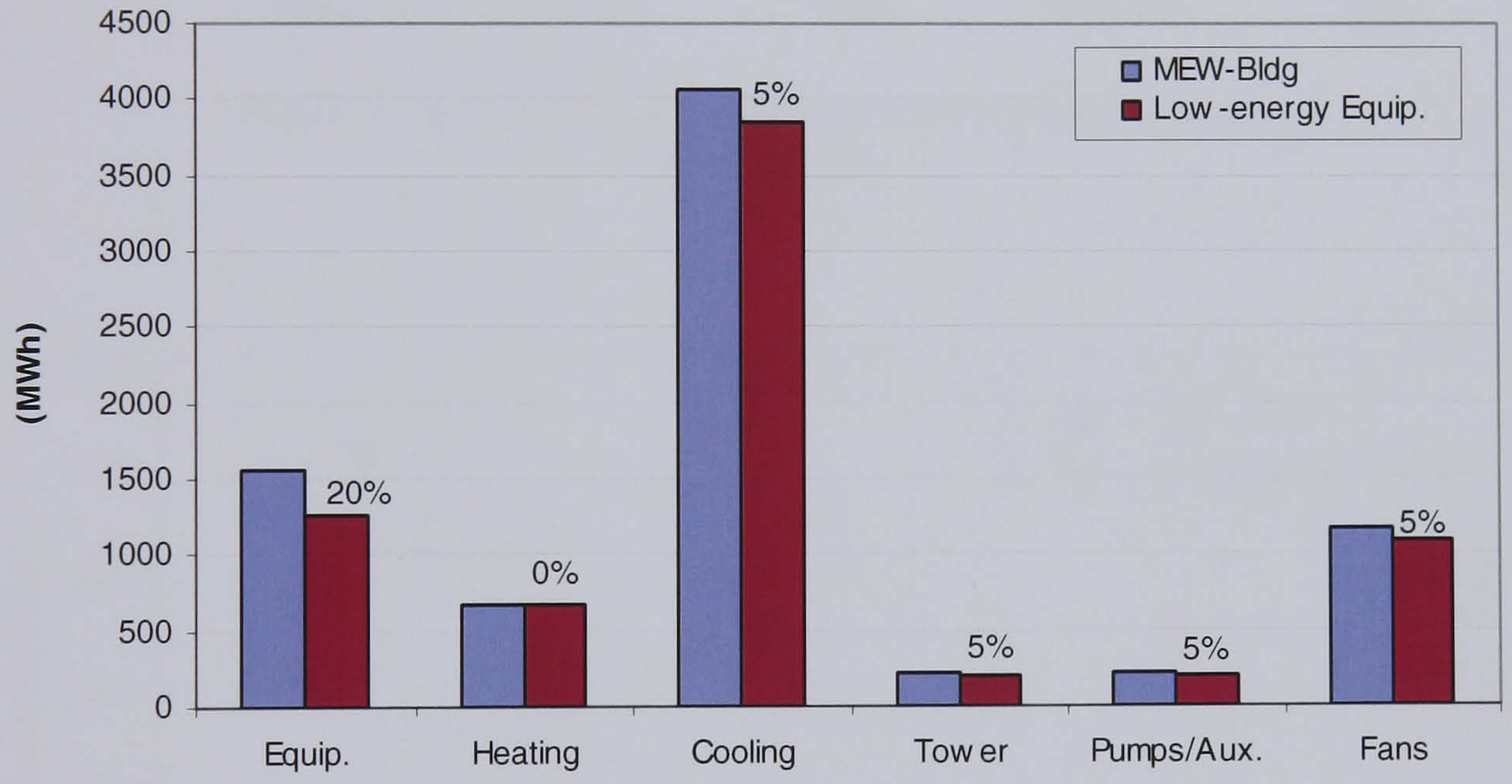

Figure 6.19 Impact of low-energy equipment on cooling loads

<u>Set point temperature</u>

Rising the set point temperature one or more degrees saves a considerable amount of electricity. In the base case building, two set point temperatures were tried: first 21-25°C and second 20-26°C for winter and summer respectively. As shown in Fig. 6.20, as the set point temperature rises, the reduction in electricity consumption improves. The maximum reduction occurs in heating loads with 11% and 27%, and the minimum in the cooling loads with 5.0% and 13% for the first and second set respectively. Furthermore, the impact of raising the set point temperature is clear with respect to the cooling peak, as can be seen in Fig. 6.21.

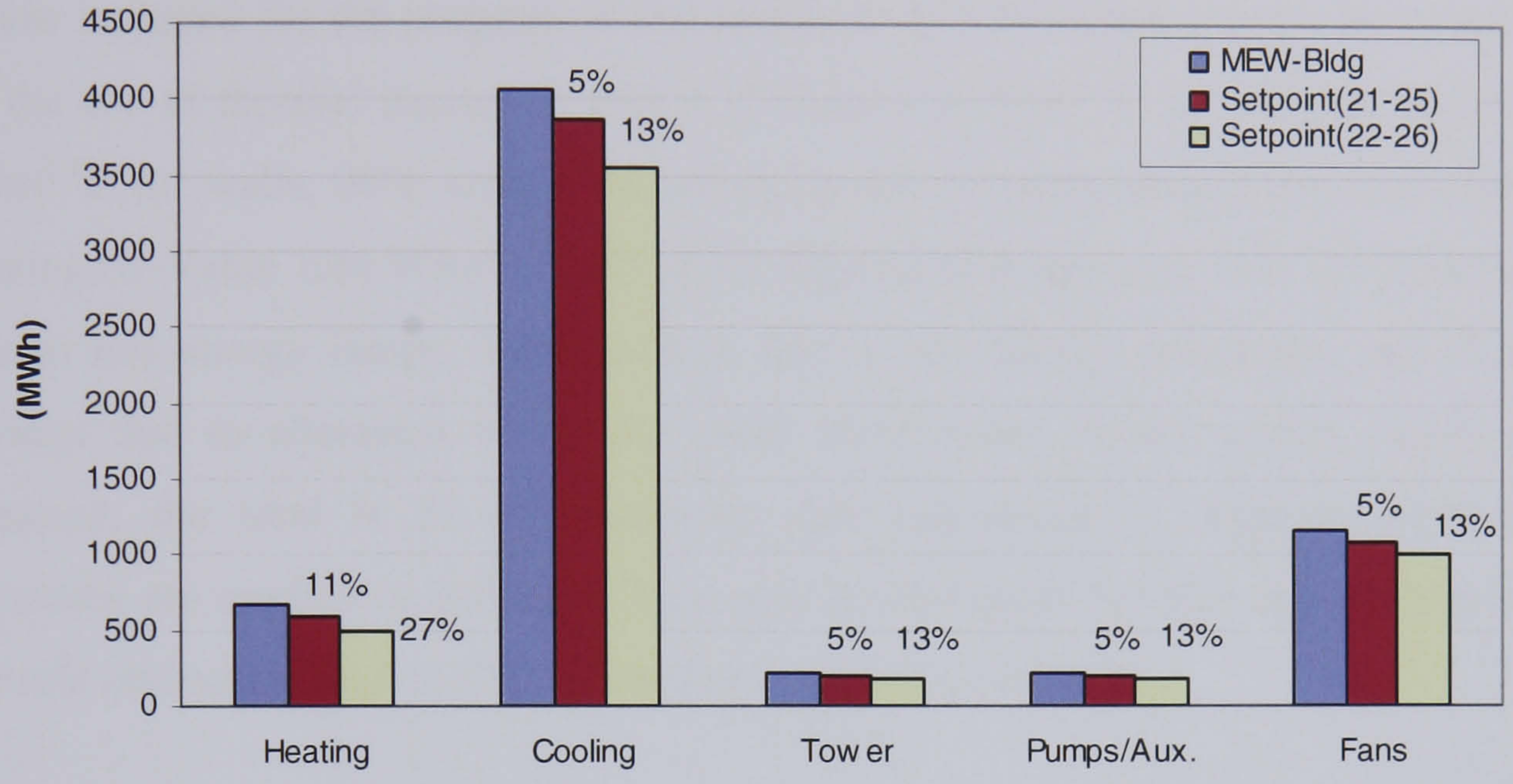

Figure 6.20 Impact of altering the set point temperature on cooling loads

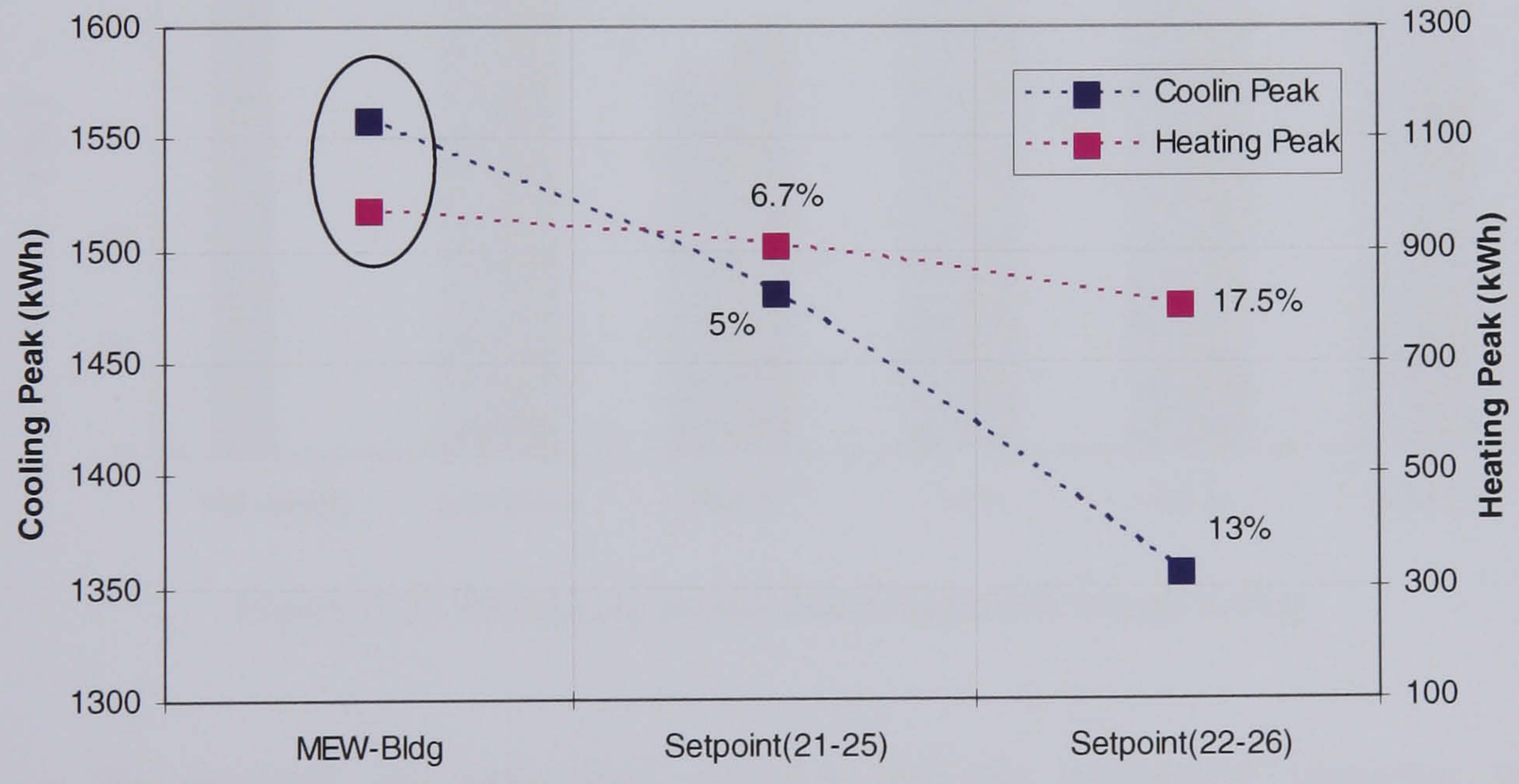

Figure 6.21 Impact of set point temperature on peak loads

6.3.6 Optimisation under the whole building approach

The purpose of this section is to put more emphasis on the role of the whole building approach in design optimisation and performance evaluation. This approach allows highlighting the interaction between prescriptive measures. Fig. 6.22 illustrates the electricity savings due to the identified and proposed measures. Although the thermal insulation was indicated as an ineffective measure in this case, it was included for the purpose of this analysis. A 0.7% reduction can be achieved by the use of thermal insulation with a U-Value 0.2 W/m^2.°C for the roof and 0.33 W/m^2.°C for walls, 29% savings in electricity due to using sensors and low-energy glazing (U-Value 1.48 W/m^2.°C, SC: 0.02, lighting transmittance: 0.5), 3.2% savings due to low-energy lamps, 7.2% savings due to low-energy equipment and 10.7% savings due to alteration of the set point temperature. When saving values are summed, the total is 51.1%. However, this percentage is obtained when the measures are applied in isolation. This way is inadequate because it cannot reflect the real interaction and conflict between prescriptive measures.

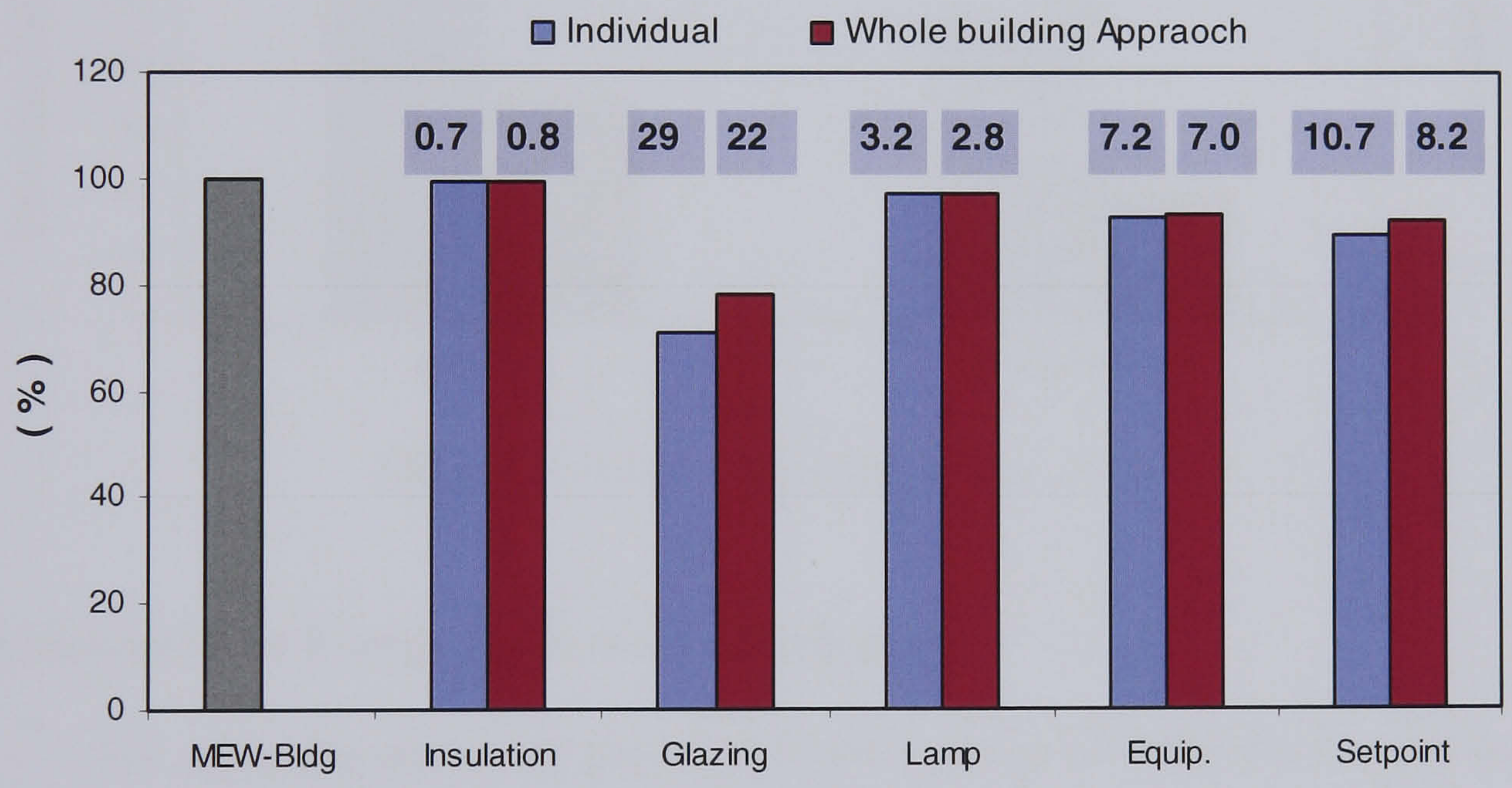

Figure 6.22 Electricity saving due to application approaches

To perform an interaction analysis, all the examined measures were combined and applied together. The percentage has become 41.6%. The difference is almost 10%. Therefore, to obtain a sufficient simulation result, it is necessary to follow a systematic analysis that takes into account the interaction and conflict between the various parameters such as the conflict between the level of U-Value and internal heat gains. It was noted that when the internal heat gain from lights and equipment was reduced, the thermal insulation became more effective

6.3.7 Target for future performance

The result of optimising the performance of the MEW-Bldg revealed a significant reduction in electricity consumption. This result provides new indices for energy, cost and environmental performance. Fig. 6.23 shows performance indices in terms of electricity consumption, electricity cost and CO_2 emissions. The obtained indices may represent a target for future energy performance, for which building management is stimulated to make improvements.

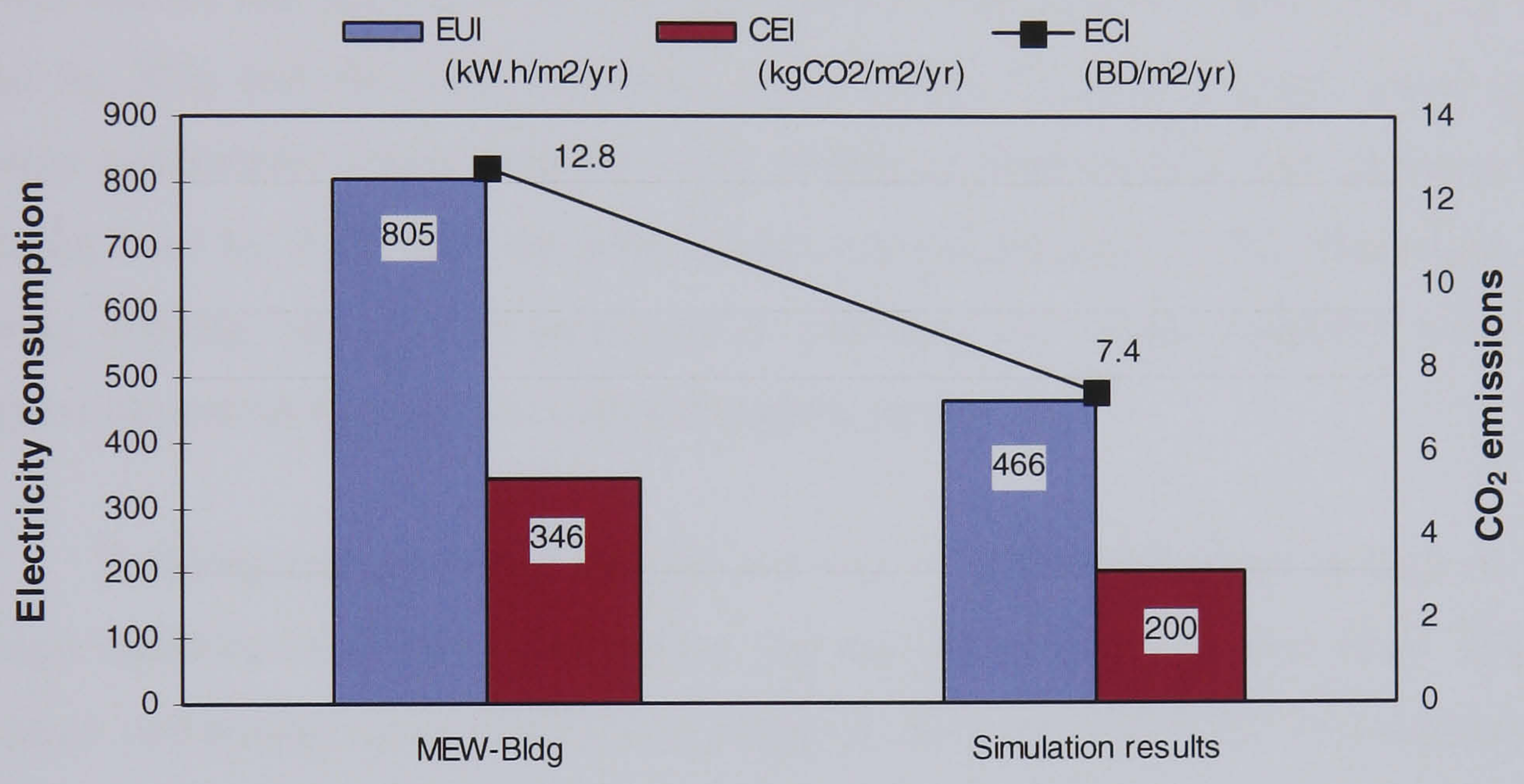

Figure 6.23 Targets for energy performance

6.4 Discussion of Energy Performance Evaluation

The quest for improving the energy performance of buildings has provided the opportunity to develop tools and methodologies for performance evaluation. In Bahrain and the Gulf region there has been a very slow uptake of such methodologies. In this study, a systematic methodology was introduced with respect to building design and operation in Bahrain. This methodology considers all the impacting parameters that influence the energy performance of office buildings. It integrates simulation programs into the analysis process. This has led to providing an accurate analysis and a reliable assessment for energy efficiency measures. The methodology appears to work well in the case tested, that is, for a high rise office building in Bahrain.

The analysis method demonstrated its ability in forecasting electricity consumption of office buildings. The Visual DOE program was used to accurately predict building loads and total energy consumption. In the building under study, approximately 65% of electricity was used for cooling systems. This was due to the large amount of external and internal heat gains. Although this building is categorised as internal load dominated, the external heat accounts for approximately 52% of the cooling load. The reason behind this was the large glass area in the southern façade without an appropriate shading device or sufficient glazing system. It was shown that the use of an efficient glazing with low SC reduced the cooling load by 35% and the total electricity consumption by 22%. Further, using low-energy equipment, which was the main source of internal heat gain, reduces the cooling load by 5.2% and the total energy consumption by 7.0%. Therefore, for saving cooling energy it is necessary to optimise the design variables with the highest impact on internal and external heating gains.

Building energy design should not only consider the direct impact of the design variables on energy consumption, but also their impact on each other. This is because optimising these variables in isolation does not reflect the real interaction and conflict between them which may negatively impact the energy consumption. Another advantage of this methodology is the emphasis on the role of the whole building approach. Considering the performance of the whole building allows for evaluation of the interaction and conflict between prescriptive measures. Some differences appeared when results of applying one measure at a time and results of applying them together were compared. The difference can reach 10% of the total energy savings.

By means of the introduced methodology, energy consumption was obtained together with energy cost and CO_2 emissions. It was indicated that the MEW-Bldg is a poor energy and environmental performer. The result in this chapter is a demonstration of the reliability of the presented methodology and a conformation of the benchmarking results in Chapter 4. Clearly, using this methodology will not only show the impact of different energy standards on electricity consumption and

CO_2 emissions of office buildings, but will also indicate the impact of these standards on various building loads. Consequently, the use of these standards to achieve a particular level of energy savings (an energy benchmark) can be examined. The next chapter highlights the role of performance evaluation and energy benchmarks for setting new standards.

Chapter 7 STANDARDS FOR LOW ENERGY BUILDINGS

Low energy buildings are becoming a hot topic in Bahrain, not just for reducing the depletion of oil and gas but also for concern about the environmental impact due to energy consumption.

(Hassan Radhi, 2008a)

7.0 Introduction

Energy standards impact upon the performance of buildings. The current study establishes a systematic approach to assess such an impact. In this study, energy standards were investigated in Chapter 4, a weather data file for building simulation was developed in Chapter 5 and a methodology for driving energy analysis introduced in Chapter 6. This chapter shows how research contributions made in the previous chapters are brought together and integrated into a systematic framework. The framework first optimises office building design, and then uses the outcome to develop energy standards in Bahrain. This chapter starts with a discussion about the lack of energy design in the Gulf region, in section 7.1. Section 7.2 introduces the framework, which is the prime purpose of this chapter. Section 7.3 proceeds to a study of the important aspects of building design optimisation. Section 7.4 explains the method of setting energy standards, while section 7.5 implements the framework.

7.1 Energy Design

7.1.1 Lack of energy design in the Gulf region

There is no question that the majority of buildings in the Gulf States, particularly offices, are designed and built without attention being paid to energy and the local environment. Today, under the umbrella of a worldwide international style of buildings, and in an attempt to embark on a new trend of modern architecture, huge glass façades facing the sun have appeared in cities such as Dubai, Riyadh, Doha, and Manama. In energy terms this strategy is generally applied to gain the most solar radiation possible in order to heat up buildings and utilise daylight and, therefore, it is often used for cold climates. For hot climates, such as those of the Gulf States, using this strategy may lead to a different scenario with respect to cooling loads. To apply this strategy in hot climates, the energy design should utilise the availability of useful daylight by striking a balance between light and heat gain.

This is, however, not the case in Gulf States. Huge projects have been constructed with enormous glazed façades facing the southeast and southwest without protection against overheating and sun glare in the summer. It is, therefore, not surprising that approximately 83% of the total electric energy in Bahrain is consumed by the HVAC system to protect the building's occupant from the harsh climate. The above statistic implies the necessity of developing new energy standards and setting benchmarks for the maximum allowable energy consumption in buildings.

7.1.2 Energy consumption in office buildings

Earlier in this study it was stated that the greatest portion of energy consumption occurs whilst buildings are in use. As far as commercial buildings are concerned, only energy end-use patterns in offices will be referred to. The amount of energy consumption in office buildings depends on many factors, including envelope design, HVAC system, types of lighting, internal plug loads, office equipment such as computers and printers and building operation and maintenance. In Bahrain the HVAC system has the largest share with an approximate 65% of the total energy consumption. The remaining is divided between the other systems. Fig. 7.1 shows a breakdown of electricity consumption by the end-uses of a typical office building in Bahrain.

It is obvious, therefore, that avoiding or, at least, reducing air-conditioning, is a primary objective and the second objective is to reduce reliance on artificial lighting by increasing and exploiting daylight availability to reduce energy demand. In order to achieve the former objective, reducing heat gains is likely to be the most significant energy efficiency strategy. One of the key methods is to invest in the building envelope as a transmission point of external heat and a tool to utilise daylight. The daylight has a large potential for energy saving through direct and indirect ways: first, it saves energy used to illuminate the building, and second, it reduces the heat gain from artificial lighting which consumes a large amount of energy to remove it (Yannas, 2001). Another method is to invest in the building system through the use of efficient HVAC system and low-energy lamps and equipment. In order to optimise the envelope and system parameters it is necessary to develop energy standards for these systems. Developing these standards, however, requires a systematic framework that takes into account building design optimisation and energy standards. This chapter approaches energy standard development within the broader concept of building design optimisation.

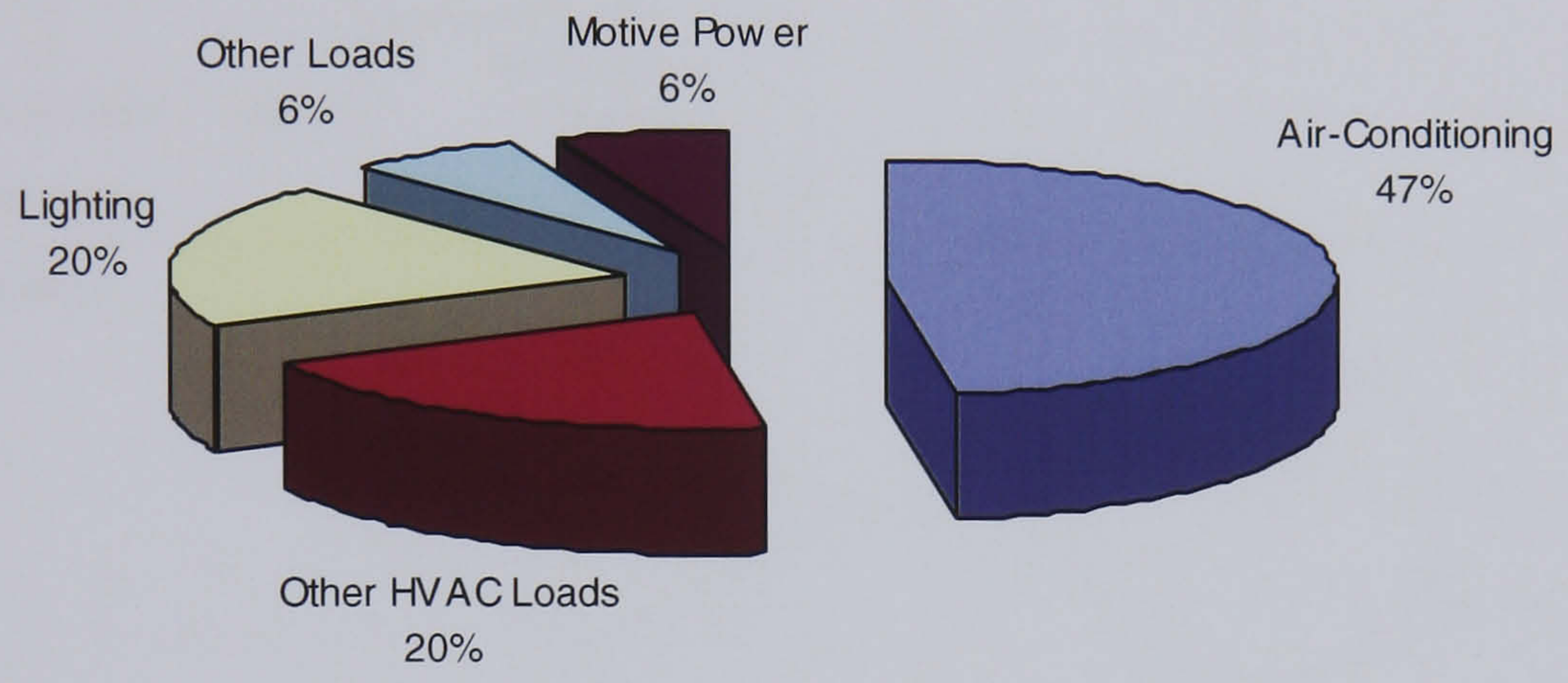

Figure 7.1 Breakdown of energy consumption of office buildings in Bahrain (MEW, 2004)

7.2 A Systematic Framework for Low Energy Buildings

Fig. 7.2 shows a framework based on the methodology of Shaviv *et al.* (2008) and the systematic structure developed by Al-Homoud (2005b). Unlike that structure, which uses the optimum thermal performance as criteria, this framework uses established energy benchmarks to optimise building design. The principal advantage of this approach is that the design objectives are based on local energy consumption and not on a target generated by an optimisation program. The generated target may not be well fitted with the actual building stock data – a reason why many developed standards have failed to achieve their objectives.

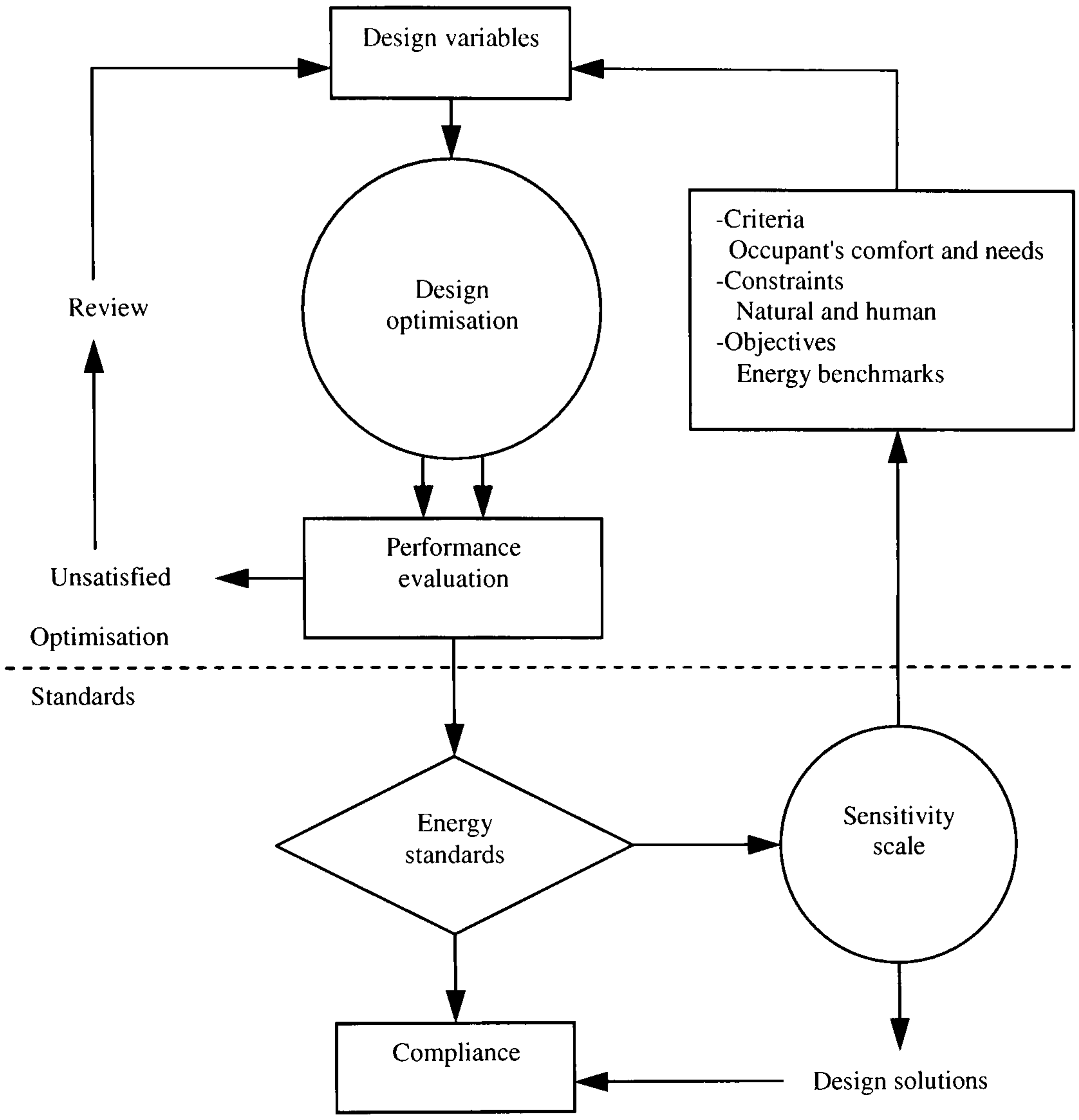

Figure 7.2 A systematic framework for optimising low energy buildings

7.2.1 Overview of the framework

As illustrates, the framework consists of two levels. The first (optimisation) concerns with building design which must be optimised before going to the second level. In this level, a systematic procedure is followed to help in reaching optimum integration of the building as a whole. The procedure of input, process and output of building design is influenced by many factors in the building optimisation process including:

- o Design boundaries – objectives, criteria and constraints
- o Design variables
- o Optimisation process

The second level (standards) focuses on the outcome of the first level. The optimisation outcome falls into two categories:

- o Performance improvement
- o Energy standards

The design optimisation allows the formulation of energy standards according to two approaches: the performance and the prescriptive. With respect to the former approach, the energy consumption of the optimised design represents an energy benchmark or a performance standard for this type of building, while the prescriptions represent prescriptive standards with respect to the latter approach. To overcome the limitation of prescriptive standards the framework provides a performance scale in order to present optimum and close-to-optimum design alternatives. These alternatives help in complying with building energy regulations.

