CHAPTER 1

INTRODUCTION

> *hile the majority of people are aware of the need for energy conservation in order to make best use of the world dwindling reserves of fossil fuels, there is still considerable scope to further reduce the energy consumption of buildings and their engineering services." – (CIBSE, 1979, Forward, pp. 5)*

Energy resources are a fundamental ingredient of all economic systems (ASHRAE, 1990b). Efficient use of energy is important since the reserve of our global energy resources is finite (and depleting) and there are adverse environmental effects from power generation using fossil fuels. Among the different energy end-use sectors, the buildings sector is often considered having large potential for substantial energy savings (Alliance to Save Energy, 1993). However, although the present energy technology for building components promise to reduce energy demands (Bevington and Rosenfeld, 1990), there is a lack of real understanding about the energy performance of buildings, especially for air-conditioned premises in hot, humid climate.

During the past thirty years building designers have been searching for a systematic way to measure, analyse and assess the building performance. Although a lot of efforts have been taken on this subject, building energy performance remains an nigma' to most people. Energy use in buildings is at present ill-conceived and not well understood because the parameters involved are complex, diverse and insubstantial in nature. Attempt to achieve

energy-efficient design of buildings is often hindered by the lack of appreciation of the way buildings respond to the climate and the various environmental and design factors.

To tackle with this difficulty, computer simulation models have been developed for conducting detailed building energy analysis. Through a couple of decades, these models have been accepted as the most powerful and flexible tools for investigating building energy performance, and have been used extensively in the world for supporting the development of modern building energy standards (Dubin and Long, 1978; Deringer and Busch, 1992; Wilcox, 1991; SRC Australia Pty Ltd, 1993c). Despite the growing implications of computer building energy simulation, application of the simulation tools and techniques is problematic. There is a gap between the technology on the computer and what is being adopted and understood by the practising building designers.

With a growing concern about energy efficiency, Hong Kong has begun to investigate and develop her building energy standards in 1990 (Hui and Lam, 1991a). Some studies have been carried out to evaluate the experience in other countries and examine appropriate options for Hong Kong (JRP, 1991; Hui and Lam, 1991b; EMSD, 1994). But the tasks were often hindered by the breadth of the subject and the complexity of building energy analysis. Efforts to investigate energy performance of buildings were impeded by the lack of suitable local climatic data and the insufficient recognition of the properties of energy analysis and simulation techniques.

This thesis elucidates the problems of building energy performance and investigates the key factors of building energy standards and building energy simulation. The aim is to establish systematic methods for the assessment and evaluation of energy performance of air-conditioned buildings in Hong Kong. The background of the research subject, the objectives and scope of this research, and the structure of the thesis are explained in this opening chapter.

1.1 Background

The energy scenarios in the world and in Hong Kong are reviewed. Key problem areas in the research are pinpointed.

1.1.1 World energy scenario

In the period from 1970 to 1992, energy consumption in the world has increased by 66% while energy-related carbon emission has increased by 51% (EIA, 1994c). There is a growing concern globally to use energy more efficiently and to reduce greenhouse gas emissions from power generation.

From the 1970 to the 1990

The energy crises and sharp oil price increases of the 1970 stimulated heightened interest in energy efficiency studies. As a result, energy conservation measures were developed to provide cost-effective solutions for meeting immediate short-term goals. In the 1980 , steady oil supply and low energy price have reduced people immediate interest in energy conservation. In the late 1980 and early 1990 , awareness of the close link between energy use and environmental pollution has brought energy efficiency back to front international agenda. There is a quest for long-term energy policy and systematic measures for achieving energy efficiency. The measures designed for buildings usually aim at improving present techniques, making the best use of unexploited research results (from the 1970), and developing new technologies and approaches for practical use (International Energy Agency, 1990). It is believed that more efficient building energy utilisation is attainable and energy optimisation is conceivable by using the present-day techniques effectively in building design and operation.