Having briefly overviewed the framework, the chapter proceeds to a study of the development of the framework. This development involves the definition of the two main levels – design optimisation and standard formulation. These two levels are discussed in more detail in the sections below.

7.3 First level: design optimisation

Section 6.2.4 stated that the purpose of the optimisation is to find the best possible design in order to achieve occupants' comfort and needs with minimal energy consumption and CO_2 emissions. To optimise building energy design the first step is the definition of design boundaries, design variables and the process of optimisation.

7.3.1 Design boundaries

There are some boundaries that should be considered in design optimisation, including design objectives, design criteria and design constraints.

Objectives

The objective of energy design is to minimise energy consumption and cost. However, some variables, such as orientation, do not cause any extra cost. Also, some aspects of building performance, such as visual and acoustic comfort, are difficult to be related directly to cost. Therefore, energy consumption can be considered a desirable objective for energy performance. Nowadays, benchmarks for energy consumption have become objectives for energy design. With the emphasis on sustainability, the concern has extended to another main issue, the impact of energy use on the environment. These benchmarks work as scales to assess and compare the performance during design process. They also enable to gauge the level of efficiency and to identify any required modification. In practice, tracking these benchmarks plays a significant role in optimising energy design. They can be effective when all building components are designed with consideration to them, and the most successful design where these benchmarks are identified in the early stage and held in a proper balance during the design process (Cheung, 2005).

The energy performance benchmarks, however, can not be considered in isolation from the internal conditions benchmarks, and the energy performance of a building is not satisfactory if the quality of its internal environment is poor. It is important, therefore, that criteria against which internal environment quality is measured are formulated. These criteria can be established based on thermal comfort, acoustic comfort, ventilation or lighting level (Baird *et al.*, 1983).

Criteria

It is necessary to appreciate that the main purpose of buildings is to serve the occupants and their needs and activities. The environmental performance of buildings represents one of the most important needs of building's occupants, including visual, acoustic and thermal comfort.

Key factors influencing thermal comfort are air movement, humidity and temperature. For an office building, it would normally be designed with set point temperature selected from range 20°C to 24°C. With a heating system one figure would be chosen, but with air-conditioning system two figures would be selected, the higher one for summer (cooling) conditions (ASHRAE, 1992; ISO, 1994). These figures are taken to apply generally for cold climates such as Canada and Europe, and for warm countries higher figures would often be used, and in the hot climates of the Gulf region (see Chapter 5), where the average maximum air temperature reaches 43°C (Riyadh) and 41°C (Manama), an internal temperature of 26°C and 27°C would be considered comfortable. Table 7.1 illustrate the comfort temperature ranges for Saudi Arabia obtained for 12 months of the year by comparing the mean monthly maximum and minimum temperature and humidity.

Table 7.1 Day and night comfort temperature
(Said & Al-Zaharnah, 1991)

	Month											
Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day (max) °C	22.5	22.5	22.5	28.5	30	30	30	30	30	30	22.5	22.5
Day (min) °C	18	18	18	22.5	22.5	22.5	22.5	22.5	22.5	22.5	18	18
Night (max) °C	20	20	20	20	20	20	20	20	20	20	20	20
Night (min) °C	16	16	16	16	16	16	16	16	16	16	16	16

Constraints

In order to design a building with high energy and environmental performance it is necessary to consider this building in the context of its constraints and restrictions. In practice, there are many constraints influencing the energy design and limiting the options to produce low energy buildings. Examples of these are site, local climate and cost. Coupled with these are some limitations related to the architectural practice such as functional requirements, aesthetics and client's preference. The impact of these constraints and limitations is often significant on building design and variables optimisation (Al-Homoud, 1997; Shaviv *et al.*, 2008).

7.3.2 Design variables

This section briefly outlines the major design variables with the highest impact on building loads and energy performance.

It is often said that the most effective asset for low energy buildings is to design with climate and with a sense of place (Oktay, 2002; Olgyay, 1963). Two types of parameters come into play to achieve a good climatic design: firstly, the climatic parameters, which building designer has little control on them, and secondly, the design variables which are affected by the climate and can be controlled by building designer. These variables influence building loads and energy consumption. However, not all of them work in the same way, and some of them have more impact over the building response than the others. For example, forming the building with respect to the sun and wind has the most impact on external heat gain and lighting loads, while designing the building system with regard to energy efficiency and technology has the largest impact on the internal heat gain. Therefore, considering these two impacts should be taken as a basic energy principle for reducing cooling loads and improving the energy performance of office buildings. As there are many variables that basically influence the energy performance of buildings, this study focuses on the variables with the highest impact on lighting and cooling loads, including form, the body and the skin of the building envelope and issues of internal heat gain from lighting and equipment.

Building design under the whole building approach

At the building level, when the envelope parameters are designed with the purpose of utilising daylight and reduce cooling load, the size and capacity of the mechanical equipments can be reduced and consequently the electrical power distribution system may also be reduced. However, minimising the external heat gain and solar effects will not necessary lead to an exemplary optimum energy design and overheating may occur due to the fact that the cooling load is strongly influenced by the internal heat gains from building occupants, equipment and artificial lighting. For reducing the cooling load it is necessary to reduce the internal and external heat gains together. This means that the reason behind the internal and external heat gain should be eliminated or, at least, the level of heat gained or generated should be reduced. Artificial lighting and equipment are considered not only a major consumer of energy but also a significant generator of heat. The use of low-energy lamps and equipment can influence the lighting load and internal heat gains and hence, the cooling load and the overall energy performance. Therefore, without accounting these parameters, the energy design is insufficient.

It is, therefore, necessary to apply an integrated approach in the process of energy design and performance evaluation (Coley & Schukat, 2002). This can be done by applying the whole building approach where there is no individual part but only patterns that contribute to the whole building. Furthermore, applying the whole building approach in the optimisation of energy design helps to achieve the desired benchmarks within the defined constraints without compromising the aesthetics or functions of the design.

7.3.3 Optimisation process

The search for the optimum design often goes through sequential processes where design variables are changed under given design constraints. These processes can be summarised as:

- *Obtaining design alternatives*: a number of design alternatives are obtained in sequential optimisation processes. Each is optimised through a manipulation between the various design variables. This method allows the interaction between various elements and systems, coupled with providing the opportunity to obtain a large number of design alternatives.
- *Testing design alternatives*: the obtained design alternatives are tested by evaluating the performance of each one; the higher performance the more optimum.

Theses processes are realised in the Energy-10 program which is essentially based on the energy balance method. It is important to mention that this program is used to optimise building design and develop an energy performance target, as can be seen in the LEO building in Malaysia (http://www.mecm.leo.gov.my). It makes trade-off between design parameters with respect to different design constraints. The output of this program provides easy quantitative measures on the best combination of the physical components of the building parameters.

7.3.4 Performing the optimisation

Design boundaries considered in this optimisation

The objective of this optimisation is to reduce the annual electricity demand by reducing cooling loads and utilising the availability of daylight. The established benchmark in Chapter 4 was used as a design objective. The set point temperature in was selected to be within the range of 26°C to 27°C for summer and 21°C to 22°C for winter. The minimum acceptable level of daylight factor (DF) was taken as 0.5%. Energy-10 was set to ignore any optimisation outputs less than this value.

Design optimisation always leads to a high level of insulation and a low rate of infiltration. However, avoiding factors that lead to sick building syndrome as well as many construction problems may require the determination of a particular level of insulation. In this optimisation the program was set to use U-values not less than 0.2 $W/m^2{}^\circ C$ for the roof and 0.3 $W/m^2{}^\circ C$ for walls. Although 0.5 Ach is recommended to maintain a good air quality, 0.3 is found to provide the best agreement between the energy use predicted and the established benchmarks. As this rate is less than the minimum requirement, forced ventilation in the day time and natural ventilation at night were provided. The obtained optimum designs, therefore, were a combination of computer-based optimisation, previous studies and human judgment.

Design variables

This study first developed a single-storey building model based on information obtained from audit reports prepared by the Electricity and Water Conservation Directorate in Bahrain. The model was examined according to two forms of architectural design constraints. These forms were selected because of their impact on lighting and cooling loads, and also due to the land and client's preference, which may require the design of the building to be influenced by current trends or by the form of its neighbours. A middle size area was chosen for the model, ranging from 600 m^2 (40 m x 15 m) to 625 m^2 (25 m x 25 m). These forms are to reflect compact and elongated buildings. The compact form was oriented in two directions, while the elongated form was oriented in three directions.

To reduce the cooling load in office buildings it is necessary to decrease the internal and external heat gains. The external heat gain was reduced by utilising the envelope components measures, including insulation, envelope thermal mass, infiltration rate, opening area, type of glazing and shading device. These variables were chosen because they impact building loads and can be control by building designer. Table 7.2 shows the optimised design variables.

The internal heat gain was reduced by improving the efficiency levels of electrical lamps and equipment. They consume 75%, 60% and 50% of energy compared to the existing lamps and equipment in Bahrain. They also generate less heat. The HVAC system was optimised with 90% heating efficiency and a 2.7 COP for cooling. In this optimisation the HVAC variables serve as some kind of a requirement, while the design variables were launched into the program as guidelines. The program was set to adjust them in order to provide the best combination to achieve the desired benchmarks within the defined constraints without compromising the architectural concept of the case model.

Table 7.2 Optimised design variables

Variables	Values	Parameters
Shape	elongated form (40m x 15m) compact form (25 m x 25 m)	2
Orientation	0° 90° 135°	3
WWR -based on †	0.15 0.25 0.35 0.45 0..55 0.75 0.85	7
Glazing type		
U-Value (w/m^2.°C) - SC	1.48 – 0.2 1.48 – 0.4 1.48 – 0.6 2.78 – 0.89 6.3 – 1.0	5
Transmittance	0.5 0.6 0.7 0.8 0.9	5
Roof ins. (w/m^2.°C)	0.2 0.4 0.5 0.65	4
Wall ins. (w/m^2.°C)	0.3 0.5 0.6 0.76	4
Envelope thermal mass	heavy light	2
Infiltration rate Ach	0.1 0.2 0.3 0.4 0.5	5
Shading device	over hang (93 cm)* horizontal blinds (93 cm)* vertical blinds internal blinds	4
Lighting efficiency (%) $^+$	50 60 75	3
Equip efficiency (%) $^+$	50 60 75	3
Night ventilation	Yes No	2

† These figures are launched into Energy-10 as guidelines. Energy-10 was set to adjust them to achieve the benchmarks

*This figure was calculated by Energy-10 as the most effective width of shading device

$^+$ The efficiency is calculated by the amount of energy use and heat generation compare to the existing lamps and equipment

Optimisation process

The optimisation passed through three stages: firstly, building design using the existing codes of Bahrain; secondly, design optimisation of the HVAC system; and finally, design optimisation with respect to the other design variables. The first stage is concerned with the existing building codes of Bahrain (see Chapter 4). The second stage focuses on optimising the HVAC system. There are no official codes for HVAC systems in Bahrain, rather there is a guideline. The last stage considers the design variables with the highest impact on cooling and lighting loads.

7.4 Second level: standards formulation

The outcome of optimising the case model falls into two categories: performance improvement and energy standards.

7.4.1 Performance improvement

The optimisation results of the compact and elongated forms are shown in Table 7.3. The thermal characteristics are very similar in both cases. The optimisation process resulted in thermal comfort with a temperature at 21°C for winter and 26°C for summer. The overall window-to-wall ratio (WWR) ranges are 0.25 and 0.27 for the elongated and compact forms respectively, which results in a better utilisation of daylight. The chosen WWR, glazing system and shading device result in an average daylight factor equal to 0.7%. The optimisation aims to improve the performance of buildings with respect to the building codes.

Table 7.3 Optimisation results

Variables	Optimisation result	
Form	elongated form	compact form
Area	600 m^2	625 m^2
Orientation	0°	0°
WWR	overall 0.25 north 0.32 & south 0.20 east 0.25 & west 0.25	overall 0.27 north 0.35 & south 0.22 east 0.26 & west 0.26
Glazing Type - Low-e	U-Value 1.48 W/m^2.°C- SC 0.2 LT 0.8	U-Value 1.48 W/m^2.°C – SC 0.2 LT- 0.8
Roof insulation	0.2 W/m^2.°C	0.2 W/m^2.°C
Wall insulation	0.33 W/m^2.°C	0.33 W/m^2.°C
Envelope thermal mass	heavy	heavy
Infiltration rate	0.3 Ach	0.3 Ach
Shading device	overhang 93 cm	overhang 93 cm
Lighting	50% (8-10 W/m^2)	50% (8-10 W/m^2)
Equipment	50% (14 W/m^2)	50% (14 W/m^2)
Set point temperature	26°C (summer) - 21°C (winter)	26°C (summer) - 21°C (winter)
Night ventilation	Yes	Yes
Minimum average DF (%)	0.7	0.7

Table 7.4 Characteristics of the case model

Variables	Bahrain codes (see Chapter 4)	Elongated form
Orientation	0°	0°
Glazing area	< 0.2 with single glazing > 0.2 with double glazing	overall 0.25 north 0.32 & south 0.20 east 0.25 & west 0.25
Glazing Type	U-Value 2.782 W/m^2.°C – SC 0.7 transmittance 0.8	U-Value 1.48 W/m^2.°C – SC 02 transmittance 0.8
Roof	200 mm concrete 50 mm insulation - 0.63 W/m^2.°C	200 mm concrete 50 mm insulation - 0.2 W/m^2.°C
Wall insulation	200 mm concrete 50 mm insulation - 0.75 W/m^2.°C	200 mm concrete 50 mm insulation - 0.33 W/m^2.°C
Internal thermal mass	gypsum & block*	CMU partition
Infiltration rate	no specification (0.5 Ach) *	0.3 Ach
Shading device	none	overhang 93 cm
Lighting power density	no specification (18-20 W/m^2)*	(50%)$^+$ 8-10 W/m^2
Ex-light	no specification (3.55 W/m^2)	2.66 W/m^2
Equip. power density	no specification (20-25 W/m^2)*	(50%)$^+$ 10-14 W/m^2
HVAC system	constant air volume (CAV)	variable air volume (VAV)
Fan	15% efficiency	25% efficiency
Rated air flow	3519 l/s	1729 l/s
Cooling	COP 2.4	COP 2.7
Capacity$^+$	103 kW	53 kW
Hot water	no specification (2.8 W/m2)	2.8 W/m2
Set point temperature	24°C (summer) - 22°C (winter)	26°C (summer) – 21°C (winter)
Night ventilation	No	Yes
Operation	60 hours/week	60 hours/week
Occupancy	25 m^2/person	25 m^2/person

*Data are not specified by the codes but are assumed based on guidelines and audits report by Electricity and Water Conservation Directorate

Table 7.4 illustrates the architectural and operational characteristics of the case model according to the existing codes and optimisation stage. As the optimisation process was directed to improve the energy performance by mainly reducing the cooling load and utilising daylight, three types of results were of interest - namely, electricity end-uses, monthly electric demand peaks, and annual electricity performance.

Figure 7.3 breaks down the electricity end-uses. The results show 25% and 75% drops in cooling and lighting loads in the optimised design related to the HVAC design stage. Figure 7.4 illustrates monthly electric energy demand peaks. The drop in the summer peak reaches 9% when an optimum HVAC system is used. This drop reaches 36.5% when the other parameters are optimised. Further, there is a drop in the winter peaks that reaches 8.9% and 47.4% due to optimising the HVAC system and the other design variables respectively. Figure 7.5 indicates the overall energy performance in terms of energy utilisation index (EUI) and CO_2 emissions index (CEI). Cleary, there is a 51% improvement in the energy and environmental performance.

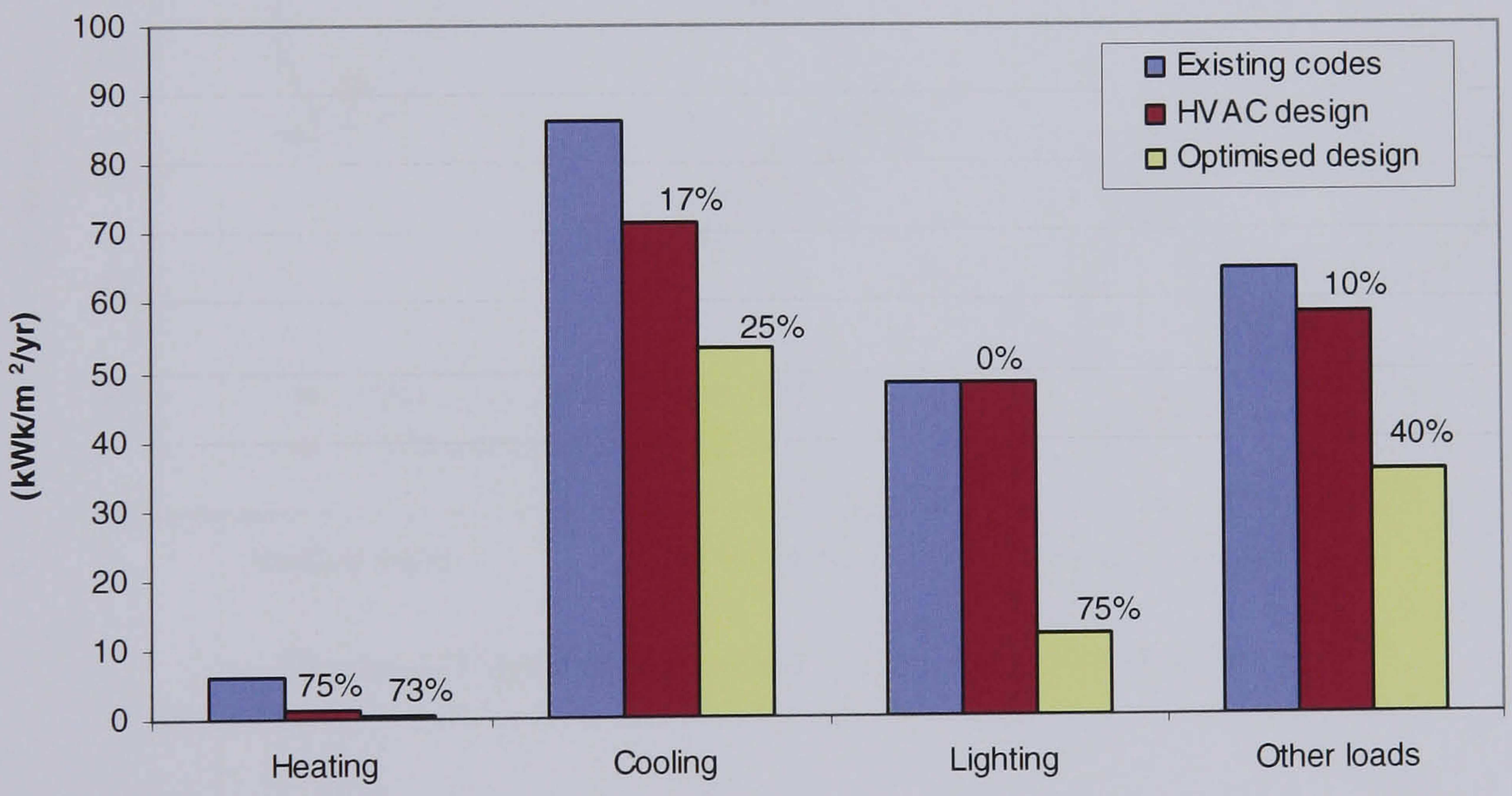

Figure 7.3 Optimisation results of electricity end-uses

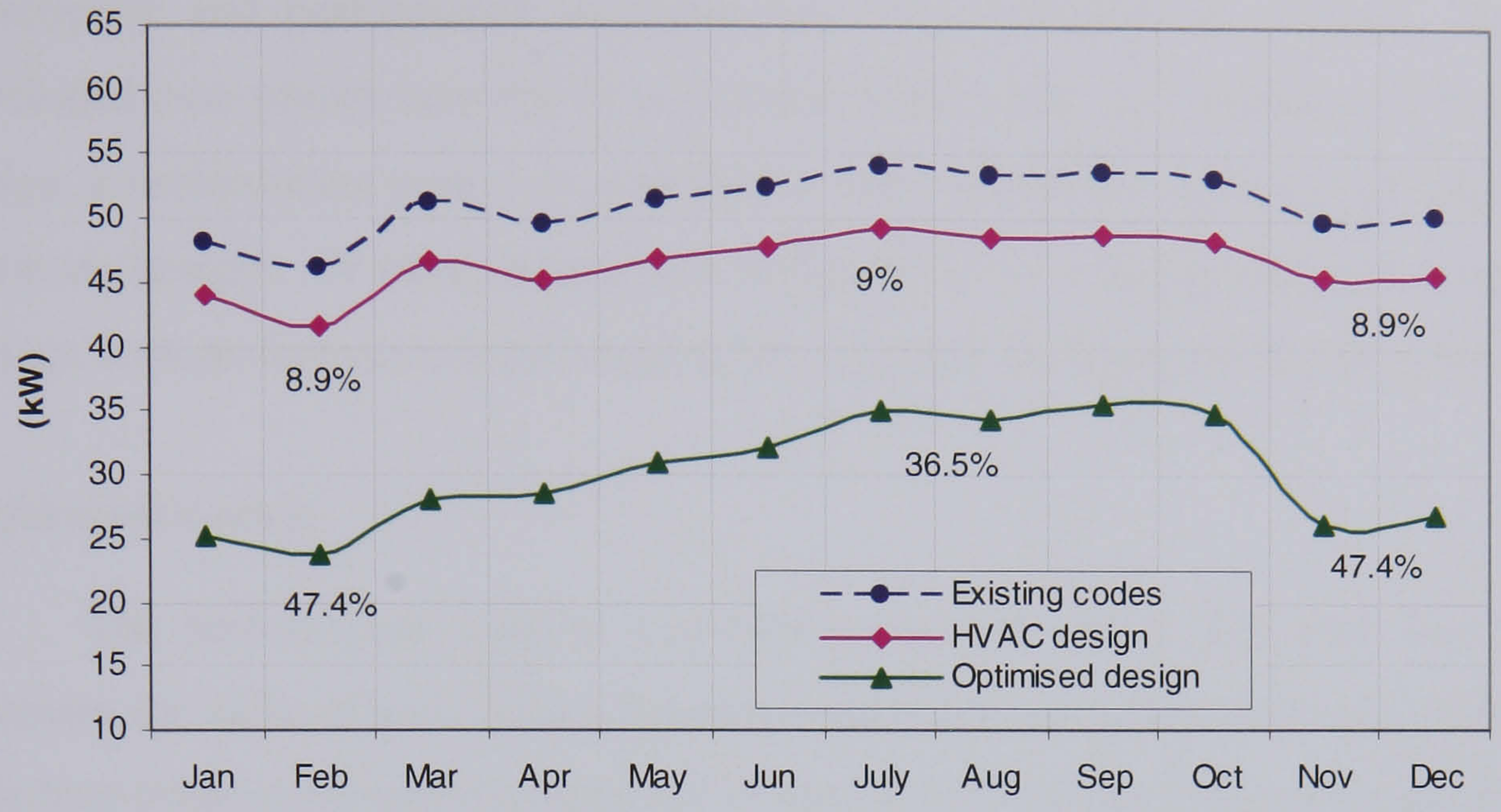

Figure 7.4 Optimisation result for electrical demand peaks

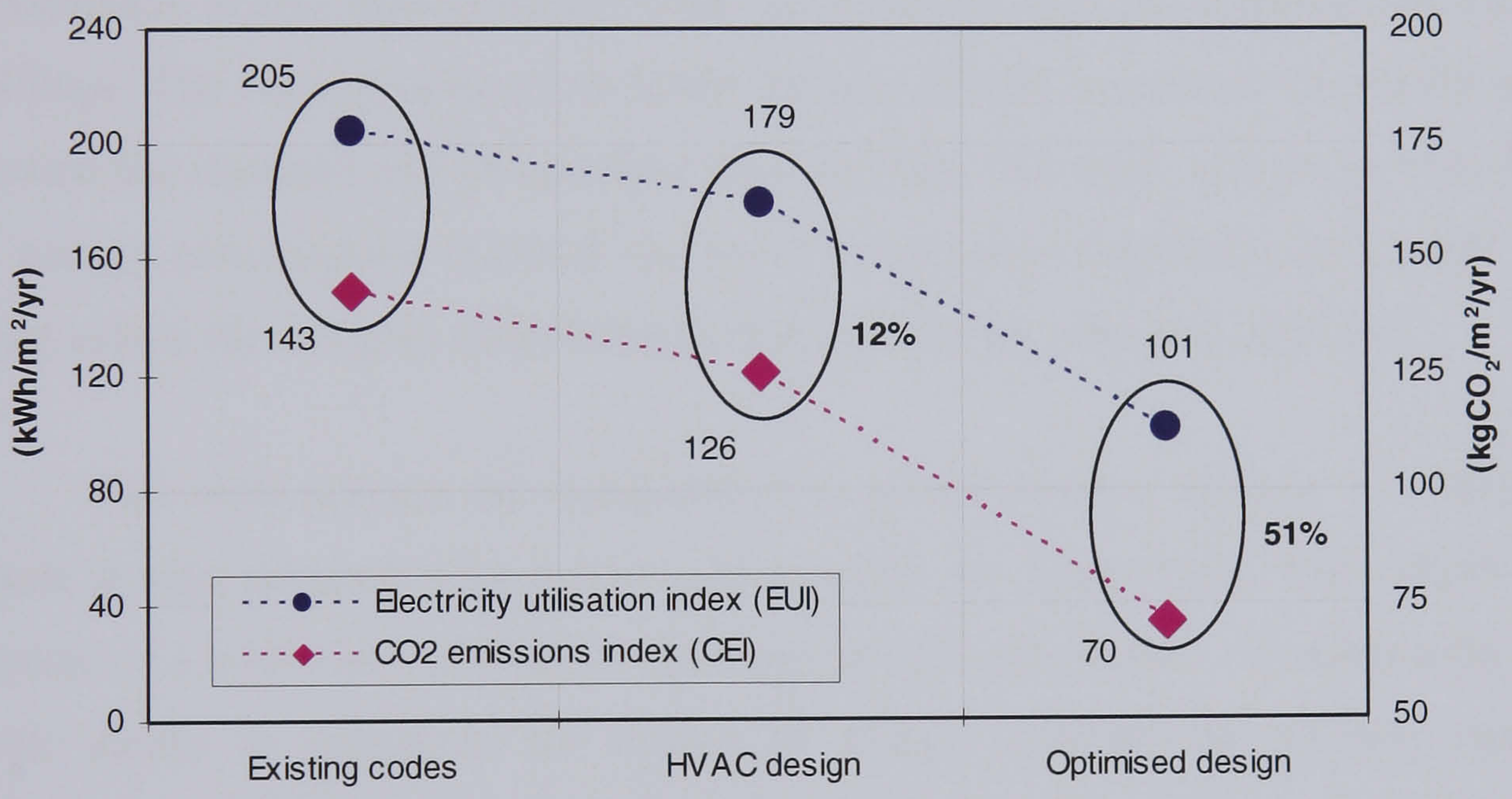

Figure 7.5 Optimisation result for energy performance

7.4.2 Building Energy Standards

The optimisation of building design allows the formulation of energy standards according to two approaches: the performance and the prescriptive. With respect to the former approach, the energy consumption of the optimised design represents an energy benchmark or a performance standard for this type of building, while the prescriptions represent prescriptive standards with respect to the latter approach. So, data in Table 7.4, along with data in Fig. 7.5, may represent new prescriptive and performance standards for office buildings in Bahrain. As the developed case model may not fit with other sensitivities and elements of building design, a performance scale was provided in order to present optimum and close-to-optimum designs. A close-to-optimum design achieves a particular level of energy savings with performance index close-to-the- optimal design performance level.

Performance scale

The performance scale is a sensitivity analysis chart. The dark bars (red) represent the value of each design measure to achieve the optimum design, while the light bars (blue) represent the impact of changing each design measure on the energy performance. The vertical hidden line in the right side (red) represents the performance index of the optimum design either in terms of energy or environmental performance. It also represents the border between the high and standard performing buildings. The vertical hidden line in the left side (black) represents the limit border between the standard and low performing buildings. The main axis at the bottom is the energy consumption (kWh/m^2/yr) or CO_2 emissions (kgCO_2/m^2/yr), while the above axis is the category of building performance (high, standard and low).

This scale permits the manipulation of energy design variables by changing certain design parameters at a time and keeping the other fixed. This allows the creation of a wide rang of close-to-optimum design alternatives. Coupled with this is the ability to determine the impact of design variables on building energy performance. Moreover, the performance scale gives more scope for the building designer to achieve a benchmark without prescribing any particular building configuration. The scale can be used with respect to the energy utilisation index (EUI), CO_2 emissions index (CEI) and cooling load index (CLI). Figure 7.6 shows the EUI-scale of the elongated form. In terms of the CLI-scale the indices are directly obtained from the optimisation outputs. Although Energy-10 provides an estimation of the environmental impact due to energy used, the CEI, in this CEI-scale, is obtained by multiplying the energy utilisation indices by the conversion factor of the fuel used in Bahrain (electricity in the current case). Figure 7.7 shows the CEI-scale of the compact form. In this way the prescribed standards can be altered and manipulated in light of the desired benchmarks and according to the determined design constraints and criteria.

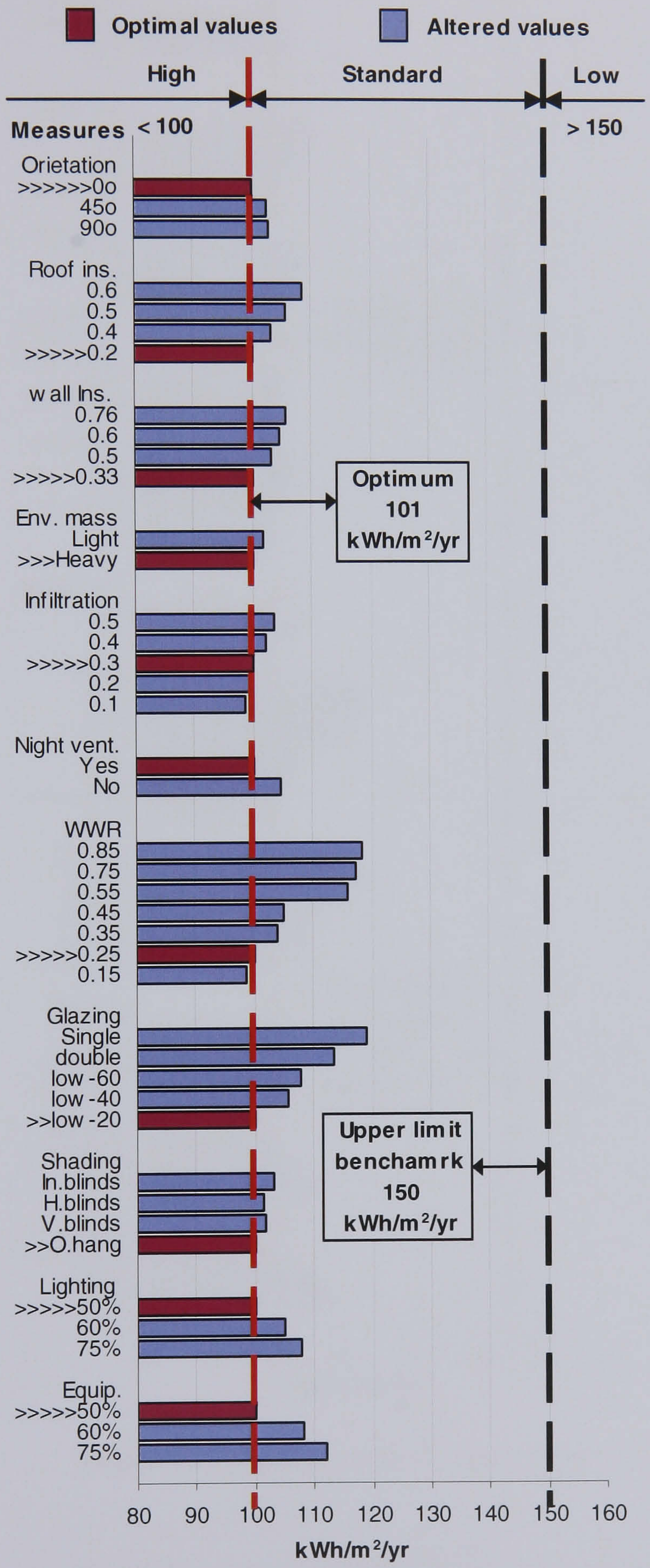

Figure 7.6 EUI-scale of the elongated form

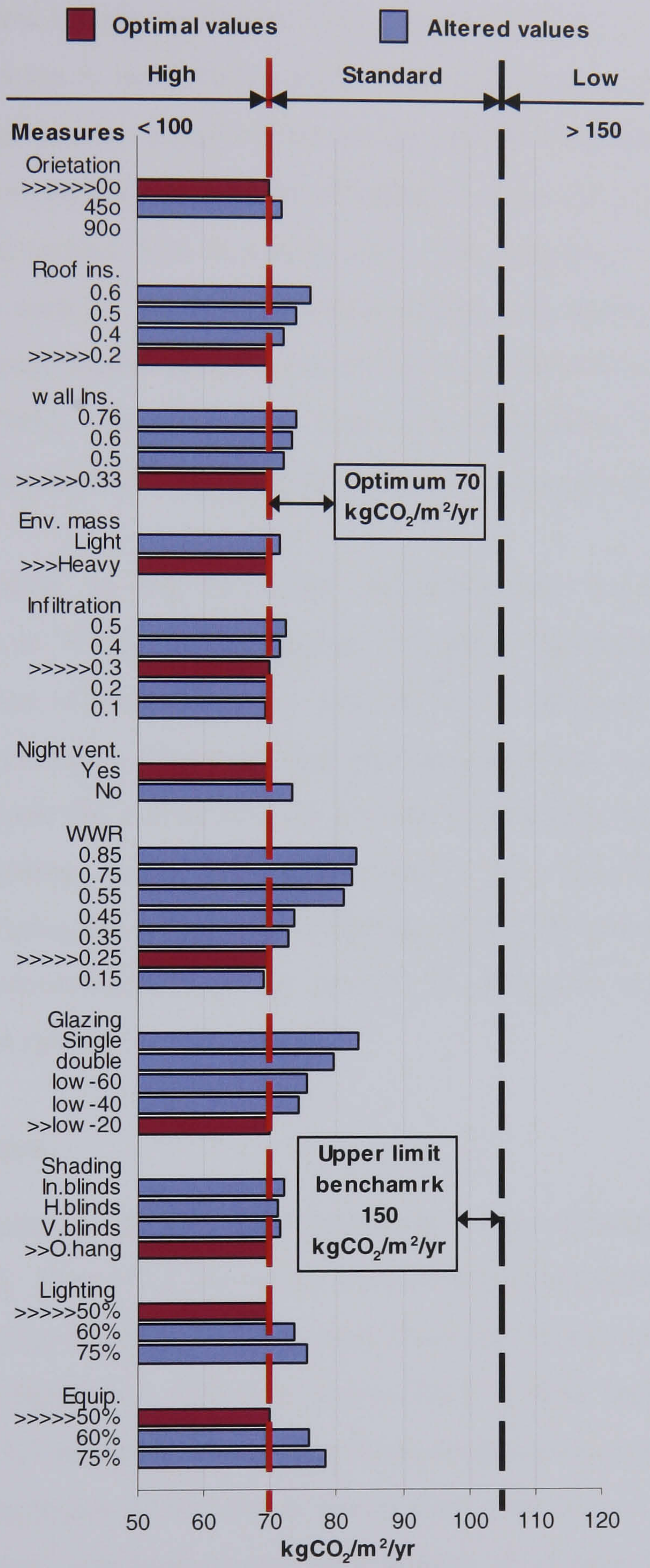

Figure 7.7 CEI-scale of the compact form

An index less than the original benchmarks is categorised as a high energy performer. If, on the other hand, the index exceeds a determined metric then it is categorised as a low energy performer. The determination of such metrics is done with the consideration to the building size. In an optimisation study (Al-Homoud, 2005) it was found that the magnitude of energy savings is increased when the size of buildings is decreased and the amount of energy savings can reach around 22% in a small office and around 50% in a large one. The variation is due to the use of different systems such as the vertical transportation and maintenance equipment. Therefore, the energy metric can be set at the value of 150 kWh/m^2/yr (the original benchmark plus 50%). In putting this framework in practice, however, the limit metric should be set for each size according to the most energy savings possible.

As illustrated, in the EUI-scale and CEI-scale the changes in some parameters, such as WWR and equipment efficiency, significantly influence the energy performance of the case model, and the largest influence occurs when the glazing system is changed. This is because glazing parameters, particularly the level of shading coefficient (SC); determine the amount of solar gain which influences the cooling and lighting loads and consequently the electricity consumption. Furthermore, changing the efficiencies of lighting and equipment has a large impact on electricity performance due to the amount of electricity consumed and heat generated by these systems.

7.5 Implementation

For the purpose of this implementation a real conceptual design from Bahrain was used. Figure 7.8 shows the architectural characteristics of a high-rise air-conditioned office building with a ground floor and 20 more storeys. The gross floor area of this building is 15015 m^2 and its floor to floor height is 5 m for the ground floor and 3.7 m for the others. The basic design has a compact plan (27.5 m x 26 m). The front façade (short side) is facing west. The area of each façade in the short side is 1960 m^2 with approximate 55% glazing in the front façade and 40% in the rear façade. The area of each façade in the long side is 2062 m^2 with approximate 42% glazing. Therefore, 0.44 was considered as an overall window-to-wall ratio for the building.

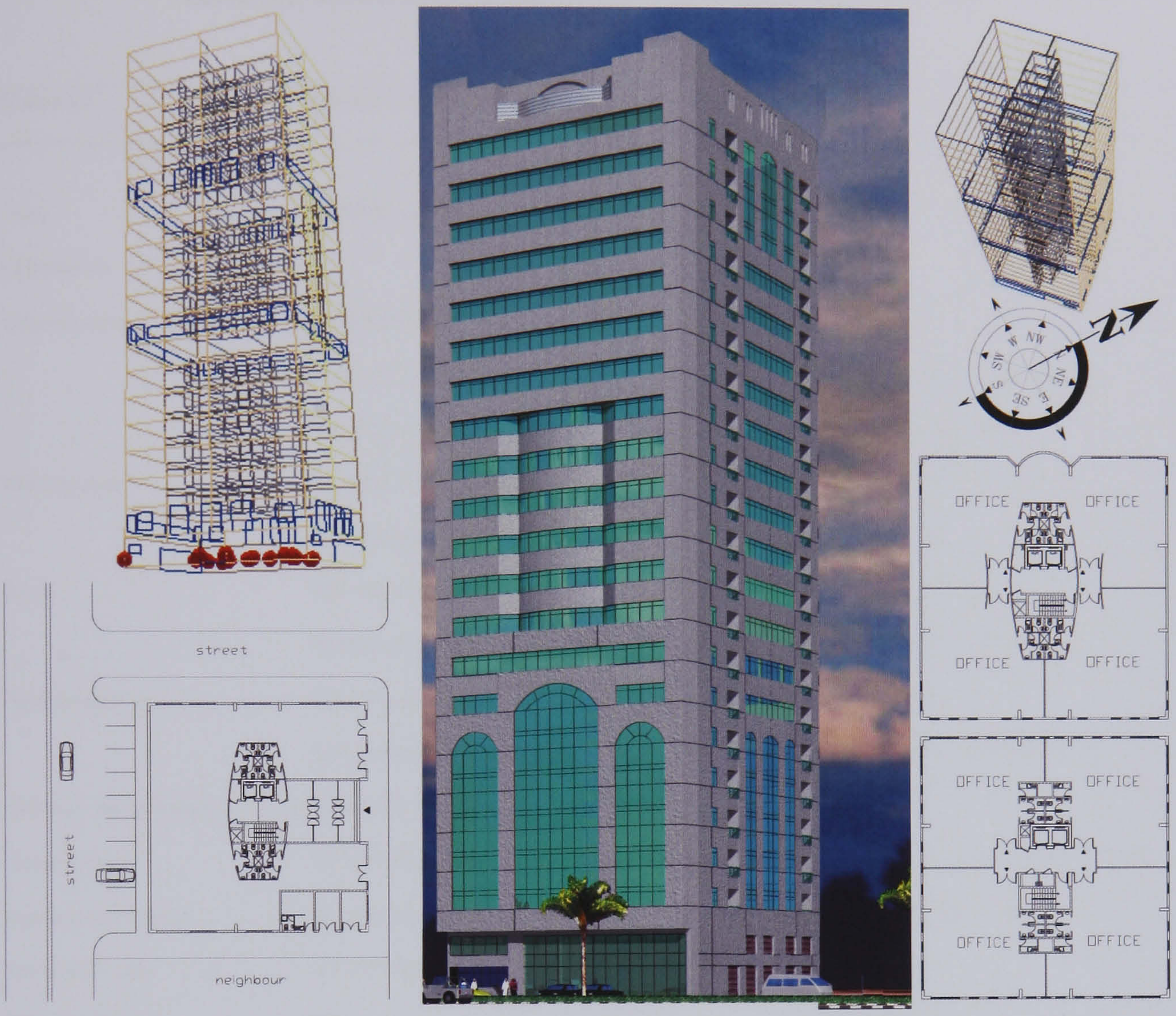

Figure 7.8 Tested conceptual design

7.5.1 Plan for applying the prescriptive standards

According to the provided data the case design can not comply with the regulations because the window area exceeds 20%, unless double glazing is used instead of single glazing. To apply the prescriptive standards without compromising the basic architectural concept the design was first defined using the Visual DOE simulation program based on the existing codes in Bahrain. The proposed prescriptive standards were then applied to the design in order to achieve the optimum case for this design. As the optimised model is a single storey building while the tested case is a multi-storeys building, the best possible U-Value for the floor and ceiling of each typical floor was determined through an optimisation search with respect to the tested design. Table 7.5 illustrates the design configuration of the basic conceptual design relative to the existing codes in Bahrain.

Table 7.5 Conceptual design relative to the existing codes and optimisation stage

Variables	Bahrain codes (see Chapter 4)	Optimum
Area	21 floors (ground -typical floor) 15015 m^2 – 715 m^2 each	
Orientation	0°	0°
Glazing area	overall 0.44	overall 0.27
	north 0.42 & south 0.42	north 0.35 & south 0.22
	east 0.40 & west 0.55	east 0.26 & west 0.26
Glazing type	U-Value 2.782 w/m^2.°C - SC 0.7	U-Value 1.48 w/m^2.°C – SC 0.2
	transmittance 0.8	transmittance 0.8
Roof	200 mm concrete	200 mm concrete
	50 mm insulation - 0.63 W/m^2.°C	50 mm insulation - 0.2 Wm^2.°C
Wall insulation	200 mm concrete	200 mm concrete
	50 mm insulation - 0.75 W/m^2.°C	50 mm insulation - 0.33 W/m^2.°C
Internal thermal mass	gypsum & block	CMU partition
Typical floor	no specification	carpet – concrete – suspended ceiling
(ceiling and floor)	no specification	insulation (0.49 W/m^2.°C)
Infiltration rate	no specification (0.5Ach)	0.3 Ach
Shading device	none	overhang 93 cm
Internal heat gain	36 W/m^2	21 W/m^2
External heat gain	52 W/m^2	28 W/m^2
2 lifts rated 15 kW	2 water pumps each rated 18 kW	1 hose reel pumps each rated 18.5 kW
HVAC system	constant air volume (CAV)	Variable air volume (VAV)
Fan (supply)	287504 m^3/h - 179 kW	160682 m^3/h - 100 kW
Fan (return)	287504 m^3/h - 86 kW	160682 m^3/h - 48 kW
Cooling	COP 2.4	COP 2.7
Capacity	2255.283 kW	1574.267 kW
Set point temperature	24°C (summer) - 22°C (winter)	26°C (summer) - 21°C (winter)
Night ventilation	No	Yes
Operation	60 hours/week	60 hours/week
Occupancy	25 m^2/person	25 m^2/person

7.5.2 Simulation results

Simulating the case building, under the two conditions of the existing codes[1], shows 22% growth in the HVAC energy demand due to enlarging the WWR from 0.2 to 0.44, along with a small drop in lighting load (2%). This small figure is because the single glazing was replaced with double glazing which means a lower shading coefficient (SC) and consequently a lower level of daylight. Single glazing transmits 87% of the available daylight falling upon it whilst double glazing has a transmission factor of 77%. Furthermore, there was no sensor to switch off the artificial lighting when the daylight factor reaches at a comfortable level. The control system was set as manual which means the utilisation of daylight depends on the attitude and culture of the occupants. This is to reflect the current situation in Bahrain.

An argument can be made that replacing the glazing parameters can cover the increase in cooling load due to enlarging the WWR. This is based on the assumption that cooling loads and external heat gain are equally responsive to the changes in the window area and glazing parameters. Technically, the variation in the window area and the change in glazing parameters, particularly the SC, do not have the same impact on the cooling load. The SC makes more significant impact than the window area. This is simply because enlarging the glazing area will enlarge the amount of solar gain. However, a reaction will occur which increases the heat loss through the glazing. Conversely, changing the SC to a higher value and keeping the window area fixed will lead to a significant increase in the solar heat gain without any reaction to heat loss through the glazing. In the current case, the WWR and glazing system were altered because of which the EUI grew by 15%. The EUI

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[1] Con (1): U-Value 0.75 W/m^2.°C for wall and 0.6 W/m^2.°C for roof - window area 0.2 with single glazing
Con (2): U-Value 0.75 W/m^2.°C for wall and 0.6 W/m^2.°C for roof - window area 0.44 with double glazing

for the double glazing case was found to be 262 kWh/m^2/yr. With this index the building can be benchmarked as a low energy performer.

The results of applying the proposed standards show a significant reduction in lighting and cooling energy demand compared to the traditional consumption of such buildings. Figure 7.9 shows a 42%, 57% and 43% reduction in HVAC system, lighting system and other loads respectively. The use of lighting sensor allows the lighting load to be dropped in spit of decreasing the window area and replacing the glazing with a lower SC. The result shows a 52% saving in the annual electricity consumption and a relative reduction in peak cooling loads of approximately 50%. However, the optimum design uses overhang shading device and has a 0.27 overall WWR, while the basic design has a 0.44 overall WWR and has no external shading device. To keep the basic conceptual design unchanged the shading device was replaced with a removable internal one and the WWRs were altered.

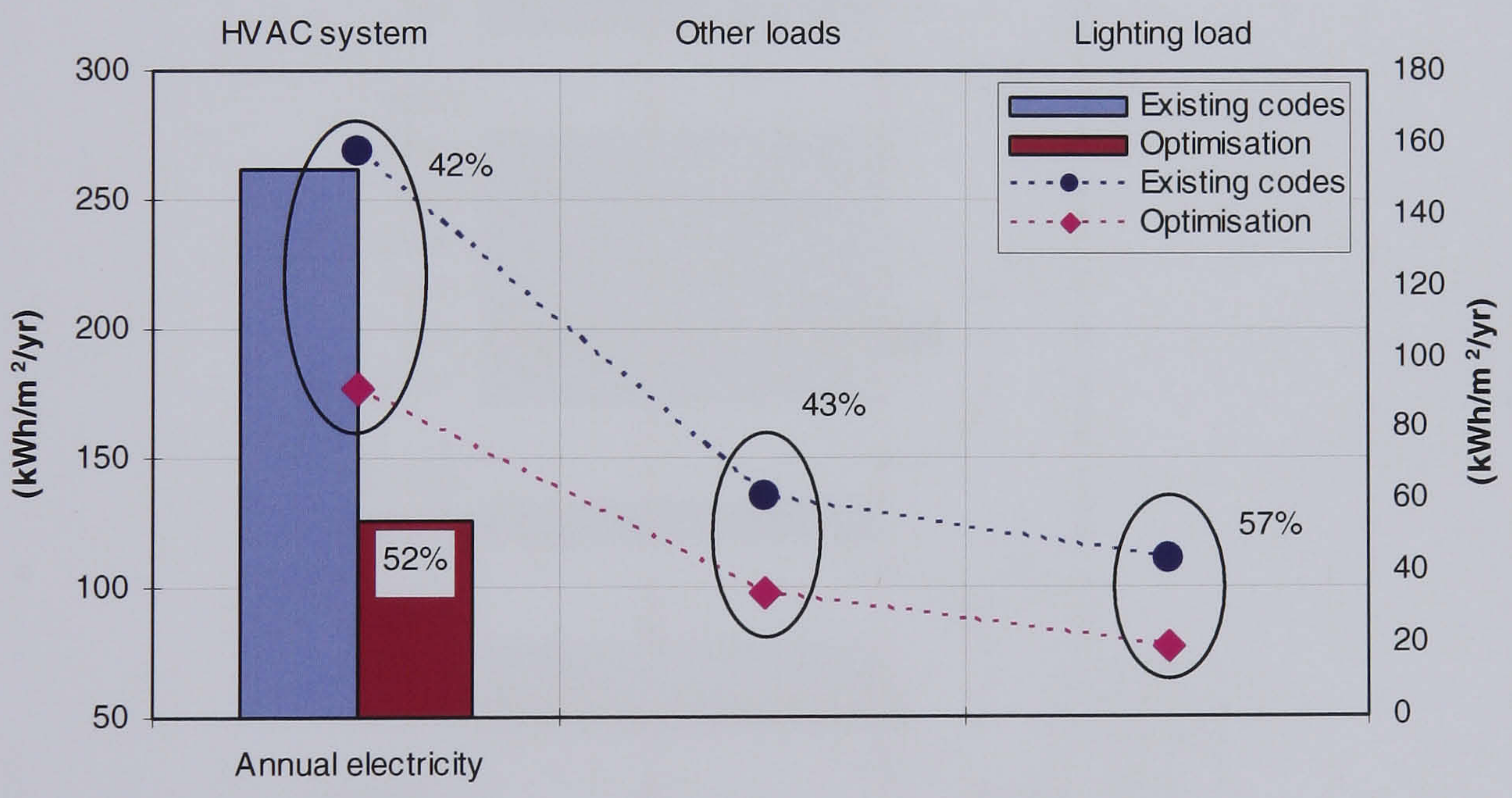

Figure 7.9 Results of applying the prescriptive standards

7.5.3 Applying the performance scale

Applying the performance scale to the conceptual design shows that a close-to-optimum design can be achieved with a small increase in energy consumption, as shown in Fig 7.10. Clearly, a 125.9 kWh/m^2/yr is the optimum energy performance for this design. By applying the performance scale it was possible to determine the impacts of changing each design parameter on the total energy consumption.

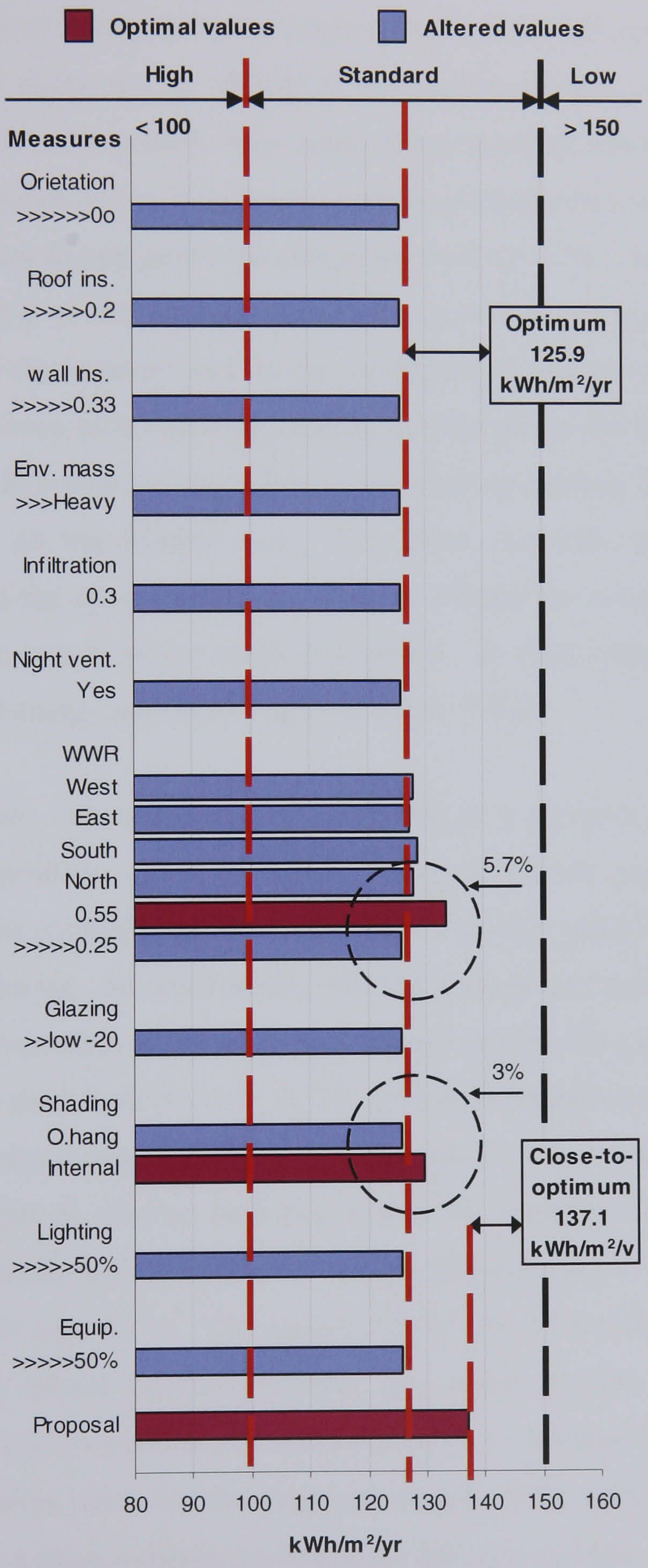

Figure 7.10 Impact of changing prescriptive standards

Altering the WWR from 0.27 to the 0.44 has reduced the lighting energy demand by 1.3% at the expense of an increase in cooling energy demand (9.8%), and therefore, additional total energy has been consumed. Altering the WWR in different orientations makes different impacts on lighting and cooling loads. The simulation results show that the WWR of the southern façade is more significant with approximately 2.3% growth in the total energy demand, while the WWR of the northern façade makes only 1.7% growth in the total energy demand. Increasing the WWR in the eastern façade grows the energy demand by 1.1%. As for the impact of changing the WWR of the western façade, the growth in energy demand reaches 1.6%. Enlarging the window area in this orientation is not practical because it is difficult to shade even with overhang shading devices due to the low position of the sun in the sky. However, in the current case internal shading devices were used which can cover all the window area. It is clear, therefore, that the impact of southern WWR is the most significant. This is because the solar intensity is at its greatest when the sun is in the south orientation. In total, increasing the WWR increases the total energy demand by approximately 5.7%.

Furthermore, Altering the shading device to a movable internal one was found to have a positive impact on lighting load (0.2%), but caused as much as a 5.2% growth in the cooling load. This is because the solar radiation is stopped after penetrating the glazing. In other words, the heat was already transferred inside the building and a proportion of this heat was trapped behind the glass and, therefore, extra energy was used to remove it. A 3% growth in energy demand is caused by replacing the overhang shading device with the interior one. When the growths in energy demand due to altering both parameters are summed the results show as much as 8.7%, while the difference in energy demand of the optimum and the proposed design is only 8.2%. The reason behind this difference is the interaction between the two altered parameters when they apply together under the whole building approach (see section 6.3.6). As a result, 137.1 kWh/m^2/yr was found to be the energy utilisation index for the proposed design. This index is still under the benchmark and is a close-to-optimum design for this size and type of building

7.6 Discussion of Standards for Low Energy Buildings

This chapter shows how building design optimisation structured towards building performance benchmarks can support the development of energy standards. A framework for setting new energy standards was presented in this chapter. To make efficient use of optimisation this framework optimised building design under the whole building performance approach. This is because energy performance is connected with other aspects of buildings, such as the internal conditions and occupants' needs; and improving some of these aspects may deteriorate others. Using the sequential search of Energy-10 identified the effective approach to the whole-building energy performance target based on the evaluation of a great number of annual hourly energy simulations, involving different combination of materials, systems and equipment efficiencies.

The evaluation of building energy performance was based on the amount of energy consumption and CO_2 emissions. The initial evaluation has identified the energy performance to achieve 51% savings relative to the current building energy codes in Bahrain. The optimisation result also showed improvement in energy performance of 101 $kWh/m^2/yr$ and 70 $kgCO_2/m^2/yr$. In addition to saving energy, the optimised design provides sufficient data and information to formulate energy standards with respect to the prescriptive and performance approaches. Since the prescriptive standards, in general, restrict innovation in building design and limit the freedom of the architect (as they prescribe how the building should be constructed), the performance scale provided in this study attempts to avoid the weakness of such standards by providing various close-to-optimum designs. The tested case building illustrated how applying the proposed standards can reduce energy consumption, cooling and lighting loads. It also showed the usefulness of using the performance scale for measuring the impact of altering design parameters to achieve a benchmark and to obtain close-to-optimum design alternatives. This is useful in compliance with building regulations.

7.7 Final Remark

This chapter brought the research contributions made in the previous chapters and integrated them into a systematic framework for setting new energy standards. The framework first optimised a case model using Energy-10, and then used the outcome of the optimisation to develop energy standards for office buildings in Bahrain. To this end, the contributions made in this study (the establishment of energy benchmarks in chapter 4, the generation of weather data file in chapter 5, the methodology for performance evaluation in chapter 6 and the framework, for setting energy standards, in this chapter) seem to work well with respect to the research aim and objectives. The next chapter concludes this thesis with a review of the research contributions and suggestions for future work.

Chapter 8 CONCLUSION AND FUTURE WORK

The building of the twenty-first century will have to perform radically better than those of the late twentieth century when, issues of climate change, fossil fuel depleting and security were not on the radar screen of building clients and users, engineers, architects and facilities managers.

(Susan Roaf, 2005: 93)

8.0 Summary of the Research Scope

Earlier in this thesis it was stated that the energy use and its impact on the environment are presently given limited consideration in Bahrain, although some attempts have been made to change this in the future. It was further noted that accurate methods for evaluating the energy performance can play a significant role in optimising building design and developing energy standards. The abundance of such methods can result in poor performance due to the unawareness of performance implications. A review to the current trends in energy efficiency identified dynamic building simulation as one of the most appropriate method for evaluating the energy performance of buildings. Today, simulation programs have advanced capabilities with respect to simulation tasks that they can carry out. However, a number of barriers remain which restrict the use of such method in Bahrain: the relative lack of appropriate weather data and the lack of systematic methodologies for performing the energy analysis. The current study, therefore, set out to develop technical solutions that remove these barriers.

To construct the envisaged information, frameworks and methodologies for evaluating the energy performance of buildings were reviewed; different approaches of energy standards investigated, energy analysis methods, particularly simulation programs, studied and related to the evaluation of building energy performance and techniques for generating representative weather data with respect to building simulation identified. Concerning Bahrain and considering the availability of information, this study has focused on the following areas:

- Examining building energy standards
- Developing a weather data file to use with simulation programs
- Introducing a methodology for energy performance evaluation
- Presenting a systematic framework for setting new energy standards

The contribution of this work has been implemented using two simulation programs (Visual DOE and Energy-10) and a number of case studies. The analyses have shown the applicability of the presented developments and led to various findings and conclusions.

8.1 Findings and Conclusions

8.1.1 Building energy standards and codes BESC

Chapter 4 reviewed the state-of-art of BESC, evaluated Bahrain energy codes, examined the OTTV standard and established energy benchmarks for office buildings in Bahrain. It was found that much work is ongoing today to develop BESC, especially with respect to performance standards. Many advanced countries have moved towards performance-based approach. However, the Gulf States, particularly Bahrain, are still living with limited and prescriptive standards in spite of their economic and architectural boom.

Energy codes in Bahrain

Energy codes in Bahrain suffer some weaknesses: firstly, they are based on a steady state clear R-value. This method is neither accurate in reflecting the R-value of the whole wall, nor is it sufficient to estimate the dynamic behaviour of complex envelopes of high mass materials such as those used in Bahrain. Secondly, the impact of these codes (envelope components codes) on the energy performance of internal load dominated buildings is small or negative. Their use in skin load dominated buildings may be effective; however, they are applicable to all types of buildings without any consideration being paid to building type, activity, design and above all building systems.

Performance standards

The OTTV standard was examined with respect to Bahrain. It was stated that this standard is suitable for a country with a hot climate and little experience in BESC such as Bahrain. This is because of many reasons such as the consideration of solar radiation, accounting all envelope thermal parameters and the ease of use and implementation. Adopting the OTTV can give benefits for improving the thermal performance of buildings. However, the OTTV and the current Bahraini codes have much in common. Their impact on the load dominated buildings is small, and also they may limit the freedom of the building designer. The principal advantage of the OTTV is the possibility to be integrated with the building systems.

Further, it was indicated that the performance standards are an effective policy to save energy. They give more flexibility to the building designers and remove restriction against architectural innovation. The principle of performance standards is to set benchmarks for the maximum allowable energy consumption. In this study, an attempt was made to benchmarking the energy performance of office buildings in Bahrain. It was shown that most offices in Bahrain are poor performers in terms of energy consumption and CO_2 emissions. This is due to many reasons such as insufficient design and operation.

8.1.2 Weather data

Chapter 5 analysed the climatic parameters of Bahrain, discussed the impact of climate on building energy performance and explained the role of weather data in building simulation. It was found that the current data used to analyse energy performance in Bahrain are limited and need to be updated with respect to the climate variability in the Gulf region. Therefore, statistical techniques in developing weather data were studied. A statistically-based weather data file was generated. It was demonstrated that the more recent the weather data the closest to the climate and the better results obtained when used in building simulations.

Weather data and climate variability

Each parameter of the climate has different influence on one or more aspects of building design and operation, and consequently on the total energy consumption. It was indicated that the accuracy of estimating the impact of these parameter largely depends on ages and methods used to collect or generate these parameters. Graphical and statistical comparisons for the major climatic parameters with different periods showed a large variation between recent measured data and data collected in the far past. It was shown that the climatic parameters tend to get warmer. This tendency impacts the thermal performance of buildings. It was found that the percentage increase in the cooling degree-days from 1960s to the present time is 5.5%.

Weather data and building simulation

The impacts of using statistical weather data files based on different climatic profiles were examined. It was found that the simulation result based on a file that reflects the recent climate conditions of Bahrain is closer to the electricity consumption than a file based on climate conditions of far past. The chance of the former file to be occurred in the near future was 80%, while the chance of the file generated from far past profile was only 23%. The comparison of the annual performance indices showed that the file based on recent data can present an accurate estimation for the annual energy consumption with only 1.4% percentage difference, while the file based on far past data tends to underestimate the monthly and the annual electricity performance by 14.5%.

8.1.3 A methodology for performance evaluation

Chapter 6 introduced a simple methodology for evaluating the energy performance of buildings. This methodology uses the simulation programs in analysing the electricity behaviour, forecasting electricity end-uses and predicting the impact of energy standards and efficiency measures on the electricity consumption. It was illustrated that using the Visual DOE program provided a sufficient estimation of electricity consumption with only small difference: 4.0% in the annual consumption and 3.4% in the average monthly consumption.

Energy analysis

The methodology was tested on an existing office building. It was found that the cooling load was dominant at approximately 65% of the total electricity consumption. This was due to the high amount of heat gains: external heat in the case of skin load dominated buildings and internal heat in the case of internal load dominated buildings. Reducing heat gain from these two sources is likely to be the most significant efficiency strategy to reduce the cooling load. The glazing parameters, particularly the SC and WWR, were found to be the most effective measures to reduce the external heat gain, while using low-energy lighting and equipment was found to be the most important technique to reduce the internal heat gain. Setting codes with respect to these two sources requires the consideration of building type. In the skin load dominated type, it was found that the cooling load due external heat gain reaches more than 60% of the total cooling load. In this case, using envelope components codes can be cost-effective. However, when the superiority is for the internal heat gain, as in the case of internal load dominated buildings, the effect of those codes becomes moderate.

Performance evaluation

To assess the impact of energy standards and efficiency measures on the performance of buildings it is necessary to follow the whole building approach. It was shown that estimating the energy consumption due to applying efficiency measures in isolation was 10% less when these measures were applied together.

8.1.4 A systematic framework for setting new standards

Chapter 7 combined all the research contributions to produce a systematic framework for setting energy standards. This framework utilised the established benchmark and the evaluation methodology, introduced in the previous chapters, to optimise energy design in order to set new standards. It showed how the building design optimisation structured towards energy benchmarks can support the development of energy standards. It was found that tracking energy benchmarks under the whole building approach and through a sequential process provides an opportunity to obtain an optimum design without comprising the occupant's needs and comfort.

Design optimisation

Using the whole building approach to optimise office design with respect to climate and internal heat gain helps to achieve determined benchmarks without compromising the defined constraints. Using these benchmarks as design objectives enables to gauge the level of efficiency and to identify any required modification. The optimisation produces the best possible design configurations for different situations. It was shown that the optimisation of energy design provides sufficient data and information that help to formulate energy standards with respect to the prescriptive and performance approach.