Driving forces

Global concerns for the environmental impact of power generation and carbon dioxide (CO_2) emissions have drawn much attentions in the control of the overall energy consumption in buildings. At the community level in most countries, by reducing the energy demand growth, excessive dependence on

imported fuels can be avoided and the resources for generating and supplying energy can be minimised. Government-initiated control measures have been developed to stimulate energy efficiency improvement and the formulation of building energy standards is a prime concern. The study of building energy performance is often driven by the need to develop or update building energy standards in a country. Economic and environmental factors are also causing the prospective building owner and developer to be increasingly concerned with energy costs and to transmit this concern to the building designers through a demand for more energy-efficient buildings.

Saving potential of electricity

Among the different forms of energy, electricity is the most convenient and important for general use (Fickett, Gellings and Lovins, 1990). It has been found that electricity use worldwide increased significantly faster than the overall energy use, particularly in developing countries (EIA, 1994c). Generally, three units of energy inputs are required to produce one unit of electricity output, with the other two units being lost as heat. To ease environmental pressures and meet the world growing energy service needs, improving electricity end-use efficiency is very essential (Levine, *et al.*, 1992).

The potential for electricity savings is probably greatest in commercial buildings where a significant portion of the energy demand is expended by the heating, ventilating and air-conditioning (HVAC) systems (Bevington and Rosenfeld, 1990). A number of technologies and opportunities have been identified and studied in developed countries (Holtz, 1990; Morse, 1990; Geller, 1988), but their applicability and effectiveness in developing countries, like Hong Kong, are seldom evaluated extensively.

1.1.2 Hong Kong situation

Hong Kong is totally dependent on outside sources of energy for its needs (Newcombe, 1975) and electricity is the principal form of energy delivered to buildings (Stones, 1988). In 1993, about 70% of the primary

energy requirements is consumed in the generation of electricity, using coal and oil products (Census and Statistics Department, 1983-94). There are increasing pressures on electricity supply to meet the growing energy demands of the community.

Growth of electricity consumption in Hong Kong

The growth of the Hong Kong economy is closely related with the growth of electricity consumption (Chou, 1983; Lam and Ng, 1994). Since Hong Kong depends heavily on commercial and financial activities for its economic survival (Chow, 1980, Chp. V), energy consumption in commercial buildings, mainly electricity, is an important part of the energy demands. Figure 1.1 shows the growth of electricity consumption for the three main sectors in Hong Kong, i.e. commercial, domestic and industrial sectors (Census and Statistics Department, 1970-94 & 1983-94).

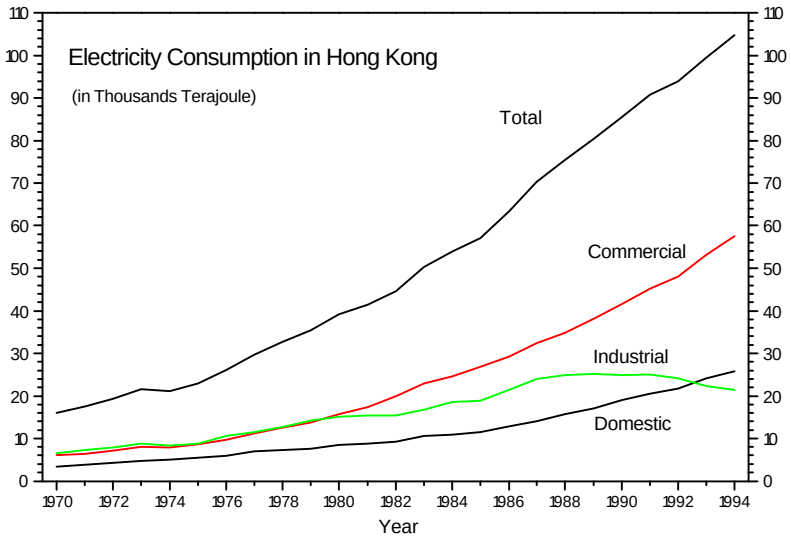

Figure 1.1 *Electricity Consumption in Hong Kong*

It is found that the commercial sector has the highest growth rate among the three main sectors; the average percentage increases per annum (for 1970-94) for the total consumption and for the commercial sector are 8.2%

and 9.9%, respectively. In 1994, the commercial sector (at 57,508 Terajoule) represents 54.9% of the total consumption. The electricity demand is expected to grow in the coming years as the development of commercial buildings and the living standards in Hong Kong continue to increase (Stones, 1991).