Performance sensitivity scale

To overcome the problem of the prescriptive standards, the sensitivity scale was presented. The scale permits the manipulation of design variables in order to obtain a wide range of optimum and close-to-optimum designs. It was shown that using the sensitivity scale gives more scope for building designer. Coupled with this is the ability of this scale to measure the impact of design variables on the total energy consumption.

8.2 Significance of the Findings

This research was investigated with the aim that the findings would be able to provide useful information and data for Bahrain. It was directed to present a systematic approach to achieve the low energy target. The significance of the research can be divided into the following area:

Introducing new approaches for BESC: a clear understanding of the weaknesses and limitations in the current energy codes is useful way in predicting their effectiveness and aspects for development. A good knowledge and experience of BESC in advanced countries will establish a platform for enhancing and strengthen the current BESC in Bahrain (e.g., energy performance benchmarks).

Developing weather data files: in addition to the developed weather data file, the investigated techniques and process will represent a guide for updating the weather data regularly.

Introducing a simple methodology for performance evaluation: this methodology explains how simulation tools can be integrated into the energy analysis of buildings.

This will facilitate building energy analysis and guide user in the input procedure, the requirements of simulation task and interpretation of results

Presenting a systematic framework for developing energy standards: the evaluation of energy performance during the design stages will make it possible to obtain optimum and close-to-optimum designs. These designs represent efficient source of data and information for developing new standards. Further, the sensitivity scale will provide the opportunity to explore more design alternatives in order to overcome the problem caused by the prescriptive standards.

From the researcher's point of view, the main finding and contribution are the fact that the research described in this thesis *was carried out in a new area with respect to Bahrain.*

8.3 Limitations of the Findings

There are some deficiencies that can be found in this study:

- Limited real detailed climatic information. Although the generated weather data file was proven accurate in estimating the energy consumption, the base for this generation is synthesis data which may be seen to be the most significant limitation in this thesis.
- The optimisation of building design was based on simulation program and human judgment which may imply that more some better designs have been omitted.

8.4 Future Work

The presented work is merely a step in the road towards low energy buildings in Bahrain. Much more work remains to be done in the area of energy standards and performance evaluation. The findings of the current work can provide the future research with various areas to investigate:

Comprehensive energy audit and analysis for commercial buildings: energy audits and analysis will not only help to explore the architectural and operation characteristics of office buildings, but also will allow identifying positive and negative energy design features and will represent the base for benchmarking the energy performance of buildings.

Establishing weather database: the climatic parameters, particularly solar data, can be studied and improved to establish a reliable database for building energy analysis.

Study the impact of energy standards on the internal conditions: there is a strong relationship between the energy standards and the indoor environment. The impact of energy standards is an area of interest especially with the new emphasis on visual comfort, thermal comfort and indoor air quality.

Investigating other types of commercial buildings: the method represented in this thesis focuses on office buildings, however, the evaluation method can be applied equally to other types of buildings.

Integrating energy regulation into building simulation: building energy regulation, particularly compliance methods can be incorporated with simulation programs in order to offer more flexibility for building design.

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APPENDIX 1

Benchmarking carbon emissions of office buildings in Bahrain

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PLEA2007. The 24th Conference on Passive and Low Energy Architecture

Benchmarking Carbon Emissions of Office Buildings in Bahrain

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ABSTRACT: Benchmarking the energy performance of buildings plays a key role in protecting the environment, reducing energy consumption and checking on energy efficiency. In this study, which is one of the first to attempt benchmarking in Bahrain, the energy and environmental performance of six public and private offices were assessed. For estimating the CO_2 emission index (CEI), samples of the annual energy consumption data were collected and analysed together with floor area data. The normalised performance index was calculated for each office building. By using a standard method it was possible to form a benchmark table that enabled comparison with building benchmark values from other countries, such as those from CIBSE and BRE in the UK. The benchmark values for the Bahraini offices indicated poor energy and environmental performance compared to international benchmarks. This study showed that the CEI was a useful tool for benchmarking the performance of office buildings in Bahrain and for providing a first index of how well those buildings were performing.

Keywords: Benchmarking, Carbon Index, Office buildings, Bahrain

1. INTRODUCTION

Building Energy Efficiency is becoming an important issue in the Gulf States, not just for reducing the depletion of oil and gas but also concerning the environmental impact due to energy consumption. The present statistics of Bahrain's electricity consumption show that buildings, particularly those in the commercial sector, are not only a major consumer of electricity, but also offer the greatest and easiest potential for conservation. (Fig. 1) shows a breakdown of the final electrical energy consumption in 2004 where 29% is consumed by the commercial sector. Commercial buildings, therefore, can save a considerable amount of non-renewable energy and reduce the CO_2 emissions through environmental design and efficient operation.

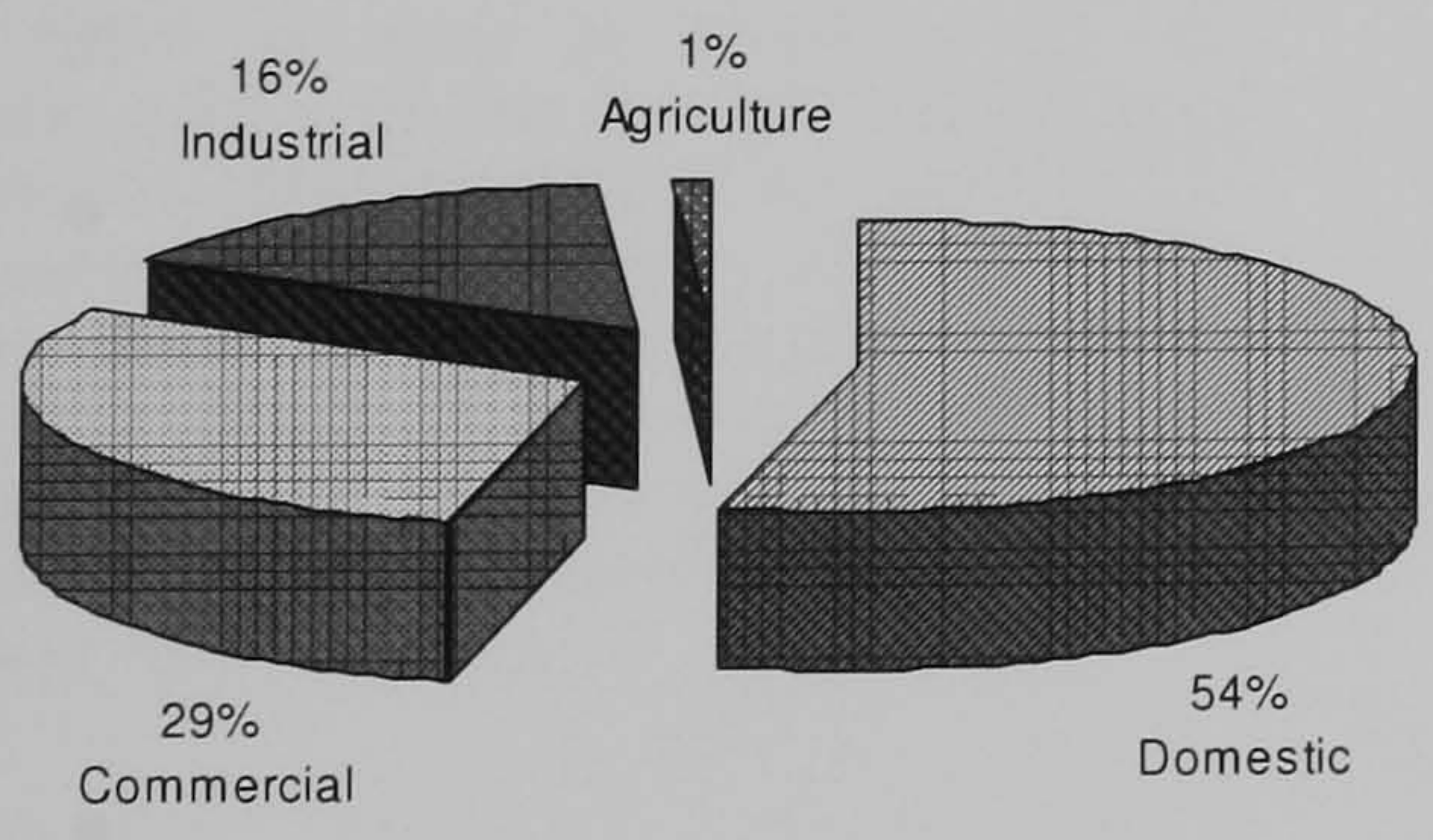

Figure 1: Bahrain Electricity Consumption per sector

In the recent past, many attempts have been made to find the best possible approaches in order to control the energy consumption in commercial buildings and to limit its consequences on the environment. Such an attempt is benchmarking the energy performance of buildings, which can be considered as an effective tool to assess the performance of buildings to achieve improvement. Benchmarking in general can be either internal to find that a particular aspect is able to perform more efficiently; or comparative that attempts to compare the performance of a building against those buildings which are considered to be the best practice [1]. Both types of benchmarking play a key role in reducing energy consumption, protecting the environment and checking on energy efficiency. By using the first type, it is possible to assess the performance of a building and to identify positive or negative energy design features in that building. The second type helps to compare the energy performances of buildings with similar types, functions and occupancy patterns in order to evaluate energy efficiency in the regional and national levels. Nowadays, with the emphasis on sustainability, several criteria are used to assess the energy performance of buildings and their impact on the environment. One such criterion is the CO_2 emissions index (CEI). The CEI represents a good indication of the impact that a building's energy use has on the environment.

2. BACKGROUND

For benchmarking energy performance with respect to CO_2 emissions, it is necessary to drive an energy efficiency index for the type of buildings in question. This index can be obtained by normalising the energy consumption with floor area and operational schedules. Further, to eliminate factors such as climatic difference, energy use can be adjusted by performing degree day's data [2]. The purpose of the normalisation is to improve comparison between similar buildings in different climatic regions or with different occupancy patterns. By using normalised performance index (kW.h/m^2/yr), four British historic buildings in Malaysia were benchmarked [3], while in Singapore, benchmarking the energy performance of office buildings was carried out through regression analysis which was used to know the relationship between consumption and factors influencing this consumption [4]. In Hong Kong, a multiplier technique was used in order to benchmark commercial buildings such as supermarkets [5]. All these attempts were directed to benchmark the performance of buildings with regard to energy consumption. However, in Argentina, 15 school buildings were benchmarked with an emphasis on the environmental sustainability. For the purpose of benchmarking those buildings, data of energy consumption and floor area were used to calculate the Energy Utilization Index (EUI) and CO_2 Emissions Index (CEI). This step was followed by ranking the resultant indices as a benchmark table [6].

3. METHODOLOGY

In this study, which is one of the first to attempt benchmarking in Bahrain and the Gulf region, a survey was carried out and technical reports of office and office cum retail buildings provided by the Electricity and Water Conservation Directorate (EWCD) [7, 8, 9, 10, 11, 12, 13, 14, 15, 16] were analysed in order to study the electricity performance of office buildings in Bahrain. The collected data include information about architectural, functional and operational characteristics of the buildings. The annual energy consumption of electricity by square metre per year of construction was measured and analysed in each case. The technique used to assess building energy performance was the Normalised Performance Index (NPI) in the form of kW.h/m^2/yr. This was done with consideration to the climate, occupancy patterns, type of building and plant and internal heat gain. The NPI was multiplied by the conversion factor in order to estimate the CO_2 emission Index (CEI) [17]. The conversion factor used in this estimation was (0.7) [18]. The resultant CEI was then used as a comparative tool of building performance. This type of indices is useful to identify the impact of a building on the environment, while the normalisation allows the comparison of office performance in Bahrain to established standards and benchmarks in other countries.

4. DISCUSSION

The consideration of the local climate, occupancy patterns, type of building and plant and the internal heat gain ensures the similarities between buildings. (Table 1) illustrates some characteristics of the buildings under study, while (Fig. 2) shows the front elevation of two of the studied buildings. This paper attempts to benchmark these buildings in two levels. The first is related to the internal performance of the buildings, while the second is related to the regional level where the studied buildings were compared with each other to determine the best and the worst performance. An attempt was made to evaluate the performance of the studied buildings in the light of well-established international benchmarks.

Table 1: Office Buildings Description

Bldg	Status	Floors	Area (m^2)	Cont Date	People/ (m^2)
ST	Private	15	8775	1997	25
MEW	Public	12	9600	1984	23
AFS	Private	9	4572	1982	21
B-05	Public	3	4500	1986	16
BSE	Public	2	1280	1990	27
HRA	Private	2	400	1985	23

Figure 2: Front Elevation of MEW-Bldg (left) and ST-Bldg (right)

4.1 Internal Level

In Bahrain, electricity is the only form of energy used for powering the building sector. (Fig. 3 and Fig. 4) illustrate monthly and annual electricity consumption per square metre in the six studied buildings. Although electricity consumption varies from one building to another due to the difference in size, it is clear that the electricity consumption increases in the six hottest months of May, June, July, August, September and October. August is at the top with an energy consumption ranging from 30kW.h/m^2 for HRA-Bldg to 75kW.h/m^2 for MEW-Bldg, while the lowest consumption occurs in December and January, ranging from 11 and 6kW.h/m^2 for HRA-Bldg and 64 and 67kW.h/m^2 for MEW-Bldg.

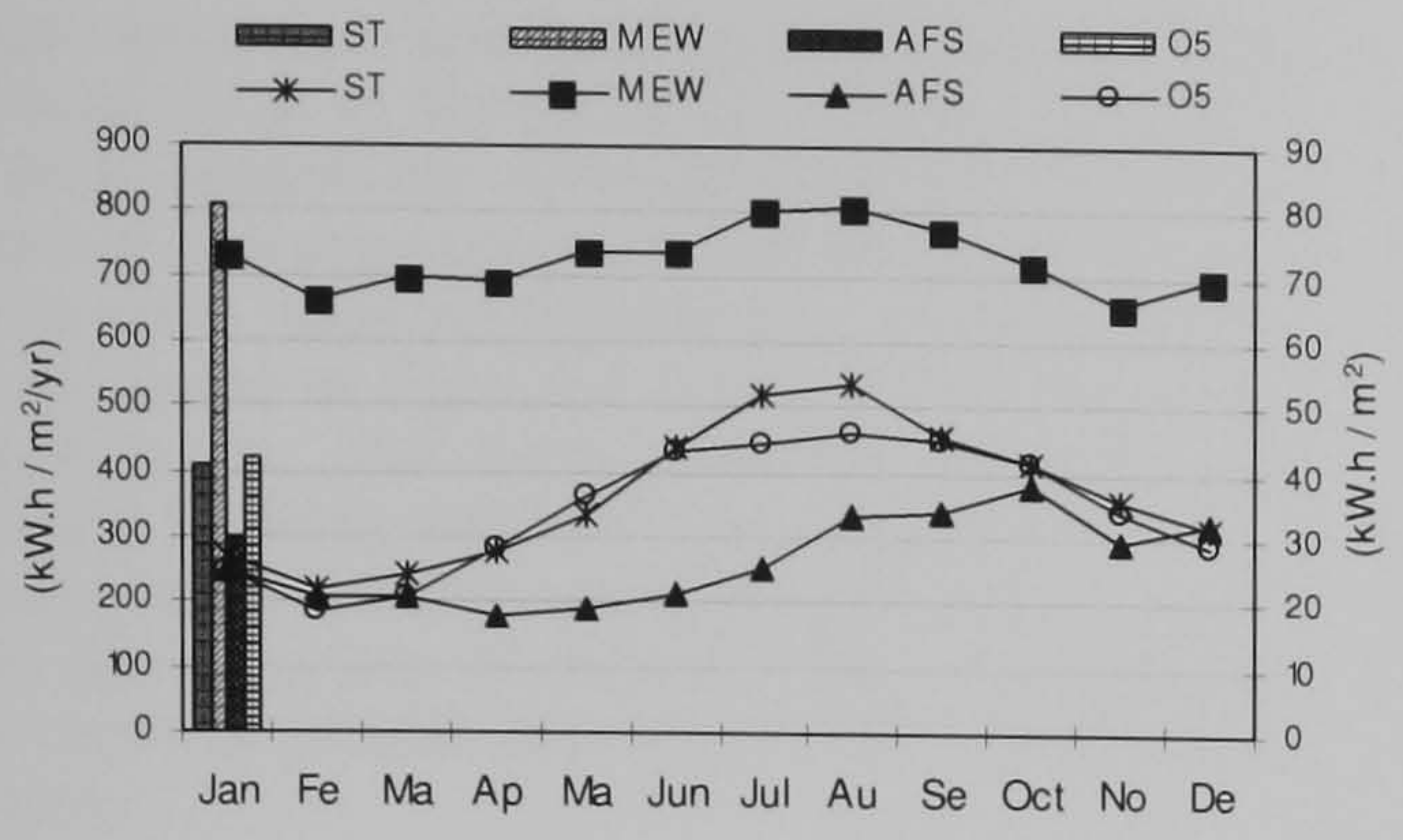

Figure 3: Electricity Consumption

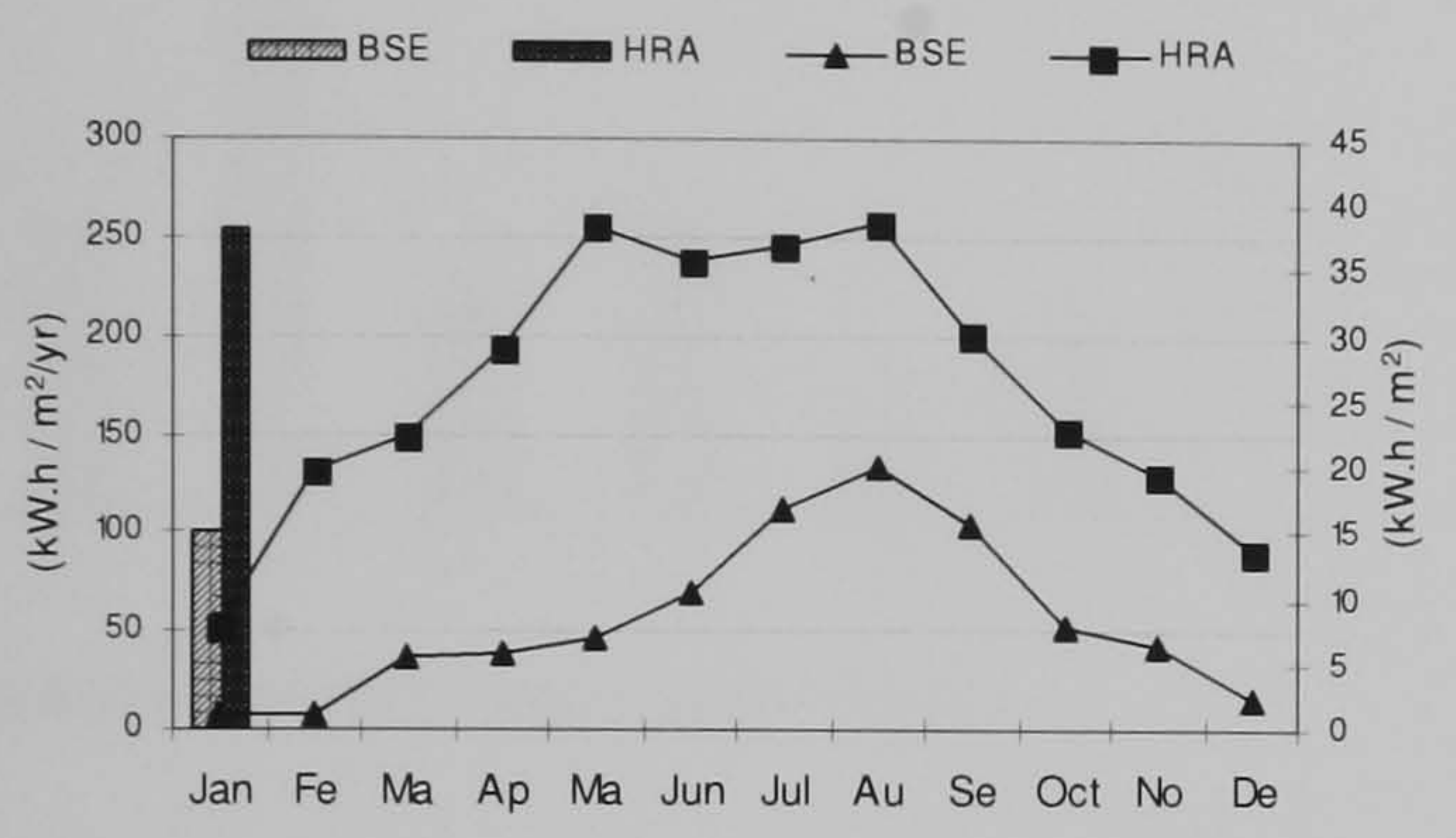

Figure 4: Electricity Consumption

Based on audit and technical reports of the building under study, (Table 3) illustrates a calculation of electricity end-uses. In the light of this calculation the annual CO_2 emission from each end-use was estimated as shown in (Fig. 5). To investigate what the factors led to this result, more analysis to the buildings' systems was conducted. Investigating the end-uses of electricity consumption indicated that there were three prime end-uses including HVAC system, lighting system and building equipment.

Table 3: Building Energy Usage

Bldg Usage	Lighting (m^2) (%)	HVAC (m^2) (%)	Equipments (m^2) (%)	Others (m^2) (%)
ST	83.0	277	53.0	-
	20.2%	67.6%	12.2%	-
MEW	50.0	458	35.0	287
	6.20%	56.9%	04.0%	32.9%
AFS	63.0	196	48.0	-
	20.7%	65.0%	14.3%	-
B-05	81.0	274	69.0	-
	19.1%	64.7%	16.2%	-
BSE	22.0	65.0	12.0	-
	22.3%	65.5%	12.2%	-
HRA	52.0	138	79.0	-
	20.3%	54.6%	25.1%	-

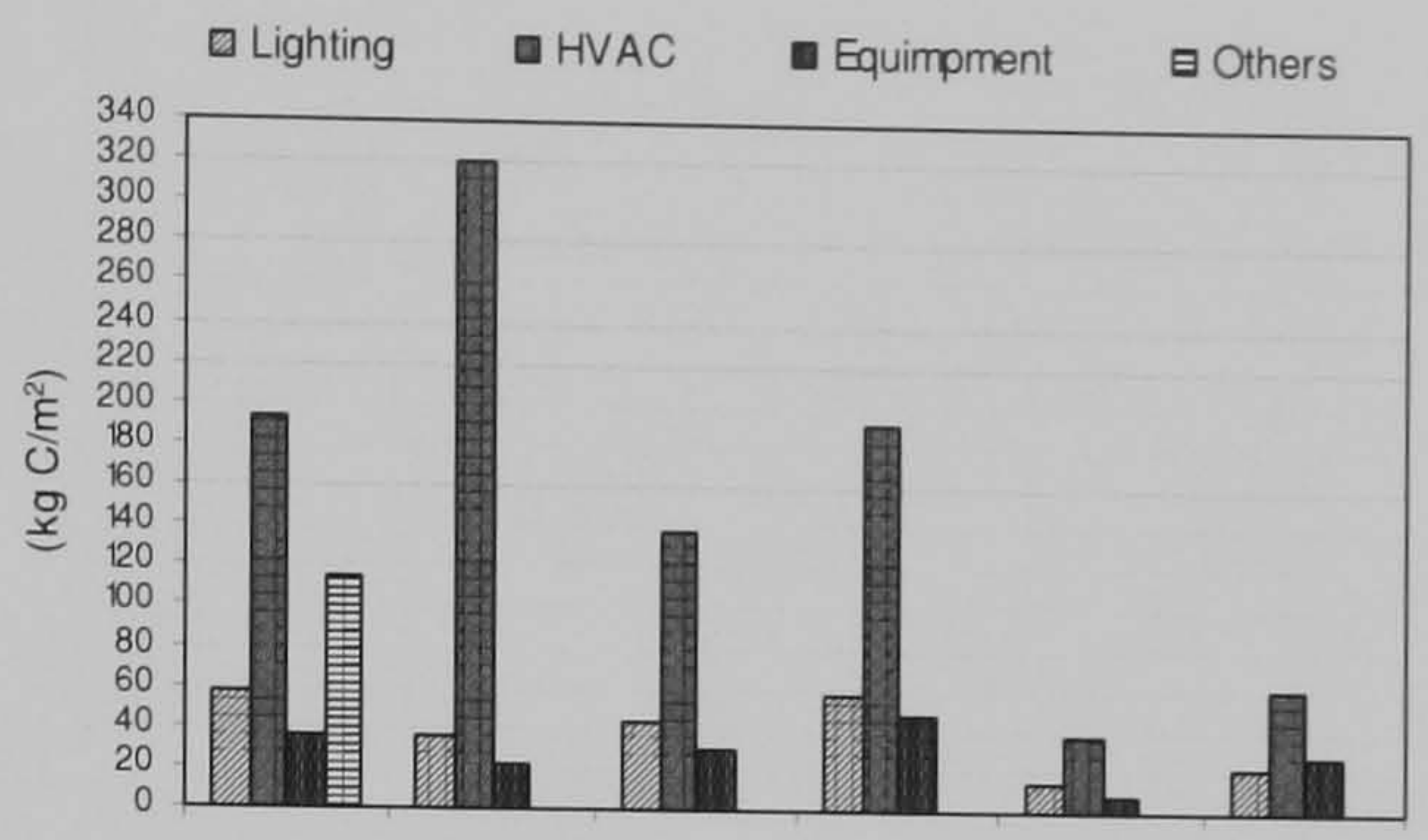

Figure 5: Annual CO_2 emissions

It is clear that the HVAC system was the main consumer of electricity, and consequently a major source of CO_2 emission. The minimum amount was emitted from BSE-Bldg with 13.1, 38.5 and 7.2kgC/m^2/yr due to lighting, HVAC and equipment use respectively. The maximum was emitted from MEW-Bldg with 34.7, 320.8, 22.6 and 185.7kgC/m^2/yr due to lighting, HVAC, equipments and others end-uses respectively. The above analysis showed that the cooling loads were dominant, and the artificial lighting was equally significant. Therefore, for improving energy performance of office buildings in Bahrain, it is necessary to reduce building and lighting loads. This can be achieved through the use of highly efficient energy system and building environmental design. These two strategies have the most influence on cooling loads, energy consumption and CO_2 emissions

4.2 Regional Level

To identify the worst and best performing building in the regional level with respect to energy consumption and CO_2 emissions, a calculation was made of the total annual electricity consumption per treated area of each building. This, in addition to the emission factor for electricity in Bahrain, enabled the estimation of the CO_2 emission indices as illustrated in (Table 4).

Table 4: Normalised Performance Indices

Bldg	Electricity Use (kW.h)	Schedule (hour/day)	Performance Indices kW.h/m^2/yr-	KgC/ m^2/yr
ST	3832007	10 / 6	409	286
MEW	8376088	10 / 5	805	564
AFS	1535220	10 / 6	302	211
B-05	1908869	10 / 5	424	297
BSE	12797	10 / 6	100	70
HRA	126808	12 / 6	253	177

This method of calculation is known as the Normalised Performance Index (NPI), which is used to measure the energy performance of buildings. It can be verified that CO_2 emissions per treated area per year varied from one building to another, ranging from 70KgC/m^2/yr to 564KgC/m^2/yr, for BSE-Bldg and MEW-Bldg respectively. Although the MEW-Bldg had the shortest operation schedules (60 hours per week), it was found to have the highest CEI, while the BSE-Bldg was found to have the lowest CEI in spite its operation hours. The same situation can also be observed in ST-Bldg with a NPI of 286KgC/m^2/yr.

Today, many benchmarking bodies use the term "tonnes and kilograms of carbon". (Fig. 6) shows the CEI in term of annual amount of CO_2 emission in Kilograms.

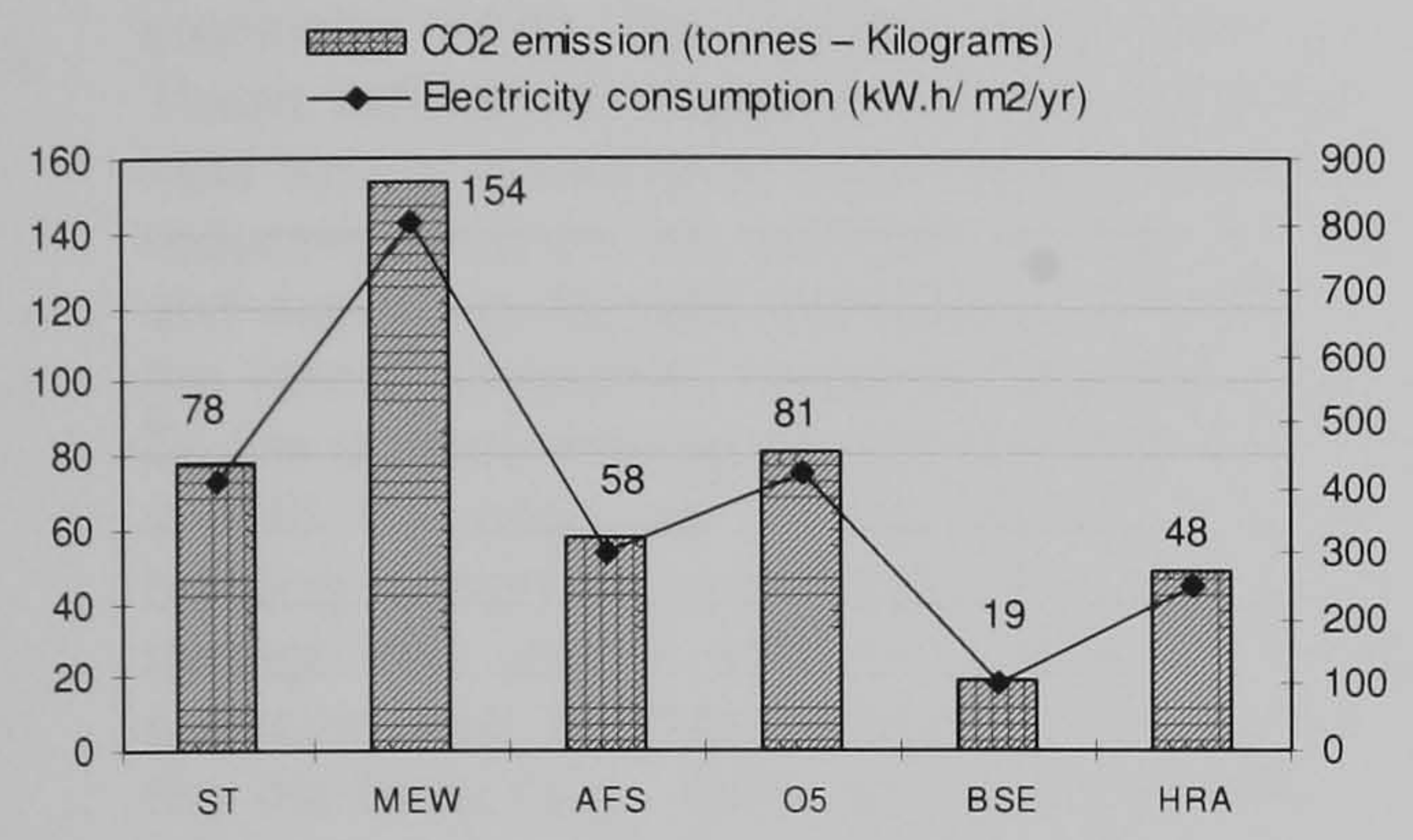

Figure 6: Normalised Performance Indices

4.3 International Level

For more efficient assessment, a country should have a scale for measuring the energy performance of buildings in line with variables and constraints in its context. However, due to the absence of such a scale in Bahrain, international standards and established benchmarks were used to assess the energy and environmental performance of buildings under study. In a comparison with published energy benchmarks by CIBSE [2] as shown in (Table 5), it was found that two offices are complied with these benchmarks. The first is the BES-Bldg as a standard practice and the HRA as a prestige office.

Table 5: Office buildings Benchmarks from CIBSE Guide F

Bldg Type	Good Practice Electricity use (KW.h/m^2)	Typical practice Electricity use (KW.h/m^2)
CIBSE		
Air-Conditioned		
Standards	128	226
Prestige	234	358
Bahrain		
BSE	100	-
HRA	-	253

At the same time, a comparison with CO_2 emissions benchmarks published by the Building Research Energy Conservation Support Unit (BRECSU) [17] for office and seminar facilities shown in (Table 6) indicates that most of the Bahraini studied buildings are overall poor environmental performers. (Fig. 7) shows a comparison with the benchmarks of BRE, which categorise office buildings into narrow plan and deep plan. It must be noted that the performance indices of the BRE were based on the emission factor for electricity in the UK (0.43), while the obtained indices were estimated with in the light of the emission factor for electricity (grid) in Bahrain (0.7). When the emission factor for electricity in the UK is considered in such a benchmarking, the BSE-Bldg can comply with a CEI of 43kgC/m^2/yr. Therefore, based on the current efficiency of the power plant and the fossil fuels (natural gas and oil) used to generate electricity in Bahrain, 70kgC/m2.yr may represent a new benchmark for CO_2 emissions of office buildings. However, according to the BRE benchmarks the other buildings are categorised as overall poor performers.

Table 6: Performance Indices for office and seminar facility (BRE)

Bldg Type	Electricity Use (KW.h/m^2)	CO_2 Emissions (KgC/m^2)
Narrow Plan	All electric 68	46
Deep Plan	All electric 75	51

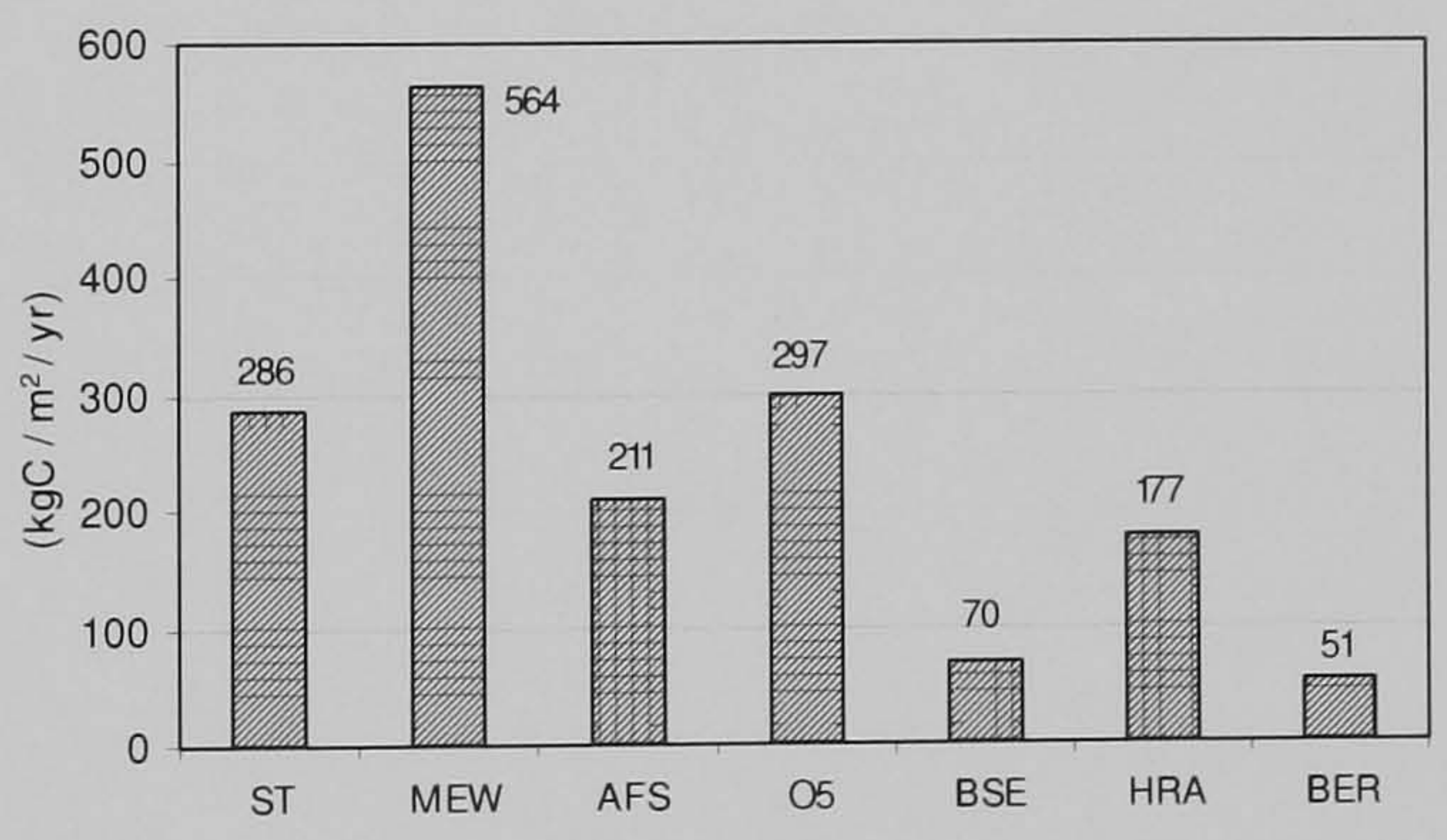

Figure 7: A comparison with published benchmarks by BRE

5. CONCLUSION

The building sector is not only one of the major consumers of electricity, it is also one of the largest contributors to the increase of CO_2 in the atmosphere and hence to global warming and climate change. Benchmarking the energy performance of buildings can play an effective role in improving the efficiency of such a sector in the Gulf States.

Today, with the increase in atmospheric temperature, performance is assessed according to the impact that a building's energy use has on the environment. In this study, it was shown that using CO_2 emission indices allows measurement of the energy and environmental performance of office buildings in Bahrain with respect to internal, regional and international standards. The obtained benchmarking values for Bahraini offices indicated poor energy and environmental performance compared to international benchmarks. With respect to the internal and regional levels, it was indicated that the cooling load was the main consumer of electricity while the lighting load was significant. These indications suggest two main changes for the near future: avoiding or reducing air-conditioning; and reducing reliance on artificial lighting by increasing and exploiting daylight availability. In order to achieve the former objective, reducing heat gains is likely to be the primary energy design strategy and, therefore, should be used as a determinant for the future building design and operation. This can be achieved through the use of efficient energy technology and environmental building design as well as the use of the bio-fuels (e.g., solar and geo-thermal). This will influence the cooling loads, the total energy consumption and the CO_2 emissions in Bahrain.

This study attempted to establish a source of guidance for energy efficiency in office buildings. The obtained results can be used as comparative benchmarks in order to provide a basic evaluation of how well the office buildings are performing. This was done with the aim of attracting some attention to the consequence of energy use on the environment and to provide some criteria for building design in the Gulf region. Much work is ongoing by the researchers in the area of energy design to encourage better design practice in Bahrain and the Gulf States.

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APPENDIX 2

A systematic methodology for optimising the energy performance of buildings in Bahrain

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A systematic methodology for optimising the energy performance of buildings in Bahrain

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Abstract

Today, a great deal of effort is ongoing all over the world to find methods for optimising the energy performance of buildings. Such efforts can be seen in the European Energy Performance of Building Directive (EPBD). This directive aims to ensure energy saving and CO_2 emission reduction without compromising the local conditions and people's comfort. In the Gulf States, however, there is a need for such methods due to their economic and environmental benefits. This study introduces a simple but reliable methodology for optimising building energy performance in Bahrain. The methodology is based on building management systems (monitoring, analysing and targeting future performance), simulation tools and other technologies. This methodology was implemented using Visual DOE and was directly related to collectively gathered data gained form experimental works and practical applications. By means of the introduced methodology, energy consumption was obtained together with energy cost and CO_2 emissions. The applicability of this methodology was demonstrated through optimising a case office building in Bahrain.

Keywords: Optimisation; Energy performance; Office buildings; Bahrain

1. Introduction

Low energy buildings are becoming a hot topic in Bahrain, not just for reducing the depletion of oil and gas but also for concern about the environmental impact due to energy consumption. The present statistics of Bahrain's energy consumption indicate that the installed capacity, energy demand and the annual energy use are growing substantially. If one excludes the electricity generation, the final energy consumption is split into four major sectors, as shown in Fig. 1.

It is clear that buildings, particularly those in the residential sector, have the largest impact on this growth, as 54% of the total energy is used in this sector; however, in the future this situation may change. The presently commercial sector, which consumes only 29% of the total energy, is likely to greatly increase its consumption. In a study [1] into energy consumption in buildings, it was found that as countries develop, the fraction of their total energy devoted to commercial buildings may increase, which may lead to greater production of CO_2. In 1998–1999, the World Resources Institutes [2] estimated that the amount of CO_2 emitted by different sectors in Bahrain was 0.1%of the total global CO_2 production. It is interesting to note that 34% of this production is caused by electricity generation and 24% by buildings. Although this fraction is small, it may increase with the present rapid architectural boom in Bahrain. Therefore, it is possible to say that commercial buildings are not only a major consumer of energy, but also a significant contributor of CO_2 emissions. However, these buildings offer the greatest and easiest potential for conservation. They can save a considerable amount of non-renewable energy and reduce CO_2 emissions through environmental design and efficient operation.

In the recent past, many attempts have been made to find the best possible approach to control the energy consumption in commercial buildings and to limit its consequences on the environment. The European Energy Performance of Building Directive (EPBD) [3] is such an attempt. This directive aims to ensure energy saving and CO_2 emissions reduction without compromising the local conditions and people's comfort. This is done by following systematic methodologies for performance evaluation and design optimisation.

At the individual level, many efforts have been spent to introduce optimisation and evaluation methodologies. For example, an overview for methods and software that can be

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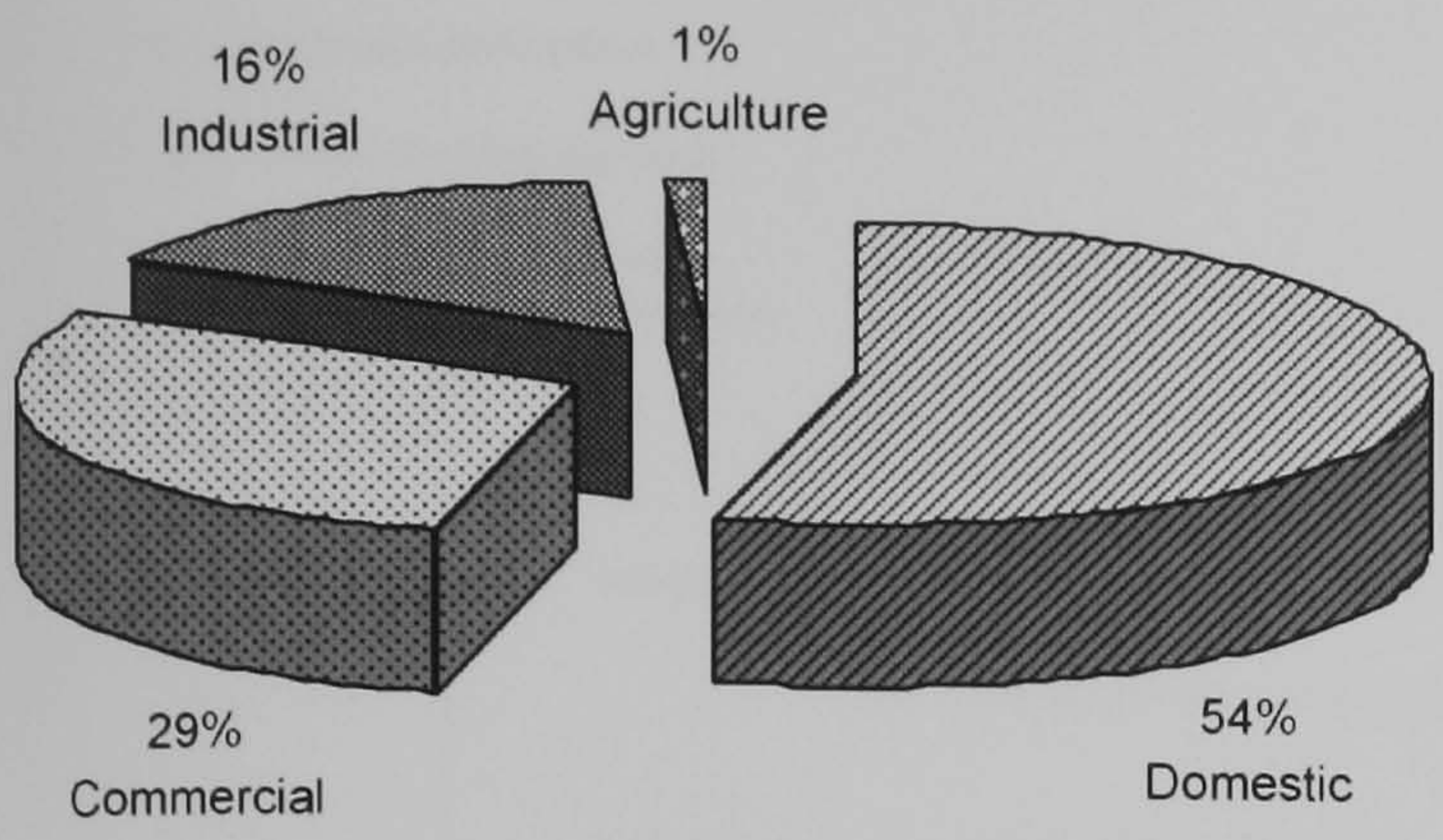

Fig. 1. Bahrain electricity consumption per sector.

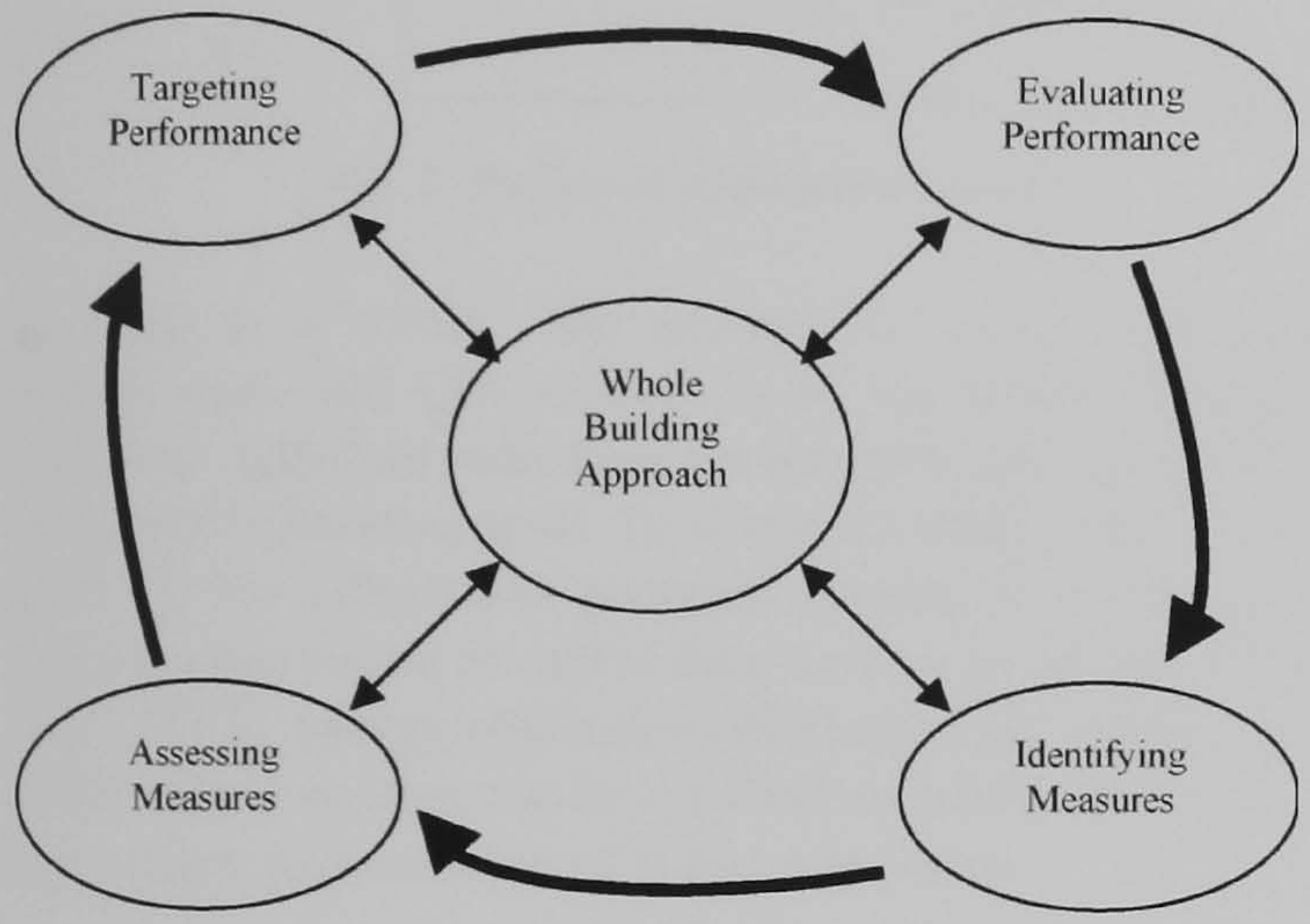

Fig. 2. Performance optimisation scenario.

used to perform building energy assessment in a uniform way was presented by Poel et al. [4], while a methodology called Building Energy Analysis (BEA) was proposed by Rey et al. [5]. In the Gulf States, although there is a small amount of research and writing that is relevant to the use of conservation measures [6–9], there is a need for such methodologies due to their economic and environmental benefits.

It is known that any attempt to improve the energy performance of buildings should go through a systematic scenario. Fig. 2 illustrates the logical steps for optimising the energy performance of buildings. This scenario offers a means of analysing the energy behaviour of a building, evaluating its performance in any stage of its lifecycle, identifying optimisation measures, assessing the measures and targeting the future performance.

2. The method

2.1. Whole building approach

At the building level, when the envelope parameters are designed with the purpose of optimising the energy performance, the size and capacity of mechanical equipment can be reduced and, consequently, the electrical power distribution system may also be reduced. However, the optimum design of the building envelope will not necessary lead to an exemplary high energy performance due to the fact that the energy consumption is strongly influenced by the building's system and occupants. The quest for optimum energy performance requires a coherent application of parameters which together optimise the performance of the whole building's systems. It is therefore necessary to apply an integrated approach to the process of optimising building design and evaluating performance [10].

2.2. Performance evaluation

The optimisation scenario begins with the evaluation of present building performance. This is done through analysing building statistics where a complete picture of the current situation of building performance is given and a basis for identifying measures for optimisation is provided. Furthermore, an initial set of performance metrics is specified and documented.

2.3. Identifying optimisation measures

Optimisation is the search for the best possible solution for a particular problem [11,12]. This search can be for minimising the energy consumption or reducing the CO_2 emissions or for any other aspects of building performance. The search for optimisation measures can be identified in a two-part sequence: measures already identified and proposed measures based on the result of energy analysis. The former are obtained from previous experiences, publications, and checklists. The latter are recognised by thoroughly reviewing the data contained in the energy analysis. The key to identifying optimisation measures is to uncover those with a rewarding return. In this step, one can ask "what if..." questions about potential modifications or changes.

One method of searching for optimisation solutions is to test optimisation measures by computing the performance of each one with respect to a base-line. Varying one measure at a time and keeping the others fixed or following what the so-called sensitivity analysis enables one to obtain a great number of optimisation solutions. This will not only show the impact of different measures on building performance but will also indicate the impact of these measures on various building aspects.

2.4. Assessing optimisation measures

In order to find the most rewarding measures, it is necessary to assess the identified and proposed measures. Fig. 3 shows one possible process that could be used to assess the impact of measures on the performance of buildings. Before performing the assessment, however, criteria for building performance should be defined. Various criteria are used to evaluate building performance, including energy performance indicators, thermal comfort, day-lighting level, visual comfort, and acoustic comfort. Each of these criteria measures one or more requirements of building performance. However, improving some performance requirements may deteriorate other aspects. Therefore, it is important to evaluate the performance of the

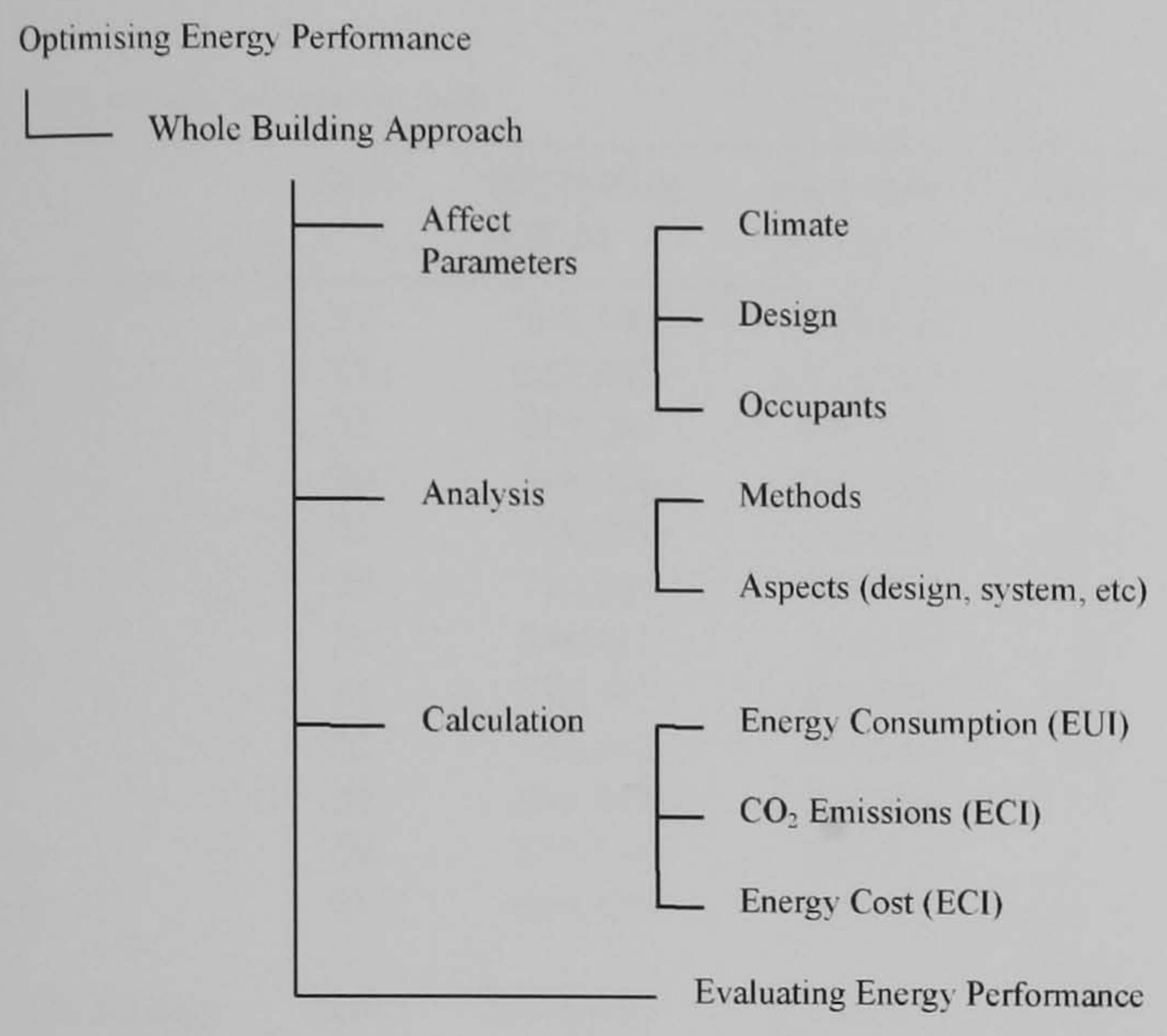

Fig. 3. Process of performance evolution

building as a whole. The amount of energy consumption, energy cost, and CO_2 emissions of the whole building can represent sufficient indicators for the performance of buildings in the whole building level. To assess the energy performance in light of the simulation program output, it is necessary to translate this output to useful data such as an energy utilisation index (EUI), energy cost index (ECI) and CO_2 emissions index (CEI). These indices can be certified and used as indications of the current performance of a given building.

2.5. Targeting future performance

The results of simulation and other assessment methods are used as a target for future energy performance, for which building management is stimulated to make improvements [13].

3. Implementation

For the purpose of this implementation, the current methodology was applied to evaluate and optimise the performance of an office building in Bahrain. MEW-Bldg is a governmental building constructed on a rectangular footing. It has a ground floor and 11 more storeys, as shown in Fig. 4. The surface area of each floor is 800 m^2, and its floor-to-floor height is 3.5–4.0 m. The walls consist of mainly 200 mm concrete block, 24 mm inside and outside plaster, and 50 mm polystyrene insulation. The roof consists of 50 mm screed, 35 mm polyurethane and 200 mm concrete slab. The glazing type is 6 mm double glass with an approximate 0.80 window-to-wall ratio. The building has multi-thermal zones with a constant centralised system. Complete details of the building's physical and operational characteristics are illustrated in Table 1.

3.1. Calibrating to building's past performance

Information obtained from previous utility bills can be used to investigate the efficiency of a building comparing to similar buildings. In the building under study, electricity bills from

Fig. 4. MEW-Bldg.

Table 1
Office buildings description

Building form parameters	
Number of storeys	12
Total area	9600 m^2
Floor height	3.5–40 m
Orientation	East to West
Building Skin	
Wall	0.63 U-Value (w/m^2 °C)
Roof	0.5 U-Value (w/m^2 °C)
Opening	0.8 window-to-wall Double glazing 6 mm
SC	0.57
Transmittance	0.7
Infiltration rate	5.0 m^3/h/m^2
Ventilation rate	7.5 l/s/person
Thermal zones	
Floor 1	Reception/managers offices
Floor 2	A canteen and offices
Floor 3	IT centre
Floor 4–12	Office cubical
Building system	
Equipment	56.4 w/m^2
HVAC system	Constant centralised system
Set point Winter	22 °C winter–24 °C summer
Building operation	
Schedules	60 h per week
Occupancy	25 m^2/person

Table 2
Monthly and annual electricity bills

Month	Days	MEW-Bldg (kW h)	Base case (kW h)	Difference (%)
January	31	701,140	728,653	−3.9
February	28	637,081	674,527	−5.9
March	31	671,294	692,402	−3.1
April	30	661,928	700,999	−5.9
May	31	709,799	735,630	−3.6
Jun	30	711,580	741,294	−4.2
July	31	768,412	787,171	−2.4
August	31	776,343	810,122	−4.4
September	30	743,842	783,264	−5.3
October	31	691,548	700,386	−1.3
November	30	633,745	659,173	−4
December	31	669,376	687,332	2.7
Average	–	–	–	−3.4
Annual (kW h/year)	365	8,376,088	8,710,971	−4.0
EUI (kW h/m^2/year)	–	805	837	–

January to December were collected on request from the Electricity and Water Conservation Directorate [14]. These bills provided sufficient information about the previous annual and monthly electricity consumption and also helped in calibrating the base case of the simulation program. Table 2 illustrates the annual and monthly electricity consumption from electricity bills and consumption obtained from Visual DOE. As illustrated, there was as much as 4.0% difference between the actual annual consumption of the MEW-Bldg and the base case. Trials were made to manipulate the estimated input performance parameters, such as schedule of use rate and set point temperature, to closely match the electricity consumption of the base case with electricity bills. For the final trials, as shown in Fig. 5, holidays, schedules of occupancy, lighting, and equipment were adjusted and different infiltration rates were tried.

Based on the above illustration, it is clear that Visual DOE predicted the monthly electricity consumption fairly well during different times of the year. When the actual consumption for the heating season from November to April was compared with the simulation results, the difference ranged from 2.3% to 0.3%, while the difference of the cooling season from May to October ranged from 2.7% to 0.5%. The above was considered an accepted result. This allowed analysis of the energy use patterns of the studied building and proposed possible measures for performance optimisation. A target for future energy performance, which had an 805 kW h/m^2/year performance index, could also be set.

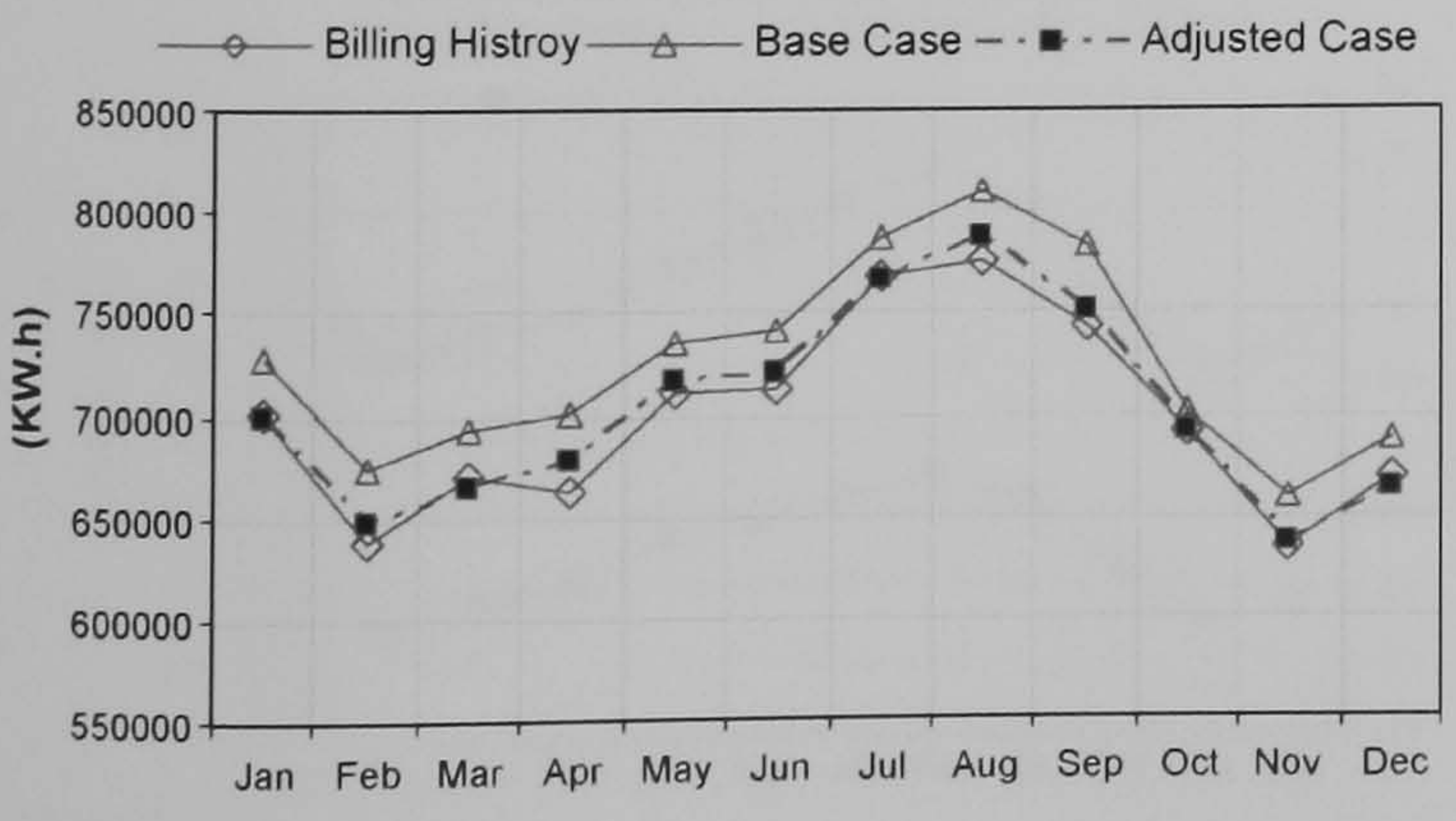

Fig. 5. Comparison of monthly electricity consumption.

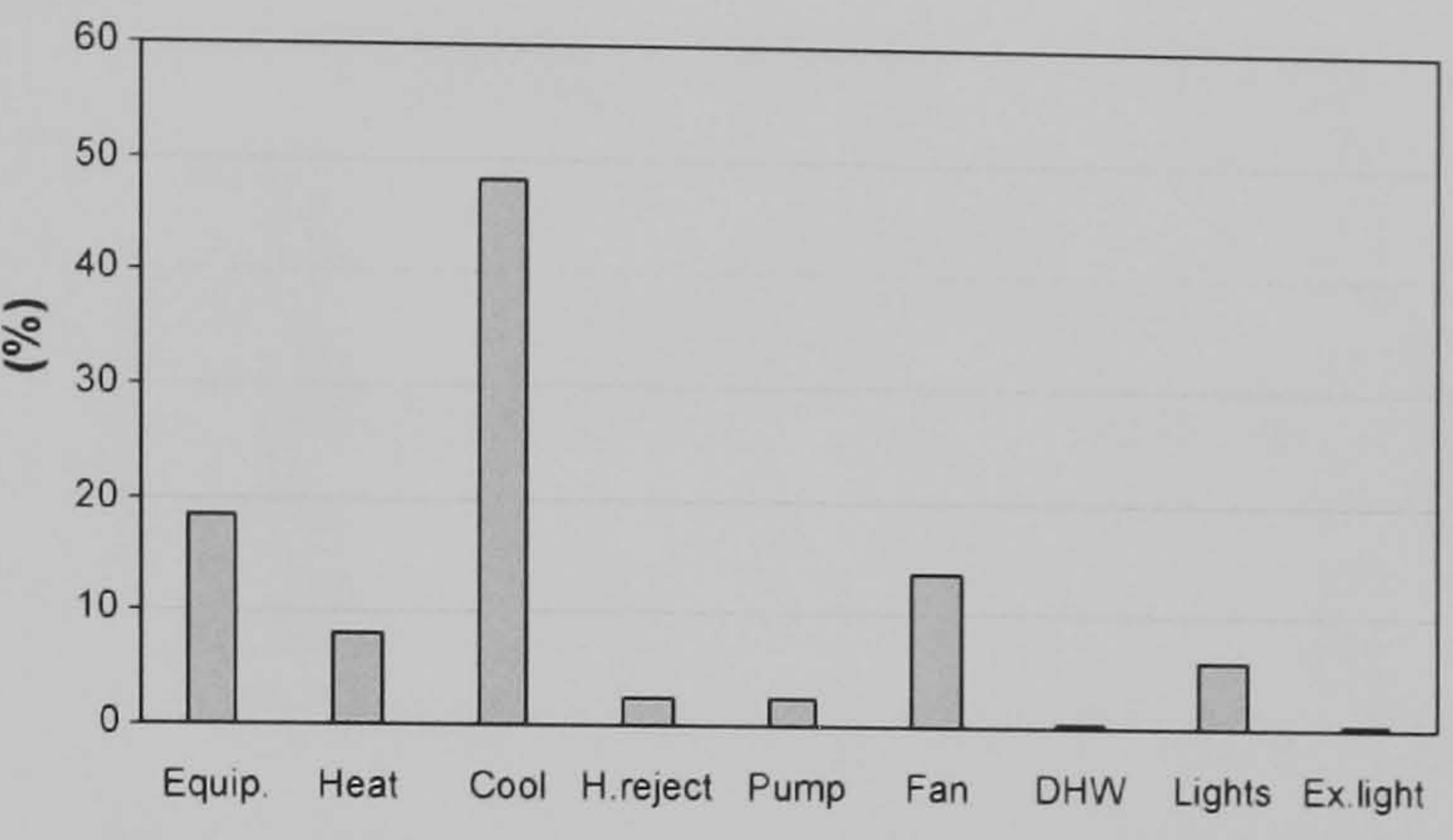

Fig. 6. Breakdown of electricity consumption components.