Electricity price

The electricity price has important influence on people priorities to energy conservation. Figure 1.2 shows the average electricity charge of the two power companies in Hong Kong (China Light & Power and Hongkong Electric) for the 22 years from 1972 to 1993, expressed in Hong Kong dollars per Megajoule of electrical energy (Census and Statistics Department, 1983-94) [1].

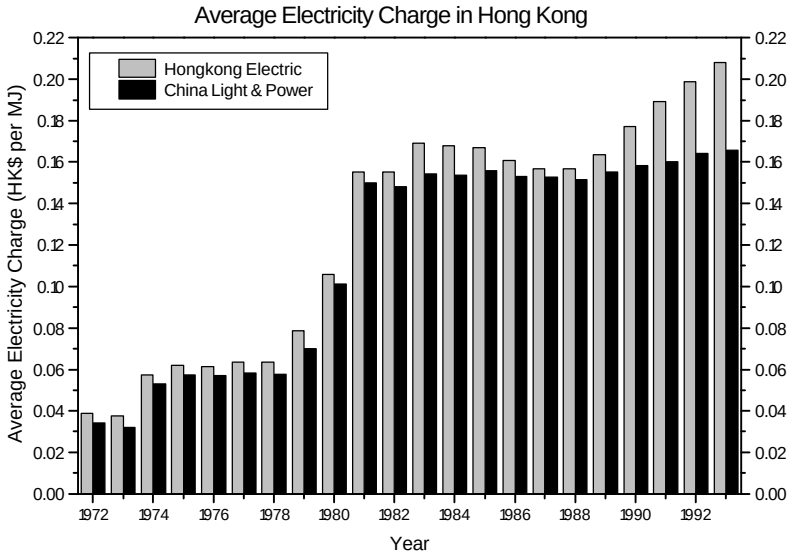

Figure 1.2 *Average Electricity Charge in Hong Kong*

It can be seen that after a sharp increase in 1980-81 (due to the world oil crisis in the late 1970), Hong Kong has enjoyed a steady, low price of electricity in the 1980 , as the two power companies were converting

[1] The exchange rate of Hong Kong dollar in 1995 is approximately: one US dollar = HK$7.73, one UK pound = HK$12.4 and one Australian dollar = HK$5.69.

their oil-fired generating plants to coal-fired ones which used less expensive (but more polluting) fuels. At the beginning of the 1990 , fuel savings achieved by the substitution of coal for oil have been fully harvested and can no longer be utilised to reduce fuel costs (CLP, 1990). The real costs of energy production are now increasing and are expected to come up steadily at the end of this century. Therefore, to ensure that Hong Kong is economically competitive, it is essential to promote energy efficiency measures.

Energy efficiency in buildings

It is believed that a significant portion of the electricity use in buildings of Hong Kong is for air-conditioning in the summer months (Lam, Hui and Yuen, 1994). Lo, *et al.* (1988) has estimated that energy consumption by air-conditioning plant constitutes over 60% of the expenditure on electricity in a high-rise commercial building in Hong Kong. The capital investment of air-conditioning system also represents a major expense in the construction of commercial buildings. Considerable saving potentials for energy and cost-effective building design can be anticipated.

Unfortunately, there was very little consideration given to energy-conscious design of buildings in the past (Goodsall, 1994). The new buildings in Hong Kong, though purposeful and attractive, are not necessarily cost-effective in energy terms (Property Division Finance Branch, 1990; Shillinglaw, 1981). Reed (1991) has estimated that half of the energy wastage in Hong Kong (the total wastage is HK$4.9 billion per year) is accounted for by the commercial sector. Blake (1991) also pointed out that the Hong Kong approach to efficient energy use has been ad-hoc by nature, with a lack of central direction and performance monitoring. There is a need to promote building energy efficiency and to develop an energy policy with substantial multi-disciplinary input (Wong, 1990; Reed, 1991).