3.2. Performing the analysis

A great number of runs were made to evaluate the energy use patterns of the MEW-Bldg. Fig. 6 shows a breakdown of electricity consumption components. It is clear that the electricity of the HVAC system is the most significant, particularly for cooling energy, which requires 66.9% of the total electricity consumption to satisfy the cooling load. This percentage is normal for commercial buildings in Bahrain. Heating the same building consumes only 7.9%, which is relatively small compared to the cooling energy. This is due to the hot climate of Bahrain and the short period that the building needs to be heated up. At the same time, domestic hot water consumes only 0.2% for the whole year. As the building is equipped with various electricity devices, the equipment has a major share of electricity consumption, which reaches to 18.6%. Lighting consumes 5.8%, which is fairly low in this type of buildings. The reason behind this is the huge glass area in the southern façade with an approximate 0.80 window-to-wall ratio. The exterior lighting consumes 0.5%, which is relatively high.

To determine what factors influence the cooling load, further analysis was carried out on the building's end-uses. Fig. 7 breaks down the cooling peak loads according to the sources of the load in the building under study. These sources include wall conduction, roof conduction, glazing conduction, glazing solar radiation, occupants, lighting, equipment and infiltration.

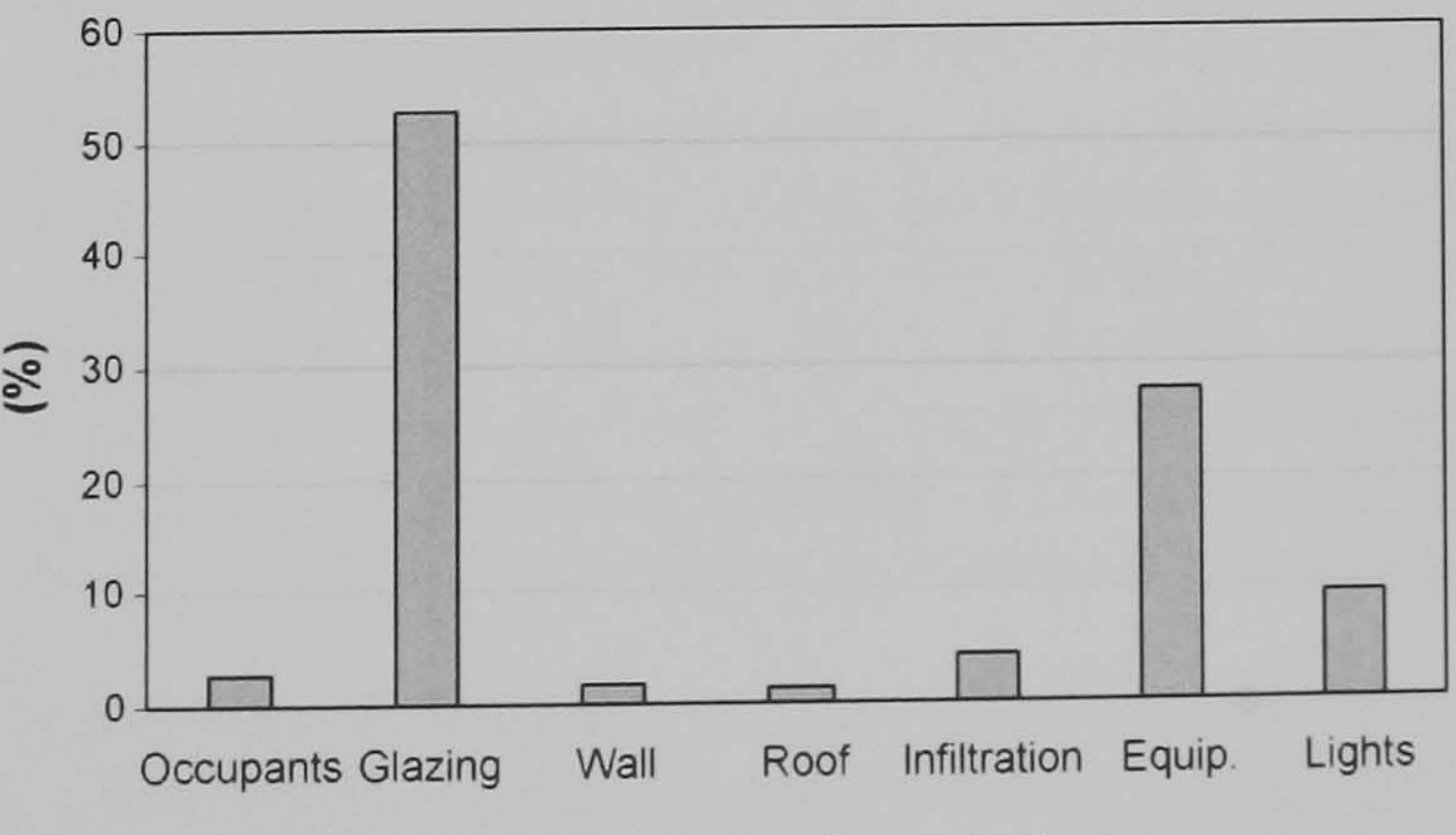

Fig. 7. Breakdown of cooling peaks loads.

3.3. Identifying and assessing optimisation measures

The analysis of the energy use patterns and the determination of relationships between these patterns and the drivers that influence them indicated that the cooling load was significant because of the high internal and external heat gains. In light of these results, a number of measures to optimise energy performance were identified. They were classified into two categories: envelope measures to reduce external heat gain and system measures to reduce internal heat gain. Due to its impact on energy consumption, altering the set point temperature was added as an operation measure.

3.3.1. Envelope measures

These are measures that can be implemented in the opaque and transparent parts of the building skin. This paper examines two envelope measures to reduce the external heat gain, including thermal insulation and glazing systems. To examine the impact of using envelope measure to reduce external heat gain, different *U*-Values for walls and the roof were tried and various glazing systems were examined. Fig. 8 illustrates the reduction in electricity consumption due to envelope measures.

The maximum reduction in energy consumption was obtained when 0.2 w/m^2 °C for the roof and 0.33 w/m^2 °C for walls was used. The result indicates a small reduction in the annual energy consumption of approximately 1.0%. This is due the dominance of glass on the overall wall formation of the building. The large area of glass has consequently led to a small amount of heat conduction through the opaque part of the building. Because the glazing system influences the cooling load and the lighting load, an attempt was made to reach a state of balance between heat and the amount of daylight, so a lighting sensor was provided. Glazing with 1.48 w/m^2 °C and SC of 0.20 was found to be the most efficient glazing system for this building. The reduction of monthly electricity consumption ranged from 28% to 30%, while there was a 35% reduction in the annual energy consumption per square metre.

3.3.2. System measures

These measures apply to building services including lighting, equipment, and the HVAC system. In Bahrain, lighting systems consume about 20% of the total electricity of commercial buildings [14]. In the building under study, 4.0% of the total electricity consumption was consumed by the lighting system. Although this amount is small, there was an opportunity to improve the efficiency of the lighting system by using low-e lamps for the interior spaces and replacing the mercury fixtures used for external lighting with more efficient hp-sodium fixtures. As a result of using the low-e lamps, two loads were influenced: the lighting load and the cooling load. The internal lighting load was reduced by 25% and the external lighting load was reduced by 41.5%. Another benefit of using the low-e system was the reduction in the internal heat gain, which led to a 2.2% fall in the cooling load. Fig. 9 illustrates the annual and monthly electricity consumption.

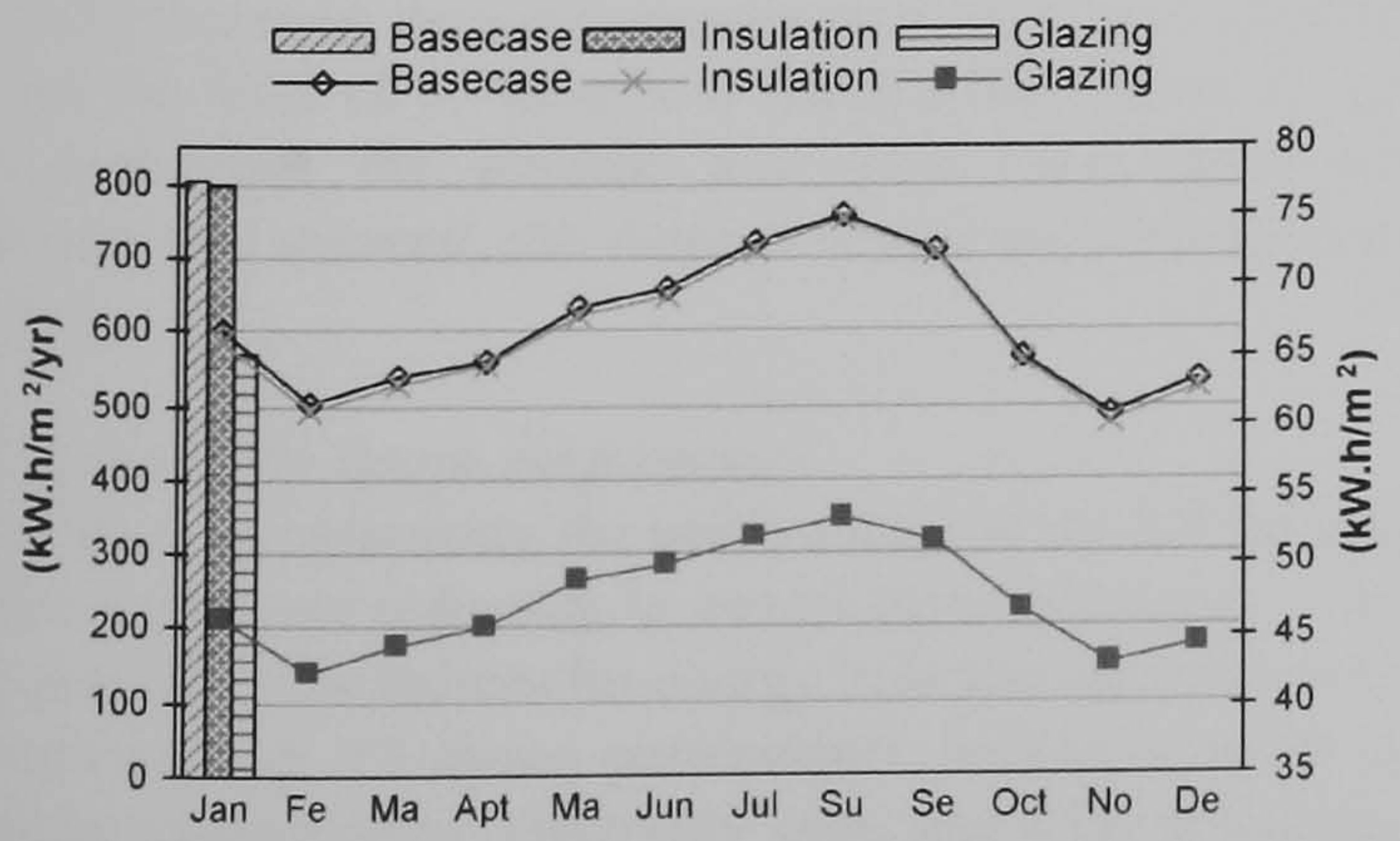

Fig. 8. Reduction in electricity consumption due to envelope measures.

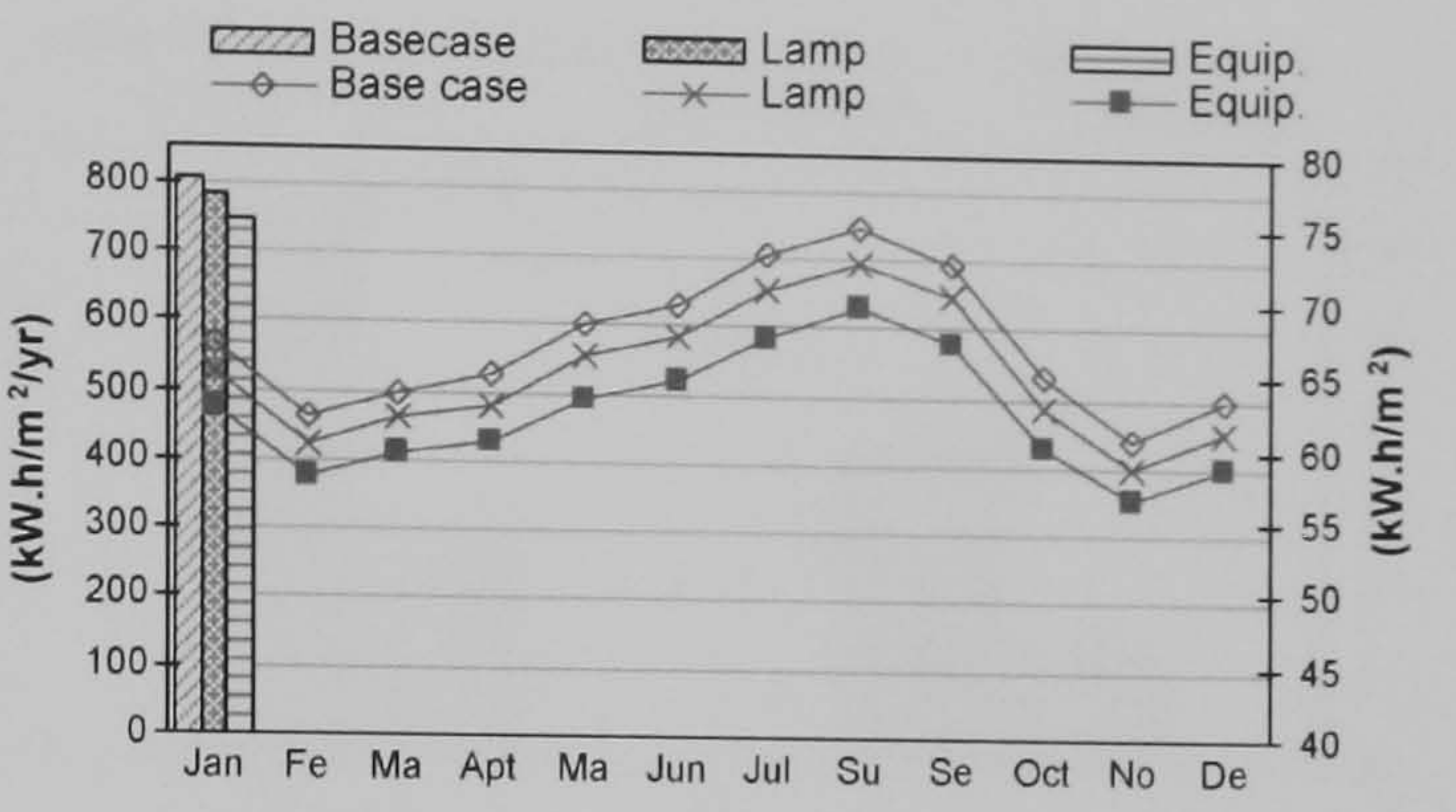

Fig. 9. Reduction in electricity consumption due to system measures.

In the building under study, there is much office equipment such as computers and printers. Two strategies can be effective: firstly, using low-e equipment, and secondly, controlling the operation by "power monitor saving". These computers remain on for an average of 10 h per day. In spite of that, the expected actual usage is 6 h. The simulation result showed a 20% reduction in electricity used for powering the equipment and a 5.2% reduction in cooling energy. As illustrated above, the monthly electricity saving due to the use of equipment measure is also significant. There is a reduction in electricity consumption during winter ranging from 6.7% to 7.0% and a reduction ranging from 7.4% and 7.8% for summer electricity consumption. This difference is because the equipment with high heat generation represents a positive participant in the heating loads (winter), but is a negative participant in the cooling loads (summer).

3.3.3. Operation measures

Rising the set point temperature one or more degrees save a considerable amount of electricity. In the base case, two sets of temperature were tried: first 21 and 25 °C, and second 22 and 26 °C, for winter and summer respectively. As shown in Fig. 10, as the set point temperature raises, the reduction in electricity consumption increases. The maximum reduction occurs in heating loads with 11% and 27%, and the minimum in the cooling loads with 4.0% and 13%, for the first and second set respectively. Furthermore, the impact of rising the set point temperature is also clear with respect to the cooling peak load.

3.3.4. Optimisation under the whole building approach

The whole building approach allows highlighting the interaction between prescriptive measures. Fig. 11 illustrates

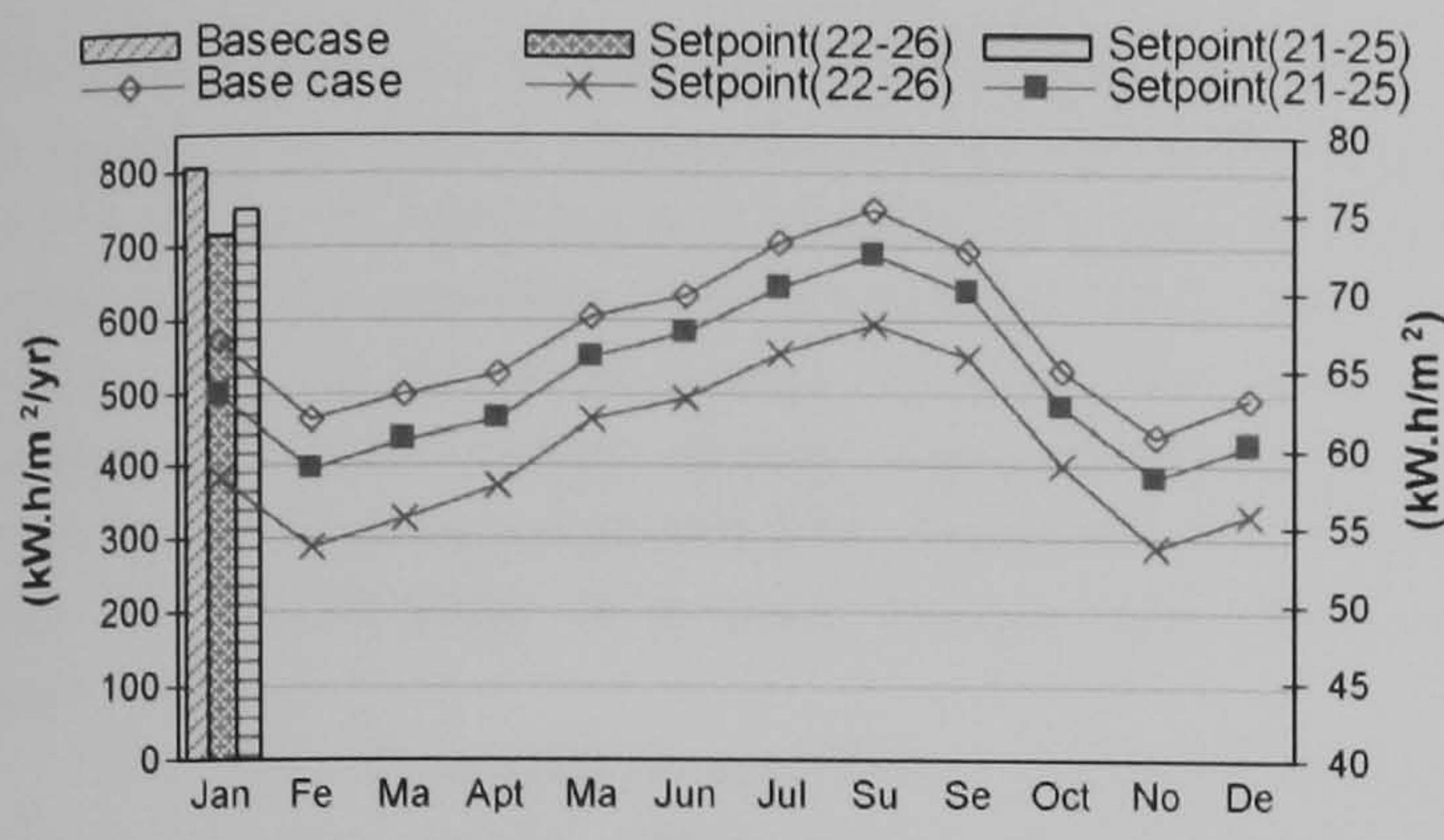

Fig. 10. Reduction in electricity consumption due to operation measures.

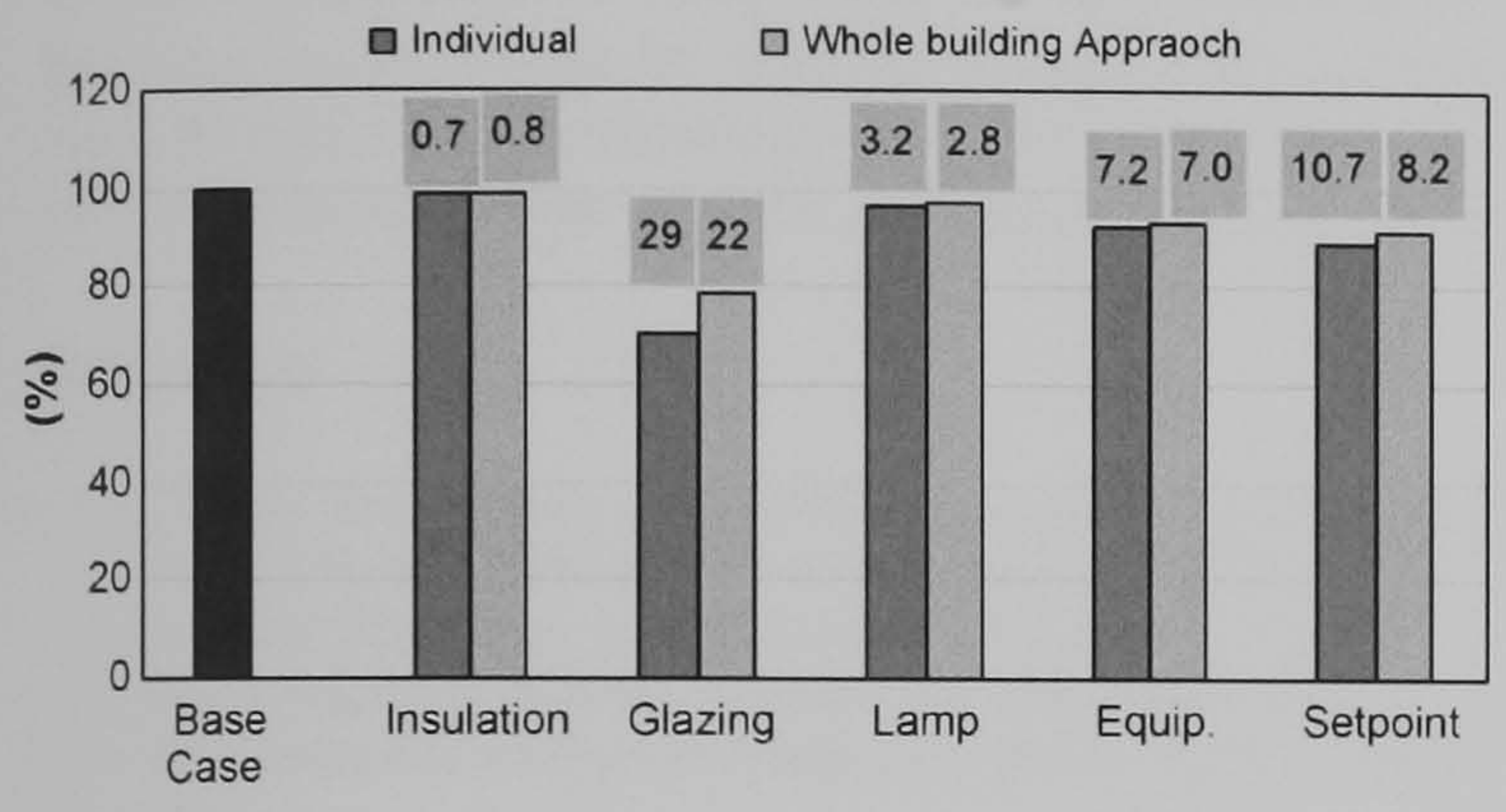

Fig. 11. Reduction in electricity consumption under the whole building approach.

the electricity savings due to the identified and proposed measures. It was found that 1.0% reduction can be achieved by the use of thermal insulation with U-Value 0.2 w/m^2 °C for the roof and 0.33 w/m^2 °C for walls, 29% savings in electricity due to using sensors and low-e glazing (U-Value 1.48 w/m^2 °C, SC: 0.02, lighting transmittance: 0.5), 3.2% savings due to low-e lamps, 7.2% savings due to low-e equipment and 10.7% savings due to alteration of the set point temperature. When saving values are summed, the total is 51.1%. However, this percentage is obtained when the measures are applied in isolation. This way is inadequate because it cannot reflect the real interaction and conflict between prescriptive measures.

To perform an interaction analysis, the above measures were combined and applied together. The percentage has become 41.6%. The difference is almost 10%. Therefore, to obtain a sufficient simulation result, it is necessary to follow a systematic analysis that takes into account the interaction and conflict between the various parameters, such as the conflict between the level of U-Value and internal heat gains. It was noted that when the internal heat gain from lights and equipment was reduced, the thermal insulation became more effective.

3.3.5. *Targets for future performance*

The result of optimising the performance of the MEW-Bldg revealed significant reduction in electricity consumption. This result provided new indices for energy, cost and environmental performance. Fig. 12 shows performance indices in terms of electricity consumption, electricity cost, and CO_2 emissions. The obtained indices may represent a target for future energy performance, for which building management is stimulated to make improvements.

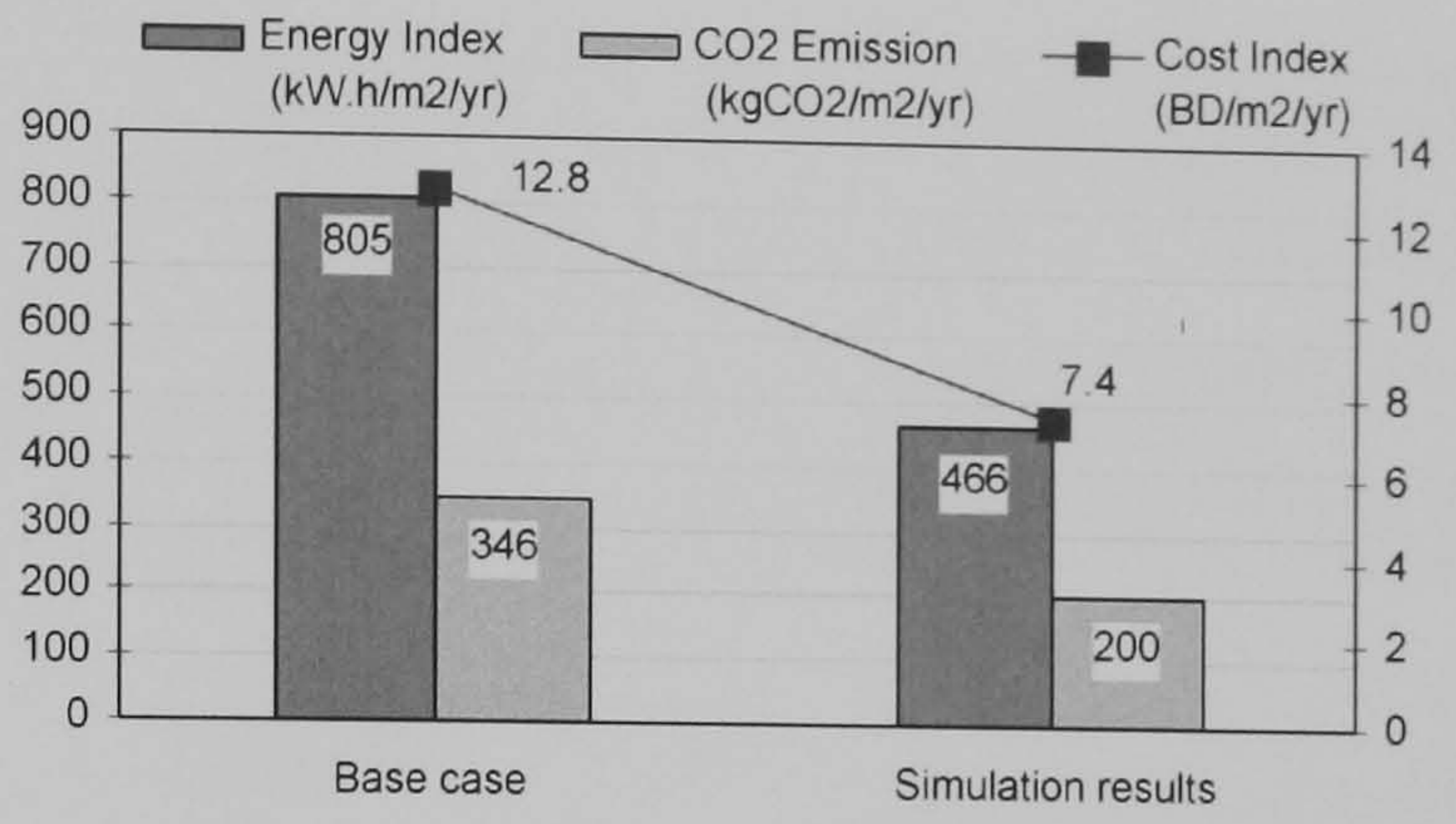

Fig. 12. Indices for future performance.

4. Discussion and conclusion

The quest for improving the energy performance of buildings has provided the opportunity to develop tools and methodologies for performance optimisation. There has been a very slow uptake of evaluation and optimisation methodologies in Bahrain and the region. In this study, a systematic methodology was introduced with respect to building design and operation. This methodology considers all the variables that influence the energy performance of office buildings. It integrates simulation programs into the analysis process. This has led to providing an accurate analysis and a reliable assessment for energy efficiency measures. The methodology appears to work well in the case tested, that is, for a high rise office building in Bahrain.

The analysis method demonstrated its ability in forecasting electricity consumption of office buildings. The Visual DOE program was used to accurately predict building loads and total energy consumption. In the building under study, approximately 65% of electricity was used for cooling systems. This was due to the large amount of external and internal heat gains. Although this building is categorised as internal load dominated, the external heat participates with approximately 52% of the cooling load. The reason behind this was the large glass facades without protection from the sun and summer glare. It was shown that the use of an efficient glazing with low (SC) reduced the cooling load by 35% and the total electricity consumption by 22%. Further, using low-e equipment, which was the main source of internal heat gain, reduces the cooling load by 5.2% and the total energy consumption by 7.0%. Therefore, for saving cooling energy, it is necessary to optimise the efficiency measures with the highest impact on internal and external heating gains.

The optimisation of efficiency measures should not only consider the direct impact of these measures on energy consumption but also their impact on each other. This is because optimising these measures in isolation does not reflect the real interaction and conflict between them which may negatively affect the energy consumption. Another advantage of this methodology is the emphasis on the role of the whole building approach. Considering the performance of the whole building allows for evaluation of the interaction and conflict between prescriptive measures. Some differences appeared when results of applying one measure at a time and results of applying them together were compared. The difference can reach 10% of the total energy savings. By means of the introduced methodology, energy consumption was obtained together with energy cost and CO_2 emissions. It was indicated that the MEW-Bldg is a poor energy and environmental performer.

This study attempted to establish a source of guidance for optimising the energy performance of office buildings in Bahrain. This was done with the aim of attracting some attention to the consequence of energy use on the environment and providing some criteria for building design in Bahrain. Much work is ongoing by the researcher in the area of energy design to encourage better design practice in Bahrain and the region.

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APPENDIX 3

A comparison of the accuracy of building energy analysis in Bahrain using data from different weather periods

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Technical Note

A comparison of the accuracy of building energy analysis in Bahrain using data from different weather periods

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ABSTRACT

Weather data are important in building design and energy analysis. In Bahrain, the weather data currently used are based on far past climatic information. Climate variability during the last few decades has raised concern over the ability of these data to provide accurate results when analysing the energy performance of buildings. This study discusses issues related to climate variability and evaluates its impact on the performance of weather data used in building simulation. An evaluation was performed using two methods: firstly, a comparison of measured climatic elements and secondly, a comparison of the thermal performance of two statistically based weather data files. With respect to their impact on typical Bahraini building thermal systems, the comparison was carried out between simulation results and the actual energy consumption of two case studies. This paper shows a 14.5% difference between simulation results based on far past data and present electricity consumption and concludes that the prediction of present and future performance based on recent updated data gives better results.

1. Introduction

The ability of simulation programs to estimate the energy consumption in buildings and the factors influencing this consumption provides an effective tool to improve the energy performance of buildings. Identifying, understanding and evaluating the impact of such factors represent the most important parts of the energy analysis. In general, there are three factors that impact the energy use in buildings: climate, design and people. As each building is unique, the impact of these factors varies from one context to another. However, climate seems to be the most important motivation for energy use; therefore, no analysis can be done without first studying the climate.

Each element of the climate influences one or more aspects of building energy performance: temperature on heating and cooling load, wind speed and direction on space heating and ventilation load, the solar radiation on cooling and lighting loads, and hours of day-light on lighting load. Although each of these elements influences particular aspects of building performance, there are correlations between them. Some recent studies [1] have reported a strong relationship between climatic elements such as the hourly variation of global solar radiation (GSR) and dry bulb temperature (DBT), as well as between the DBT and the relative humidity (RH). The change in any of these elements, especially the solar radiation, influences the other elements. Consequently, building performance can be influenced in direct and indirect ways. To make an effective estimation of the impact of climate on the overall energy performance, the selection of climate element collection should be based on the combined integrated impacts of the climatic elements [2,3].

For developing a weather data collection, one needs hourly and long term data for the major climatic elements (e.g. solar radiation, dry bulb temperature, dew point temperature, and wind speed and direction). There are two approaches to develop detailed weather data: firstly, statistical approach and secondly, simulation approach. The former uses statistical methods to provide standard timescale data for solar radiation and other climatic elements. The latter is based on using weather data generator. Today, it is a commonplace to use the statistical methods to generate detailed weather data based on basic actual measured data. More recently, these methods have represented the basis for weather data generators as can be seen in the TRY software [4], RUNEOLE [5], TRNSYS [6] and the MeteoNorm software [7].

The MeteoNorm software is a weather data generator and database developed by the Swiss Federal Office of Energy [8]. The database is a comprehensive source of weather data covering 7700 meteorological stations worldwide. These data were obtained from different organisations such as the World Meteorological Origination (WMO). A principal advantage of the MeteoNorm software is its ability to calculate the solar data based on meteorological data (air-temperature and relative humidity). It generates synthetic

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hourly weather data based on long term monthly averages. The generator uses statistical methods to develop synthetic weather data ranging from simplified to hourly weather data. It utilises the concept of the probabilistic transition between thresholds of the parameters to generate weather data in various formats from Markov chains [9]. Three methods can be followed to generate detailed weather data: first, using the comprehensive database, second, inserting the climatic element values, and finally, importing files of monthly and hourly averages of the key climatic elements. A statistical weather data file produced by MeteoNorm is the result of a statistically generated sequence of weather data values representing the typical weather for the site. This sequence includes almost all climatic patterns possible.

Although statistical methods and data generators represent good tools to generate hourly weather data, the quality of the generated data is subject to a number of effects related to the original raw data including the following [10]:

1. Sources: the location (e.g. typology and landscape) and methods of observation.
2. Length of record and climate change: the age and variation in weather conditions from year-to-year and, to some extent, from decade-to-decade due to the inherent variability in climate.

The variability of climate occurs due to various human and natural reasons, such as global warming, greenhouse gases and pollution [11]. This situation is notable in the Gulf region. This region has become a hot spot because of many events that have occurred during the last two decades. The consequences of the First Gulf War in 1991, such as the plumes of smoke created from firing the Kuwaiti oil fields, are an example of such events. They influenced the natural environment, particularly the climate. It was reported that these plumes influenced the climate in some parts of Saudi Arabia and Bahrain [12,13].

2. Climate of Bahrain

Bahrain is an island located in the Gulf region, with a total land area of 700 km^2. Today, however, the land area of Bahrain is steadily increasing due to enormous reclaiming activity. The climate of Bahrain can be described as a mild winter and extremely hot summer. The characteristics of this climate resemble those of arid and semi-arid zones: rainfall is low, irregular, seasonal and variable, relative humidity is also high, especially during the rainy seasons, and temperatures are variable but high [14].

Fig. 1 shows a brief analysis of climatic elements in Bahrain. The meteorological data were provided by the Directorate of Meteorology located at Bahrain international airport, while the solar data were obtained from research projects conducted by the University of Bahrain [15,16]. One of these projects was carried out at the airport. It is important to note that the distance between the airport and the University does not exceed 35 km. An important result of these projects shows that the climatic elements, particularly solar parameters, have almost the same values at different sites in Bahrain including the airport and the University. The analysis of the climatic elements shows an overall yearly average temperature of 26.5 °C with a monthly average maximum temperature of 41 °C (August) and a monthly average minimum temperature of 14.4 °C (January). The cold season in Bahrain spans from late December through January and February. March until early May is considered the transitional period between the mild winter and the hot summer. This season is characterised by sudden and daily variations of the diurnal temperature. The summer season spans from late May to September, during which the monthly mean temperature is around 30–35 °C. In October and November sunny skies are dominant with dry conditions and monthly mean temperatures between 29 °C and 24 °C, respectively.

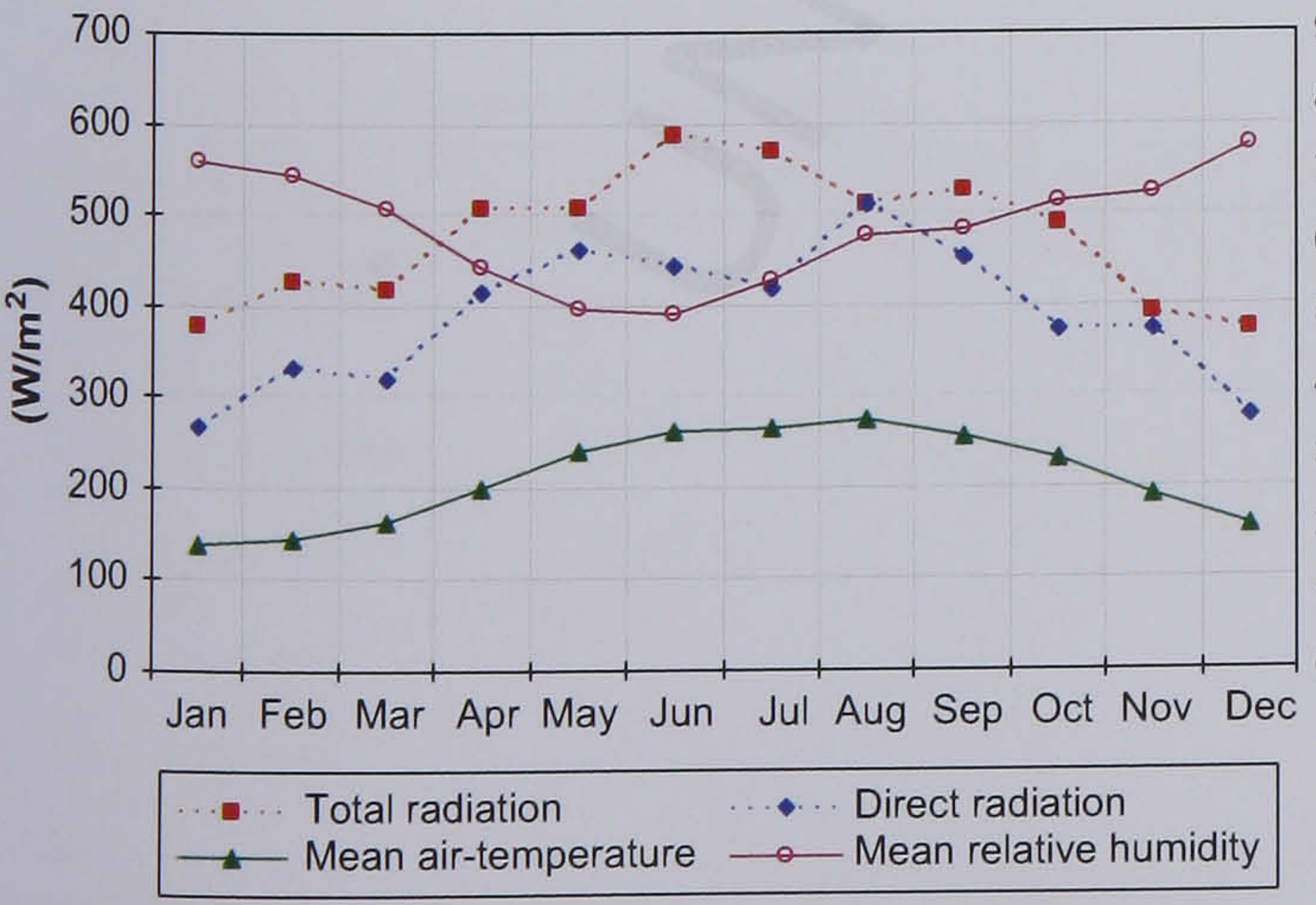

Fig. 1. Analysis of Bahrain's climate.

The monthly average relative humidity is 62%, with a maximum monthly average of 72% (January) and a minimum monthly average of 50% (June). Wind from east north direction throughout the year is a characteristic of Bahrain. The wind speed average shows slight variation, being generally low from April to December with a monthly average of 4.2 m/s, while from January to March it is well above 5.1 m/s, reaching a monthly average of 5.2 m/s in February. On average, rainfall in Bahrain can reach up to 26 mm in January. The annual rainfall is 76 mm. The rainy season is broken up by four dry months extending from June to September.

Bahrain is blessed with a high solar radiation level. The highest monthly averages of total and direct radiation are 585 W/m^2 and 383 W/m^2 in June and September, respectively. The lowest monthly averages of the same parameters are in December and January with 373 W/m^2 and 267 W/m^2, respectively. Bahrain has an average of 3468 sunshine hours per year [15]. It is important to mention that the solar data were measured using the rotating shadow band (RSB) pyrometer manufactured by Ascension Technology, Inc., Lincoln Centre, and MA, USA. It was installed on the roof of the University of Bahrain. The data were measured continuously and the results averaged hourly. The daily and monthly averages for direct solar parameter are calculated by subtracting the actually measured total solar radiation.

This analysis illustrates the climate of Bahrain in the present time, which is quite different from the climate conditions in the 1960s, 1970s and even the 1980s. However, the climatic conditions of those decades still represent the base of most weather data collections in Bahrain. Today, some of these collections are still used in spite of the variation in the climatic elements, as indicated by many sources. A recent study into insolation on vertical surfaces in Bahrain indicated that in 2007 there was a reduction in diffuse solar radiation by 24.5% and an increase in direct solar radiation by 10.7% when compared with records of one decade ago [16]. Coupled with this is the increase in air-temperature. A regression analysis shows a temperature rising trend at a rate of 1.4 °C per decade [17]. It is of interest to highlight some of the reasons behind this variation. One possible reason is the heat island caused by the massive new construction in Bahrain. There has recently been rapid and increasing economic expenditure on huge architectural projects. The changes in atmospheric pollution and CO$_2$ emissions due to burning fossil fuels are other reasons for this increase. The variations in Bahrain's climate may reduce the reliability of weather data developed from previously collected climatic information.

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3. Methodology

3.1. Methods

This study aims to investigate the impact of weather data on the accuracy of building energy analysis with respect to the climate variability in Bahrain. The investigation passed through two main stages: firstly, forming two weather data sets and generating two weather data files and secondly, comparing the two formed weather data sets to examine the climate variability along with comparing the two generated weather data files in order to assess their impact on the accuracy of building energy analysis.

3.1.1. First stage

In the first stage two sets of measured data were formed based on long term meteorological climatic elements provided by the Directorate of Meteorology of Bahrain (air-temperature, relative humidity, precipitation, and wind speed and direction) and measured solar data (total solar radiation, diffuse solar radiation, and direct solar radiation) obtained from recent studies conducted in Bahrain [15,16]. The First Gulf War and the Kuwait oil fires of 1991 were taken as a border between the two weather data sets. The former represents the period from 1961 to 1990, and will be indicated as climate-before-91. The latter represents the period from 1992 to 2005 and will be indicated as climate-after-91. Year 1991 was excluded. Nevertheless, the consequences of the oil fires can be noted in the later years.

In addition, two weather data files were generated using the MeteoNorm software. Each file contains the main climatic elements shown in Table 1. The two files are for Bahrain international airport. The former is a result of using data from 1961 to 1990, and will be indicated as DATA (61–90). The latter is a result of using data from 1961 to 2005, and will be indicated as DATA (61–05). It is interesting to mention that the data of the two weather periods (1961–1990 and 1961–2005) are existed in the MeteoNorm database. This database is an option to generate these two files. However, the solar data of some countries such as Bahrain are not actual measured data; rather they are calculated based on meteorological data (air-temperature and relative humidity) monthly means. Furthermore, the computational models in the MeteoNorm only approximate the real situation. Therefore, the development of the weather data files in this study was done by utilising the actual measured monthly means meteorological elements (air-temperature, relative humidity, wind speed and direction and precipitation) in the MeteoNorm database coupled with inserting the actual measured monthly means of solar data into the software in order to ensure that all the climatic elements are real.

Table 1
Weather elements for weather data generation

Weather elements	Measures
Dry bulb temperature	°C
Wet bulb temperature	°C
Wind speed	m/s
Wind direction	From north
Atmospheric pressure	Bar
Net long wave radiation	W/m^2
Precipitation	Mm
Global horizontal solar radiation	W/m^2
Diffuse horizontal solar radiation	W/m^2
Cloud cover and type	%
Sunshine hours	h

The obtained files, therefore, are statistically derived hourly weather data that were generated based on long terms measured monthly means using the statistical procedure in the MeteoNorm software. This was done to reflect the climate of Bahrain before and after 1991 with the aim of obtaining hourly weather data. The obtained files were converted to binary files for the use in building simulation. This conversion was done in light of the design conditions of Bahrain, as indicated by ASHRAE [10].

3.1.2. Second stage

The second stage of the investigation was carried out in a two-part sequence: first, the climate variability was studied through a comparison of the climatic elements of the two sets (climate-before-91 and climate-after-91) formed in the previous stage. Since the concern in this study is within the thermal aspects of buildings, the elements of climate of immediate interest are thermal. Therefore, the comparison was carried out on four key thermal elements including air-temperature, relative humidity, solar radiation and wind speed. These parameters were chosen due to their impact on the thermal performance of buildings. Wind speed was included due to its impact on cooling and heating loads.

Second, the impact of this variation on the accuracy of building energy analysis was evaluated through a comparison of the thermal performance of the two weather data files (DATA 61–90 and DATA 61–05) developed earlier. This comparison was to examine the reliability of the developed weather data files to give the closest result to the actual consumption when used with simulation programs. The Visual DOE program was used in this case. It has been developed to provide energy performance assessment that is as close as possible to the real performance of buildings throughout their life-cycle [18]. Two case studies were simulated using the Visual DOE program. The output of the simulation programs was first plotted graphically and then compared using a well-known statistical test.

3.2. Building characteristics considered in this study

For a sufficient comparison, two case buildings were used. Fig. 2 shows the plans and front elevations of the studied buildings. The first case building (Bldg-1) is a low rise office building oriented north to south. It has a rectangular shape (24 m × 18 m) with a total floor area of 1280 m^2. The floor-to-floor height is 4.0 m. The walls of the building consist mainly of 200 mm concrete blocks and 50 mm polystyrene insulation. The roof consists of 200 mm concrete blocks and 50 mm polystyrene expanded insulation. The building consists of two thermal zones with a central HVAC system. Each of the conditioned zones has set points between 24 °C and 26 °C for summer and between 21 °C and 22 °C for winter.

The second case building (Bldg-2) is a high rise commercial building constructed on a rectangular footing. It has a ground floor and 11 more storeys. The surface area of each floor is 800 m^2, and its floor-to-floor height is 4.0 m. The walls consist of mainly 200 mm concrete block, 24 mm inside and outside plaster, and 50 mm polystyrene insulation. The roof consists of 50 mm screed, 35 mm polyurethane and 200 mm concrete slab. The glazing type is 6 mm double glass with an approximate 0.80 window-to-wall ratio in the southern and northern façades. The building has multi-thermal zones with a constant centralised system. Complete details of the buildings' physical and operational characteristics are illustrated in Table 2.

4. Evaluation of the weather data

4.1. Comparison of measured climatic elements

Figs. 3–8 show the monthly average values of the key elements of the two sets of measured data (climate-before-91 and

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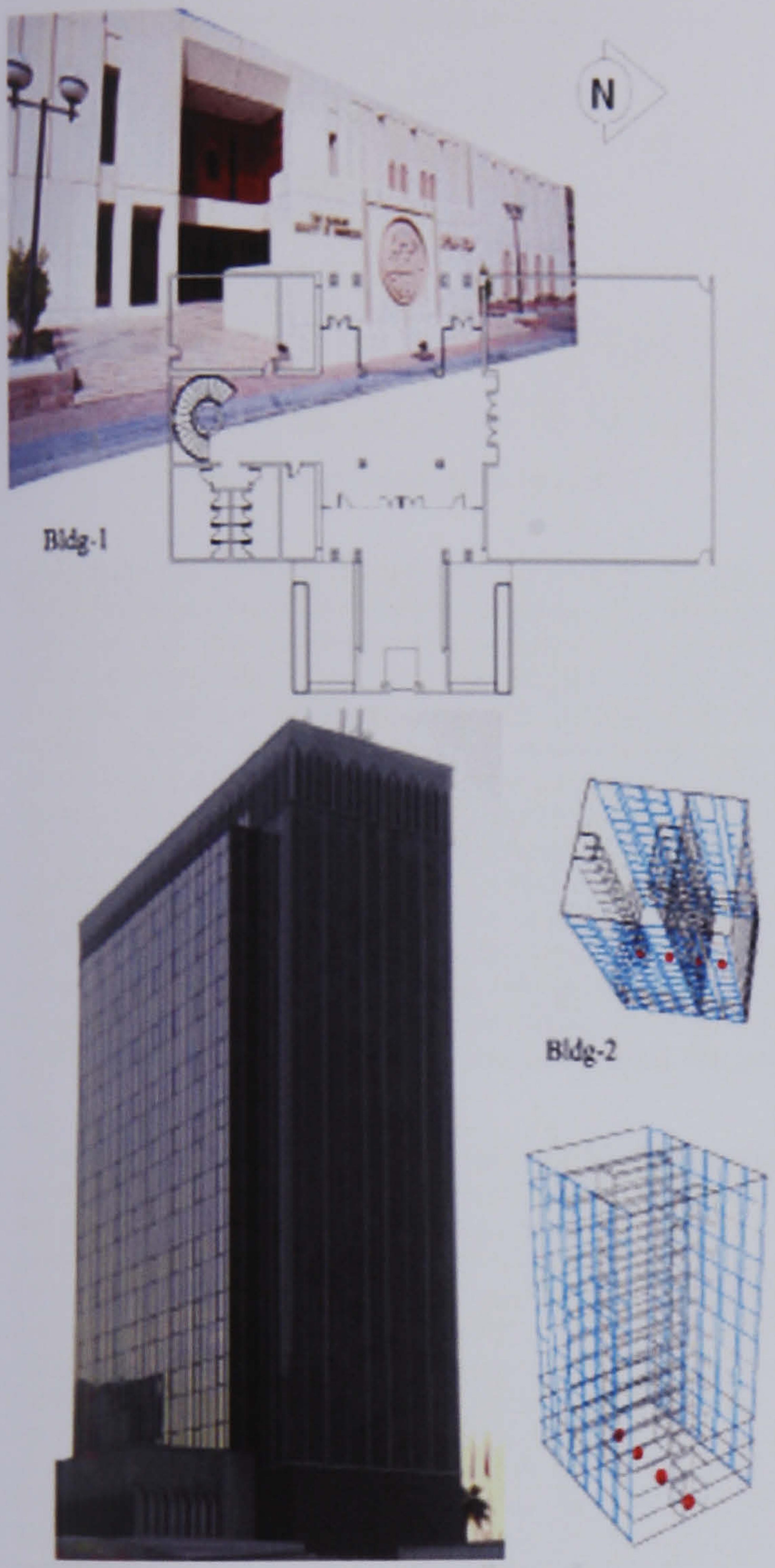

Fig. 2. Architectural characteristics of the studied buildings.

climate-after-91), including mean air-temperature, maximum air-temperature, relative humidity, wind speed and solar radiation. In Fig. 3, a variation of monthly average mean air-temperature of the two periods appears especially in the summer month. The maximum increase was found to be 1.4 °C, while the minimum was found to be 0.1 °C. The same situation can be noted in the monthly average maximum air-temperature, as shown in Fig. 4. The maximum increase occurs in July with 2.6 °C, while the minimum increase occurs in January with 1.2 °C. The distribution of the two curves with respect to relative humidity shows a different scenario. Fig. 5 illustrates a drop in the recent values of relative humidity. The curve of climate-before-91 has relatively higher values from the curve of climate-after-91, especially in the summer months from May to August. The maximum reduction was found to be in May with an approximate 8.2%. For wind speed, as shown in Fig. 6, it is clear that there is a considerable difference between the two curves. The illustration shows a drop in the wind speed with respect to climate-after-91. Considering the small area of Bahrain and the recent constructional boom, this reduction seems logical due to the massive architectural projects and local influence.

Table 2
Buildings description

Parameters	Bldg-1	Bldg-2
No. of floor	2	12
Total area (m^2)	1280	9600
Floor height (m)	4.0	3.5–4.0
Orientation	North to south	East to west
Wall *U*-value ($W/m^2\,{}^\circ C$)	0.5	0.63
Roof *U*-value ($W/m^2\,{}^\circ C$)	0.33	0.5
WWR	0.2	0.8
Double glazing	1.6	1.48
SC	0.57	0.27
Infiltration rate ($m^3/h/m^2$)	3.0	5.0
Ventilation rate (L/s/person)	7.0	7.5
Thermal zones	Multi-zones	Multi-zones
Equipment (W/m^2)	60	56.4
Lighting (W/m^2)	30–45	13–18
HVAC	Central	Central
Set point (°C)	(24–25.5) Summer	(22–24) Summer
Temperature (°C)	(21–22) Winter	(20–22) Winter
Schedules (h/weeks)	72	60
Occupancy (m^2/person)	30	25

The same scenario can be noted in the solar radiation distribution. When the direct and diffuse solar radiation of climate-before-91 and climate-after-91 plotted against each other, as shown in Figs. 7 and 8, a deviation appears between the two curves. Fig. 7 shows a declination in the diffuse radiation especially in the summer months. Unlike the diffuse solar radiation, there is an increase in the direct solar radiation, as illustrated in Fig. 8. It is worth mentioning that the share of direct radiation in the total solar radiation reaches 69.4%, while the share of diffuse radiation is only 30.6%. A recent study [16] suggested that the reason behind this difference is the reduction in the atmospheric pollution.

It is clear that the reasons why climatic elements tend to get warmer are numerous. The heat island, changes in atmospheric pollution, greenhouse gases such as CO_2 caused by energy use and ~~burring~~ fossil fuels are just some of the reasons. These reasons, **Q3** along with many others may lead to a warming of the region. In the long run they may change the climate characteristics. To investigate the impact of this tendency on the energy performance of buildings, computer binary files were developed and incorporated into the Visual DOE simulation program.

4.2. *Weather data performance and building energy simulation*

A computer simulation based on the developed files and buildings from Bahrain ~~was~~ undertaken as a comparative study of building energy analysis. A great number of runs were carried out

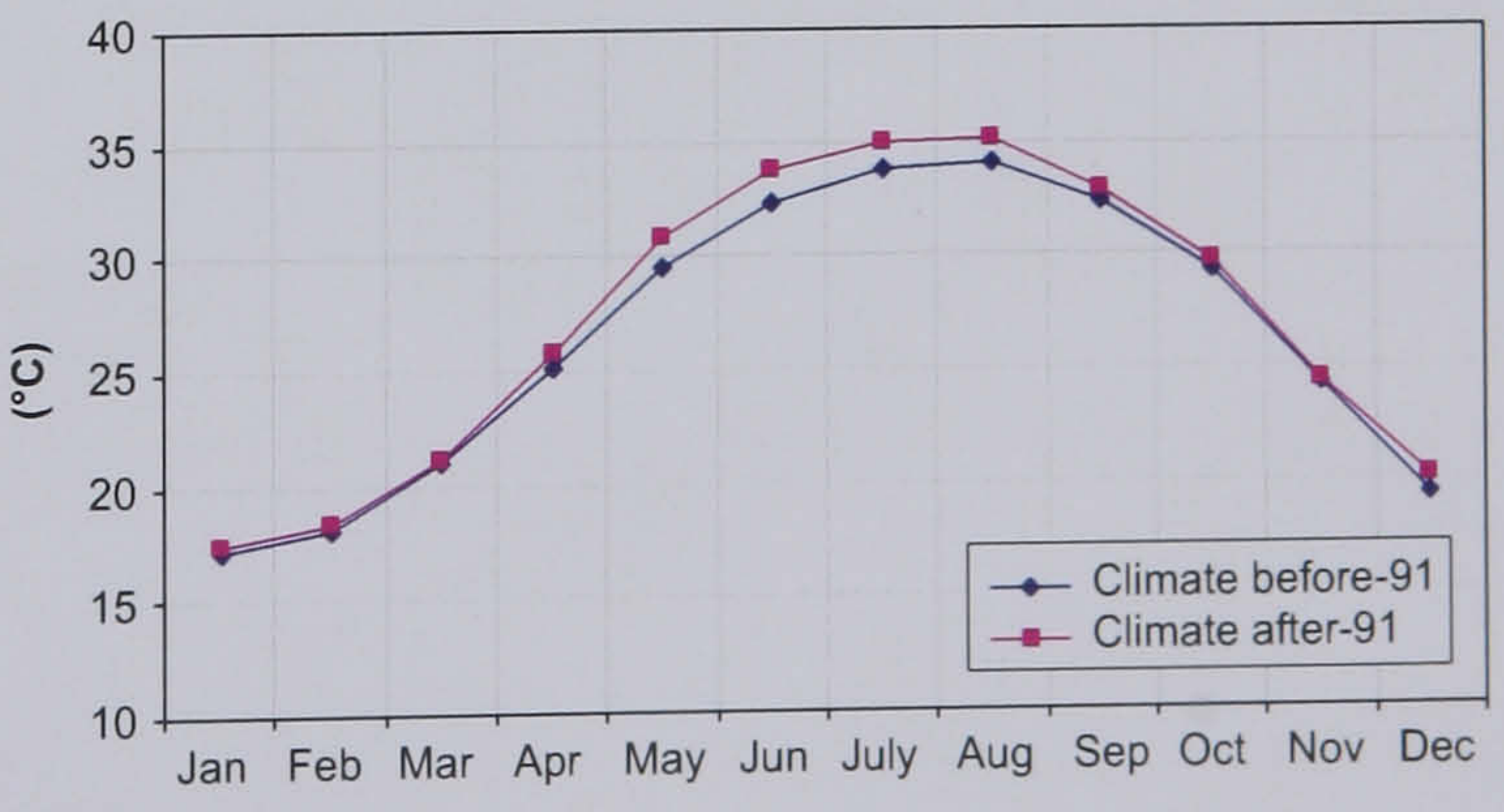

Fig. 3. Monthly average mean air-temperature.

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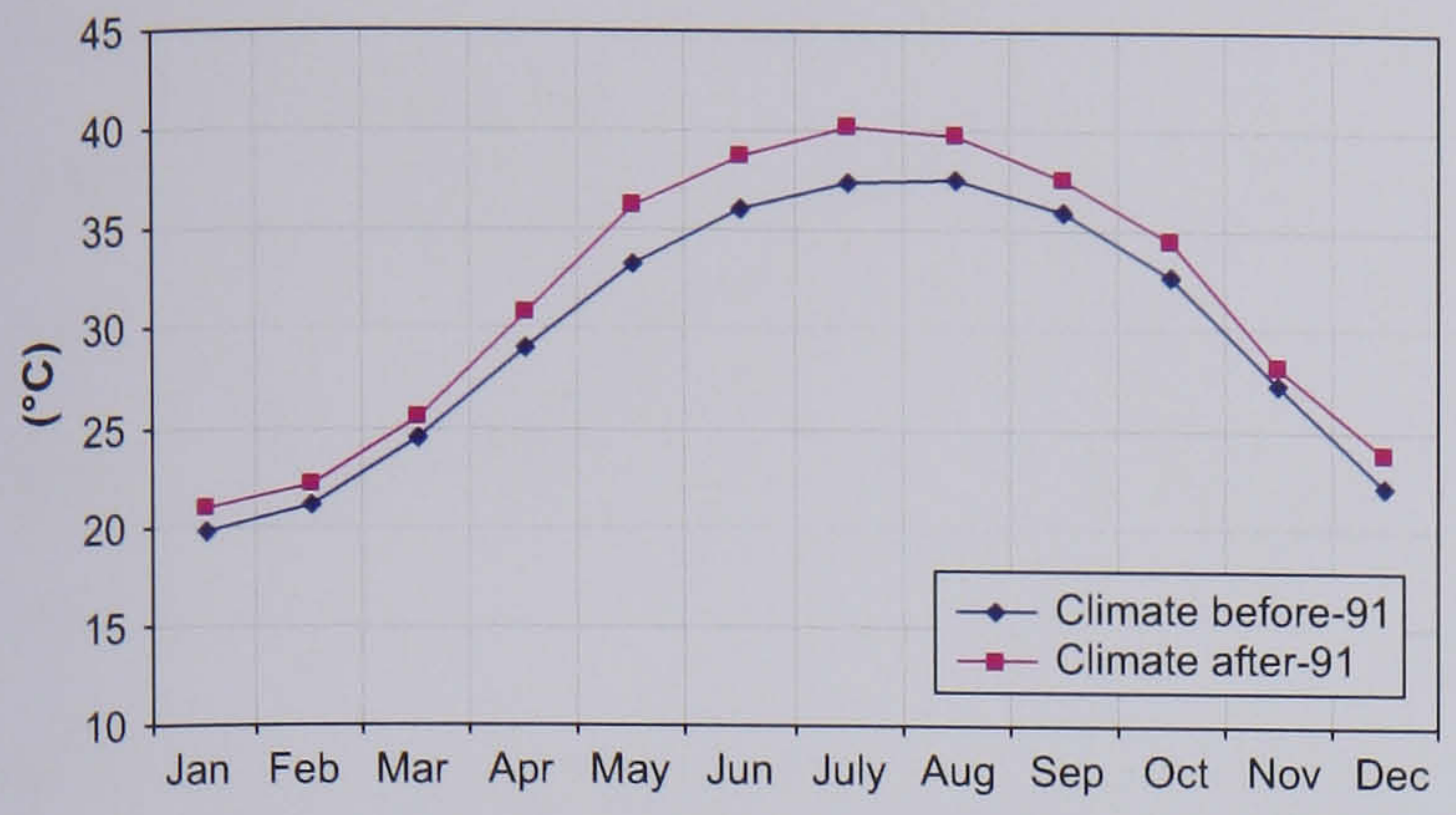

Fig. 4. Monthly average max air-temperature.

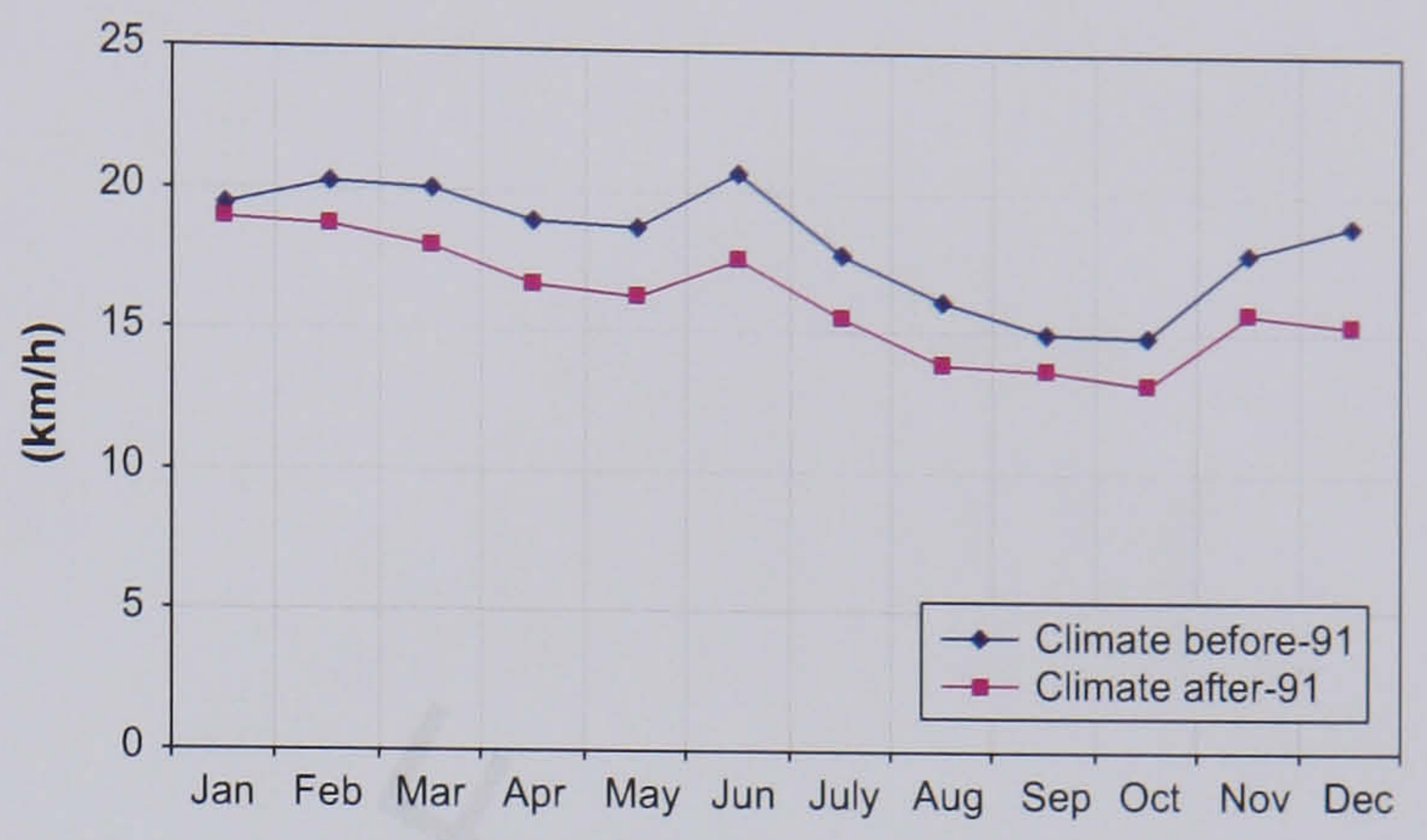

Fig. 6. Monthly average wind speed.

to examine the accuracy of each weather data file to reflect the energy performance of the studied buildings. It is interesting to note that the two buildings were subject to an auditing and benchmarking process [19]. It was indicated that the electricity of the HVAC system is the most significant, particularly for cooling energy, requiring 45% and 66.9% of the total electricity consumption in Bldg-1 and Bldg-2, respectively, to satisfy the cooling load. Therefore, the estimation of the total electricity consumption and cooling load was the criteria. In this evaluation, consumption data were chosen from different periods. For Bldg-1 the data were from the year 2006. The energy utilisation index for that year was 100 kWh/m^2/yr. For Bldg-2 the data were from the year 1996. The energy utilisation index for that year was 805 kWh/m^2/yr. In this comparison, two types of simulation output were of interest: monthly and annual profile of electricity and cooling load profile.