Development of building energy standards

In order to encourage more energy-efficient design in buildings, the Hong Kong government has begun planning regulatory energy conservation

standards for buildings in 1990. As a first step of the task, a new regulation using the Overall Thermal Transfer Value (OTTV) method has recently been legislated in July 1995 to control the building envelope design in new commercial buildings (Hong Kong Government, 1995). Other codes on HVAC equipment and lighting installation are now being considered by the authority. The regulation has long-reaching effects on the next generation of buildings in Hong Kong and the future development of the building industry. But there is a lack of detailed technical knowledge about how the regulation can achieve the objectives and what measures are needed to improve it. More research studies are needed to provide systematic methods and data for evaluating building energy performance, so as to strengthen the technical basis of the building energy standards and to help designers achieve the efficiency goal.

1.1.3 Problem areas

Having briefly looked at the energy issues in the world and in Hong Kong, it will be useful to outline the general problems surrounding the research subject and to understand the specific needs of Hong Kong.

General problems

Although the principles of energy efficiency may be widely understood, studies of building energy performance are still in their infancy and are not clearly defined (Baird, *et al.*, 1984, pp. 8). Because of the lack of a theoretical basis, energy performance of buildings is an area we only partially understand. Its study involves a cluster of intricately related problems, such as climatic conditions, heat transfer mechanism, human behaviours, load calculation, system design and energy estimation. There are no simple, definitive answers to these problems and the analysis will require a clear understanding of their interactions, limitations and implications. As the author believes, there are four major difficulties surrounding the subject:

- Vague concepts of building energy performance.
- Abstract nature of the building design process.

- Unclear understandings about load and energy calculations.
- Complexity of building energy simulation and its weather inputs.

These difficulties form the crux of the whole problem of building energy performance and complicate assessment of the performance. In order to develop a consistent and effective means for the analysis, they should be studied carefully and understood in context (see Chapter 2 for detail).

Specific needs of Hong Kong

Apart from the general difficulties, investigations for Hong Kong are hindered by the fact that many essential data and information about HVAC system design and building energy use are either incomplete or non-existing. To provide the information for energy analysis, inferences may be drawn from the research in developed countries (such as Europe and North America). But, as the research studies in western countries usually focus on heating system design and thermal insulation, the effectiveness of their approaches for the warmer part of the world is uncertain. Even if some information may be obtained from the early research studies in developing countries in tropical climate (such as countries in Southeast Asia), the validity of the data and methods needs to be verified when applied to Hong Kong.

As Hong Kong does not yet have a sound research background for building energy study, it is important to learn and evaluate the experience of other more advanced countries, and to establish information and methods in the local context. Three aspects are considered the most important at this stage:

- Evaluation of building energy standards.
- Development and analysis of local climatic data.
- Development of building energy simulation techniques and skills.

By evaluating the experience and strategies in other countries, it is possible to generate valuable information and techniques for analysing the

energy performance of buildings in Hong Kong. By studying the local climate, useful information and design principles most appropriate to the weather conditions of Hong Kong can be developed.

1.2 Objectives and Scope

1.2.1 Purpose and objectives

The purpose of the research in this thesis is to establish systematic methods for the assessment and evaluation of energy performance of air-conditioned buildings in Hong Kong. The research study was initiated and motivated by the need in Hong Kong to develop comprehensive building energy standards. Results presented in this thesis are ordered in a way similar to how building energy performance study is carried out and the required information is coming in. It is hoped that the research can draw useful information to Hong Kong for analysing and achieving optimum energy efficiency in building design and operation.

Objectives of this thesis

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

- To study and explain the problems and important aspects of building energy performance.
- To evaluate building energy standards and distil useful experience and information.
- To examine the effects of climate on building thermal design and to analyse the major characteristics of Hong Kong weather.
- To study the weather files for building energy analysis and to establish weather data for building energy simulation in Hong Kong.
- To develop computer simulation models for the analysis of energy performance of air-conditioned buildings and to investigate the interactions between design and performance parameters.