4.2.1. Monthly and annual profile

For the purposes of this comparison, electricity consumption due to DATA (61–90), electricity consumption data due to DATA (61–05) and the consumption data from electricity bills are represented by three curves in Figs. 9 and 10. For Bldg-1, as shown in Fig. 9, it is clear that during the summer months there is a large deviation between the curve of DATA (61–90) and the electricity bills, while DATA (61–05) is quite normally distributed with respect to the corresponding monthly consumption of the electricity bills. For Bldg-2, as shown in Fig. 10, the curve of DATA (61–05) is closer to the electricity bills, while the curve of the DATA (61–90) has relatively larger deviation from the actual monthly consumption distribution, especially in the summer months from May to September.

The analysis shows that DATA (61–90) tends to underestimate the monthly electricity consumption. The underestimation ranged from 7.7% in February to 21% in July. To confirm this result a *t*-test

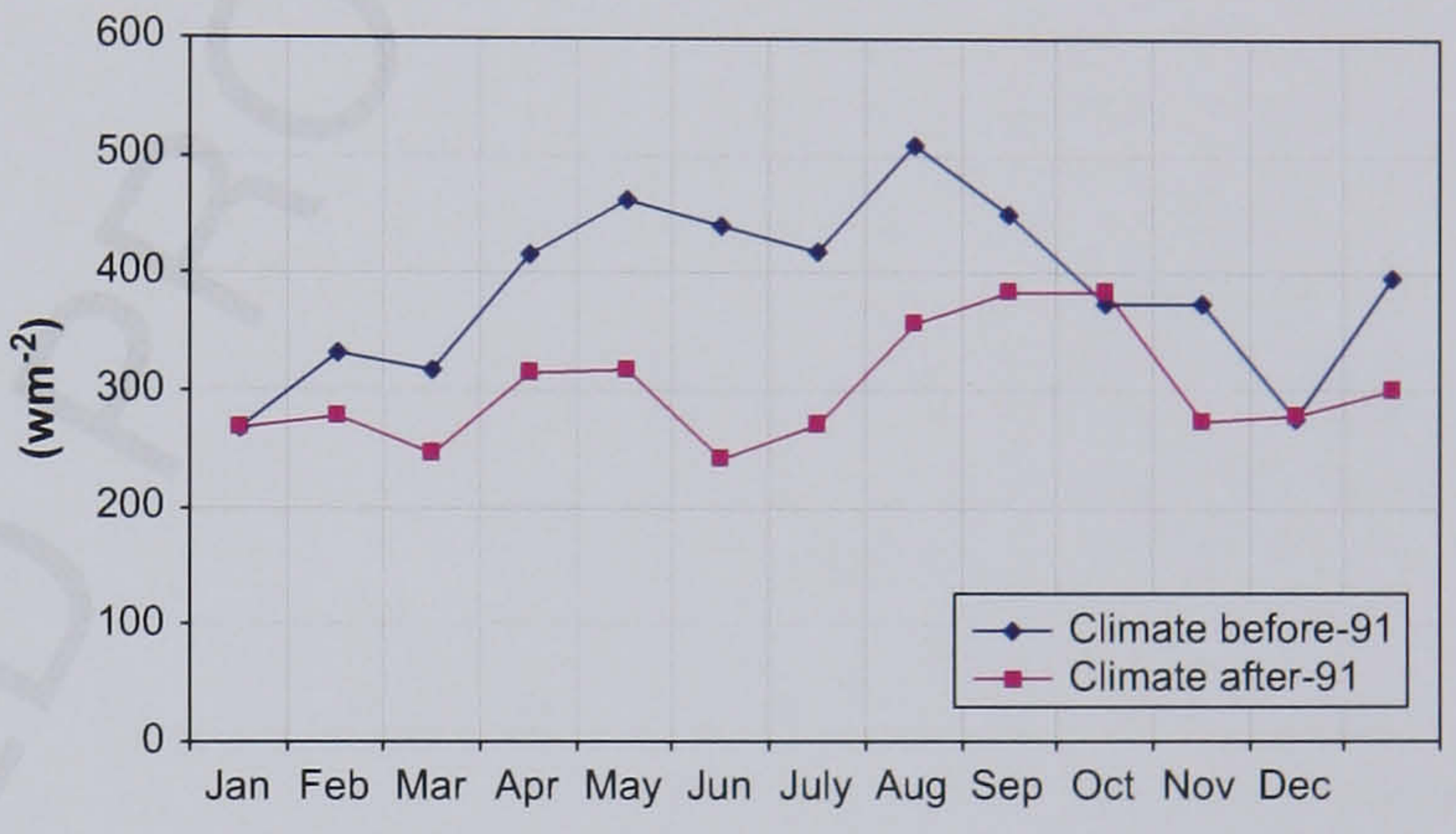

Fig. 7. Monthly average diffuse solar radiation.

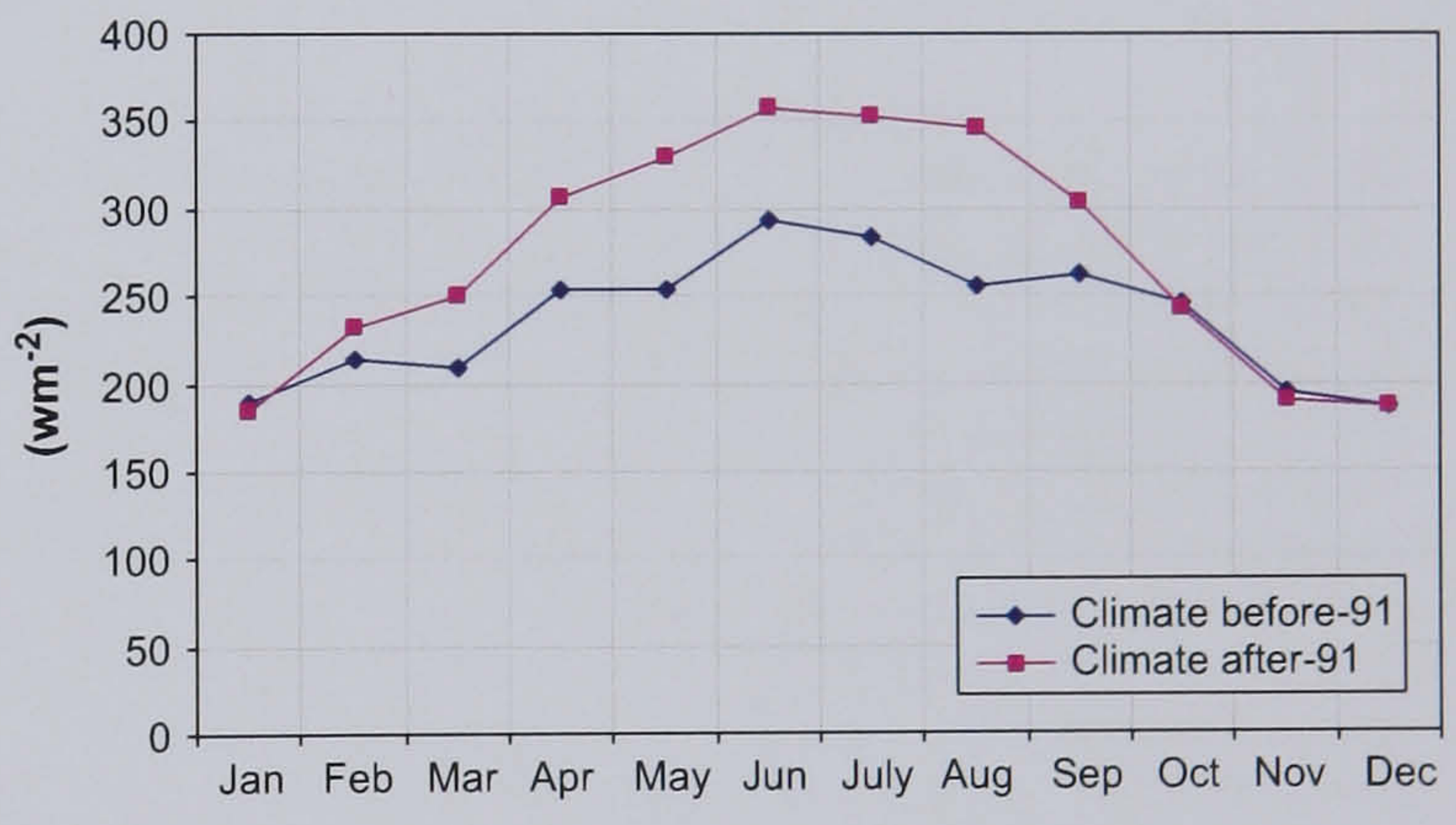

Fig. 8. Monthly average direct solar radiation.

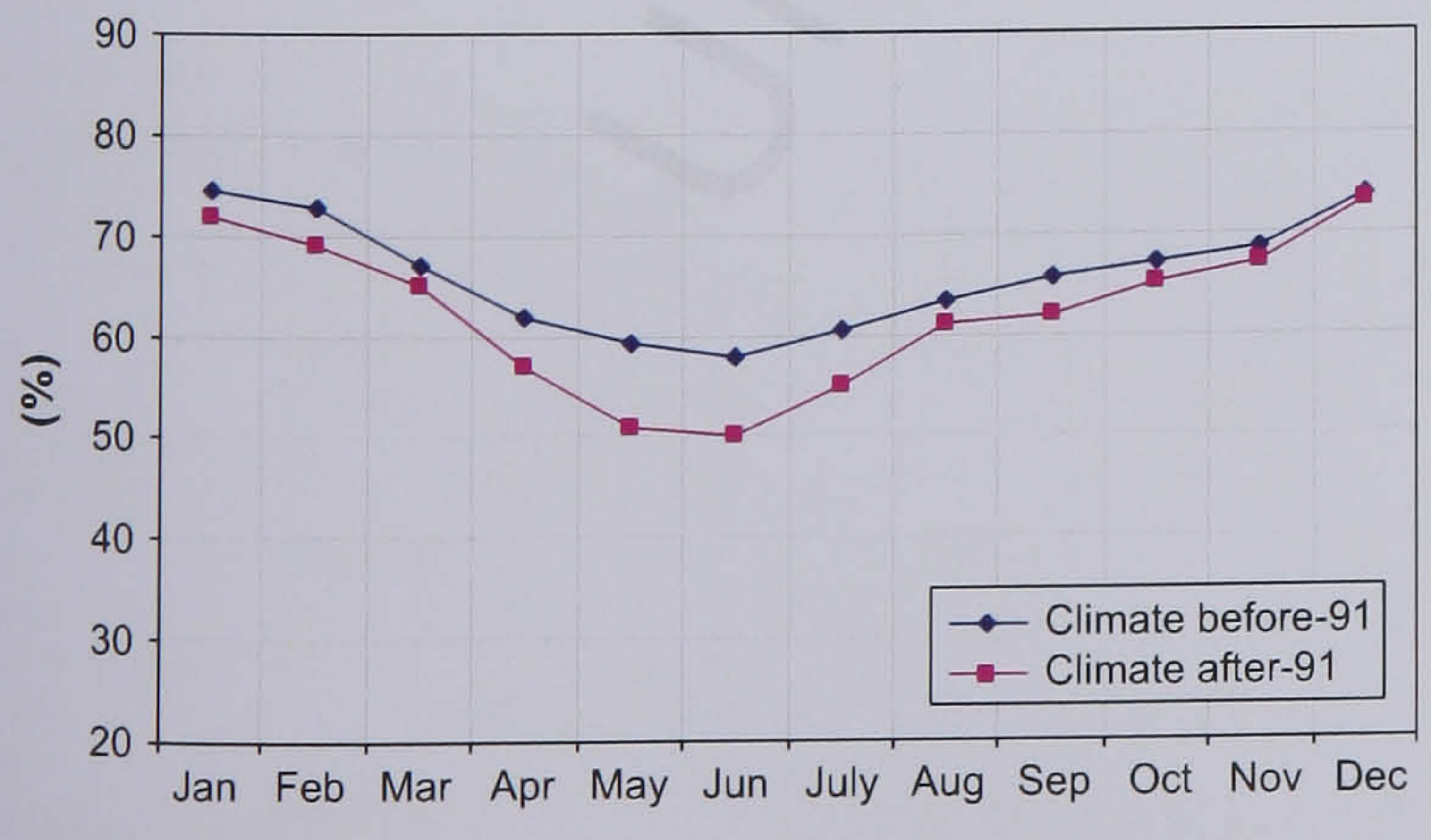

Fig. 5. Monthly average relative humidity.

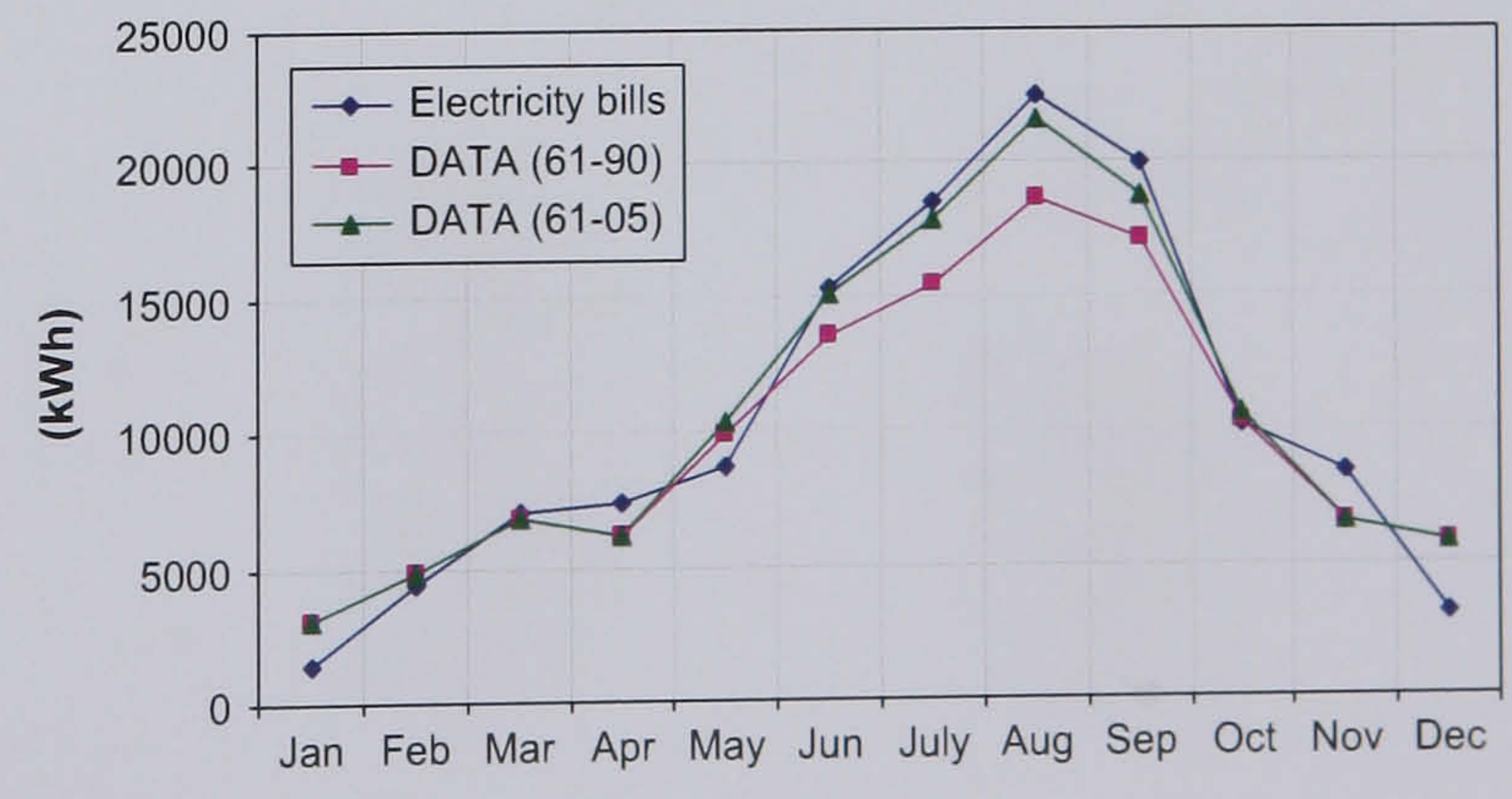

Fig. 9. Electricity consumption in Bldg-1.

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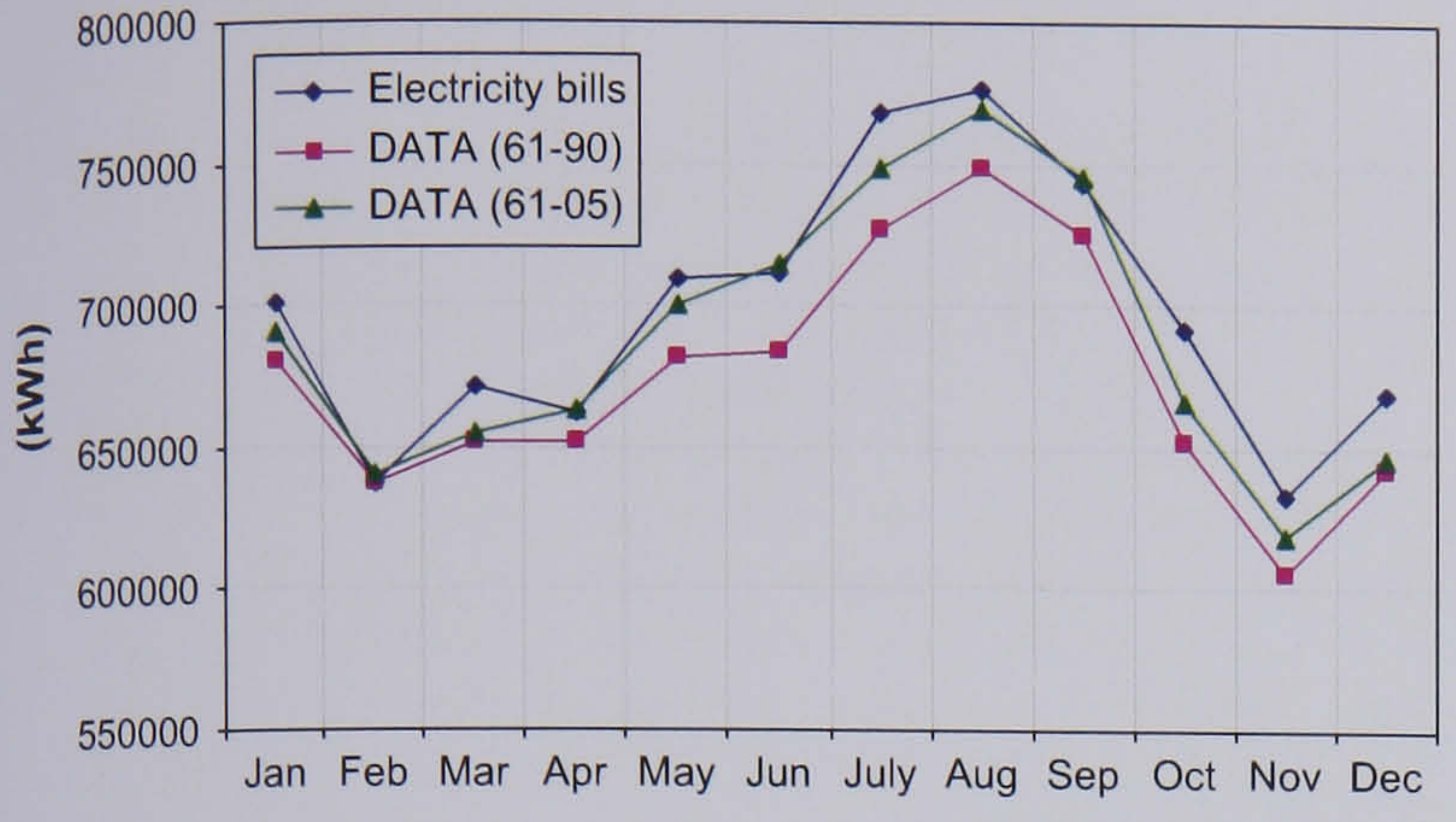

Fig. 10. Electricity consumption in Bldg-2.

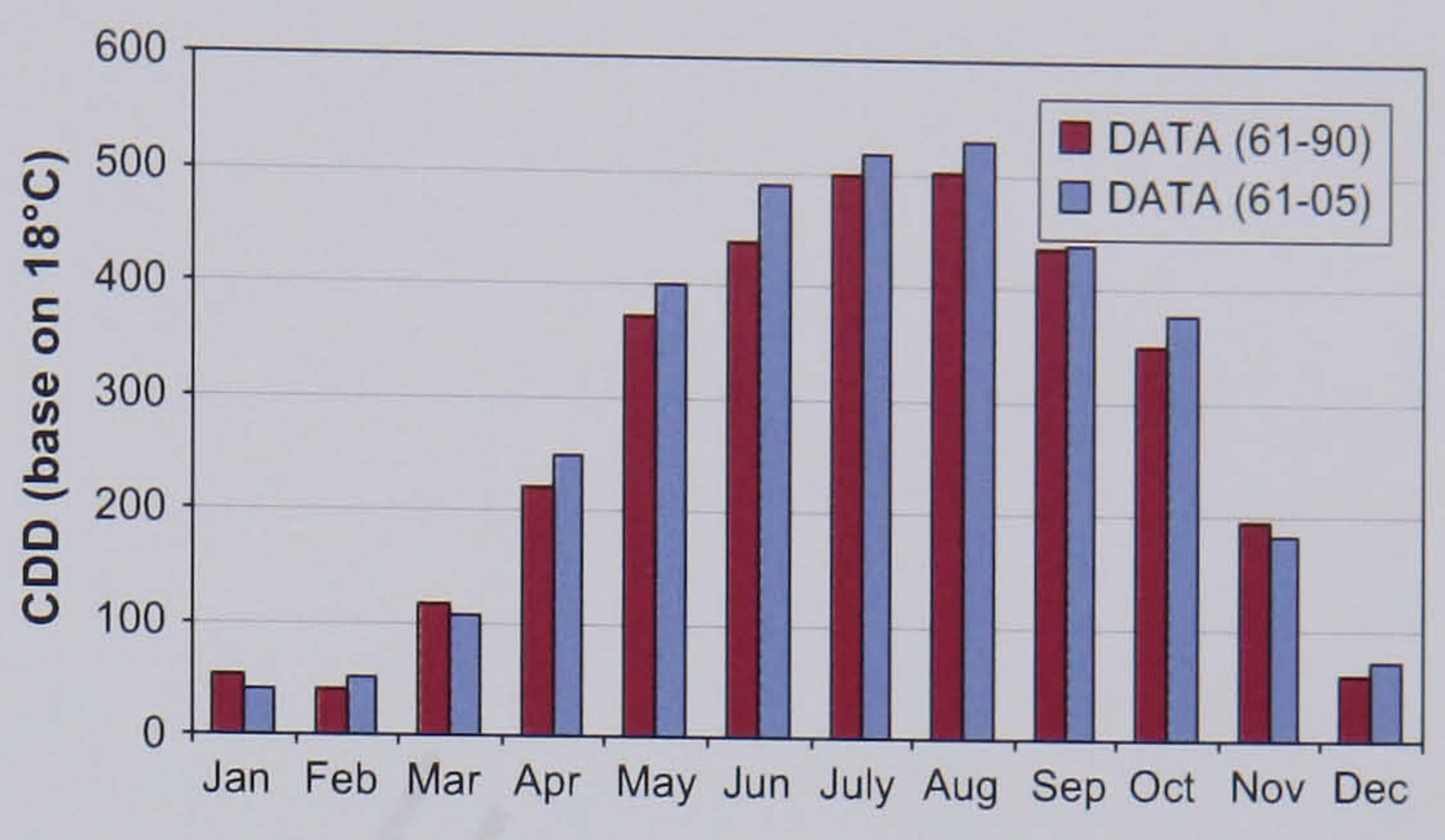

Fig. 11. Cooling degree-days.

was performed on the actual monthly electricity consumption of Bldg-1 and the estimated consumption which was obtained by simulating the buildings under study using Visual DOE based on the DATA (61–90) and DATA (61–05). The results show that the *t*-statistic of DATA (61–90) is much higher than DATA (61–05), as shown in Table 3, and hence is less similar to the electricity bills. Also, the probability of the DATA (61–90) occurring during that year (2006) was 23%, while the probability of the DATA (61–05) occurring was 80%, where the lower the *p*-value, the less chance of occurrence, and hence the difference is more significant.

The level of accuracy of each file in representing the weather and its impact on the electricity consumption was found to be the same in both cases. It can be noted that there is as much difference as 14.5% between the actual annual electricity consumption and the consumption related to DATA (61–90), while this difference becomes only 1.4% in the case of DATA (61–05). Furthermore, when the benchmarked energy utilisation indices (EUIs) of the buildings were compared with indices obtained from the simulation results, a variation appeared among those indices. Using DATA (61–90) to assess the electricity performance of Bldg-1 and Bldg-2 misrepresented the EUI by 7.8 kWh/m^2/yr and 117 kWh/m^2/yr, respectively, while using DATA (61–05) misrepresented the EUI with only 0.59 kWh/m^2/yr and 11 kWh/m^2/yr.

4.2.2. *Cooling load profile*

To investigate how climate variability influences electricity consumption end-uses, the cooling and heating degree-days were first calculated, as they represent the key impact on cooling and heating energy consumption. When the cooling degree-days of both file are compared, as shown in Fig. 11, the analysis shows a 5.5% difference between DATA (61–05) and DATA (61–90). In the summer months, the amount of cooling degree-days in DATA (61–90) is less than DATA (61–05) by 6.6%. In the winter months, the amount of heating degree-days in DATA (61–05) is 0.7% less. The increase in cooling degree-days can be related to the increase in the air-temperature and direct solar radiation in the months from May to October. The reduction in wind speed may represent a negative impact on cooling load, as speedy wind reduces the impact of temperature and solar radiation on the outer surface of buildings.

Fig. 12 shows the share of the AC system, as indicated by the benchmarking study and as obtained from the Visual DOE program using DATA (61–90) and DATA (61–05). It can be seen that DATA (61–05) estimates the annual cooling load more accurately than DATA (61–90) in both buildings. The percentage differences between DATA (61–05) and the benchmarked cooling load in Bldg-1 and Bldg-2 are 1.0% and 2.4%, respectively. These differences become 5.9% and 8.9% when DATA (61–90) are used for estimating the cooling load. ~~Reference was made to the~~ increase in the direct solar **Q4** radiation and air-temperature. ~~The increases in these two elements can be assumed as~~ the most possible reason for the difference between ~~the actual consumption data,~~ DATA (61–05) and DATA (61–90).

4.2.3. *Assessment of weather data performance*

Cleary, the performance of DATA (61–05) is better than the performance of DATA (61–90). Based on DATA (61–05) it was possible to estimate the monthly consumption, annual consumption, energy benchmarks and cooling load more accurately. However, an argument can be made that the electricity consumption and the energy benchmark of Bldg-2 are of the year 1996 which is included in DATA (61–05) and is not included in DATA (61–90). Nevertheless, although the electricity consumption and the energy benchmark in the case of Bldg-1 are of the year 2006 which is not included in either data, DATA (61–05) are still giving better estimation than DATA (61–90). Therefore, it is clear that the more recent data may give better and more accurate results when used in building energy analysis.

Table 3
t-Test for weather data

t-Test: paired two sample for means	Bills and DATA (61–90)		Bills and DATA (61–05)	
	Bills	DATA (61–90)	Bills	DATA (61–05)
Mean	10 564.17	9835	47 463 059	40 133 891.06
Variance	47 463 059	27 013 470	47 463 059	40 133 891.06
Observations (months)	12	12	12	12
Pearson correlation	0.983655		0.988405	
Hypothesized mean	0		0	
df	11		11	
t-Statistic	1.257774		0.257357	
$P(T \leq t)$ two-tail	0.234519		0.801654	

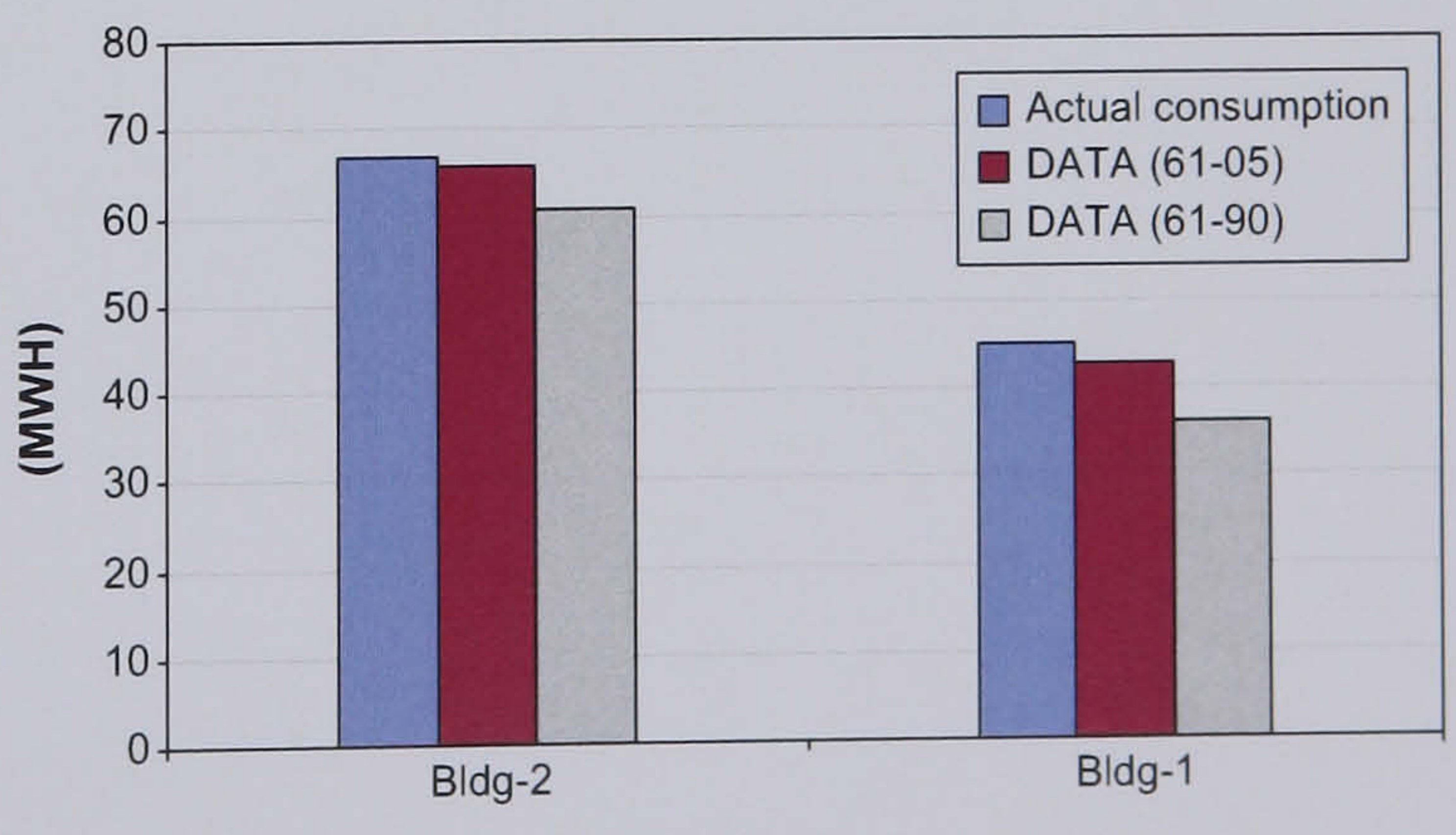

Fig. 12. Annual cooling load.

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5. Conclusions

The analysis carried out in this study has shown that there is a variation in the climatic elements of Bahrain. These elements tend to get warmer. The temperature is rising at a rate of 1.4 °C per decade, while the relative humidity is decreasing by approximately 8.2% per the same period. Wind speed tends to be slower than before due to buildings and local influences. Direct solar radiation is increasing, especially in the cooling months. However, there is a drop in diffuse solar radiation. Weather data currently used in Bahrain were developed based on far past climatic information – a reason why the variations in climatic elements during the last few decades has been neglected. This puts the reliability of those data in question. A computer simulation based on two weather data files related to different periods was undertaken as a comparative study of the performance of weather data. The weather file developed based on far past data tends to underestimate the electricity consumption by 14.5% and misrepresents the cooling load by 5.9–8.9%. Conversely, the weather file developed based on recent updated data underestimates the actual consumption by only 1.4%.

The set of results, in this study, shows how inefficient the use of far past data to predict the present and future performance is. The recent past data may represent better option. However, it is important to remember that weather data based on the historical information of what has occurred in the past only disclose a range of situations that are most likely to occur, not necessarily a situation that will definitely occur.

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