It is not the intention of this thesis to offer a complete and definite solution to the study of building energy performance. As the possible approaches and conditions are endless, a universal solution to the general problems becomes an impossibility. It is hoped that the present study can serve as a useful piece for solving the puzzle of energy systems behaviour in buildings, and that findings for Hong Kong can form a basis for setting up a framework to understand and improve building energy efficiency in other parts of the world with similar climate and conditions.

1.2.2 Scope of work

This thesis focuses on air-conditioned buildings in Hong Kong. High-rise commercial buildings equipped with central HVAC system is the main theme of the investigation. Existing and proposed building energy standards in the world are studied and evaluated; the climatic data of Hong Kong for HVAC design and building energy simulation are developed and analysed; the characteristics of building energy performance in a cooling-dominated climate are examined using computer simulation methods.

The studies on energy standards and climatic data apply to all types of air-conditioned buildings in general. Whereas, the simulation analysis in this thesis concentrates primarily on large office buildings since the office sector has the highest construction volume and energy consumption, and is particularly active in the commercial sector in Hong Kong (Woodroffe, 1993). Improving of office environment and design is usually the focal point of building performance for high-quality buildings (Hartkopf, *et al.*, 1993). As large office buildings are the principal energy-using category in the commercial sector and encompass many key design features, investigation of their energy performance has been the subject of many detailed studies in other countries. The methodology used for studying the office buildings can be extended to help characterise other building types.

Hong Kong as a typical example

Air-conditioning system to maintain comfortable indoor environmental conditions is the major electricity end-user in buildings in tropical and sub-tropical climates. As most of the nations in this region are developing countries having very fast economic and building developments, energy efficiency is a fledging field in these territories (AAC, 1992; Matsui, 1994; Drysdale, 1994; Levine, Meyers and Wilbanks, 1991). Improving building energy performance for air-conditioned buildings is a key issue for these countries since many of them have profligate energy use in cooling systems. Although the investigation in this thesis is specifically concerned with Hong Kong, some of the methods and results have more general implications. It is believed that the problems encountered in Hong Kong are representative of those encountered in many other developing countries or cities. It is hoped that by studying and comparing the building energy performance, a useful basis can be formulated for understanding the nature and properties of energy use in high-rise commercial buildings in this climate.

1.3 Organisation of the Thesis

This thesis is organised into seven chapters, each dealing with a particular aspect of the investigation on building energy performance.

Chapter 2 provides an overview of the research problems and explains the current development and understanding in this field. The basic approach and worldwide concern are described; the characteristics of the building design process and the concepts of load and energy calculations are expounded; the problems surrounding building energy simulation are discussed.

Chapter 3 highlights the importance of building energy performance standards and investigates their development in worldwide countries. The newly implemented OTTV standard of Hong Kong is studied and evaluated. Useful experience from more advanced countries is distilled and discussed.

Chapters 4 studies building climatic design and the properties of outdoor design conditions. Weather data of Hong Kong are investigated and useful climatic design data are established from the local meteorological records. The climatic properties of Hong Kong are examined using statistical and graphical methods.

Chapter 5 explains the concepts of typical weather and investigates two common methods for selecting typical years: ASHRAE Test Reference Year (TRY) method and Typical Meteorological Year (TMY) method. Typical years for Hong Kong are determined and weather files for building energy simulation are developed. The weather files are evaluated by studying their simulated performance and the effectiveness of the typical year approach is discussed.

Chapter 6 focuses on the simulation methods for analysing building energy performance. The basic concept of energy modelling is explained and simulation tools are selected for this research. A base case office building model for Hong Kong is established on detailed simulation programs (DOE-2 and BLAST); sensitivity analysis is carried out to examine the important design parameters; regression analysis is performed to generate and analyse energy equations for Hong Kong.

Chapter 7 summarises the key research findings, explains the significance and limitations of this study, and recommends future research work for enhancing building energy performance study.