CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

> *lthough designers are forced by present demands to pay increased attention to performance standards of buildings, the wide-spread lack of appreciation of rational functional design procedures remains a disturbing feature of modern building practice." – (Van Straaten, 1967, Chp. 1)*

In the context of Hong Kong, this thesis has examined three important aspects surrounding the energy performance of air-conditioned buildings: (a) building energy standards, (b) climatic data and (c) building energy simulation. This chapter summarises the key findings of the research, explains the significance and limitations of this study, and recommends future research work for futhering the study of building energy performance and strengthening the technical basis in Hong Kong.

7.1 Summary of Major Findings

Major research findings for building energy standards, climatic data of Hong Kong and building energy simulation methods are presented.

7.1.1 Building energy standards

The study of the BES in the world shows that considerable efforts have been expended in the past two decades to develop or update the standards for promoting building energy efficiency. With the advancement of computer-based techniques, pioneering countries of BES (such as USA, UK

and New Zealand) have been moving towards performance-based approach through detailed analysis of building energy performance whereas developing countries are establishing new BES using a prescriptive approach, such as OTTV. Since most developing countries did not have any form of BES in the past, they tend to learn the experience of more advanced countries and adopt their approach as a reference model.

Current status

The ASHRAE Standards (90 series) is the most widely adopted model nowadays and the methods proposed in the current and previous versions of the standards have been commonly used in many locations of the world. In the 1980 and early 1990 , the countries in ASEAN, with technical support from USA, have developed their own BES which are designed specifically for hot climate. The OTTV method, adapted from ASHRAE (1980 & 1975a), has been expanded in ASEAN (Deringer and Busch, 1992) and this approach has been generalised and applied to other developing countries as well, such as Hong Kong (JRP, 1991; Building Authority Hong Kong, 1995) and Jamaica (Jamaica Bureau of Standards, 1992).

At the same time, some western countries, including UK and New Zealand, have developed their BES based on an energy target approach, which they believe is simple and more performance-oriented. The approach addresses energy consumption of the building as a whole to avoid prescriptive requirements which may limit trade-offs among different components and systems. The main drawback is the need to determine the energy performance of the building and to compare it with a easonable' target. UK has used a manual method for this compliance (CIBS, 1981) (a computerised version is currently under test); New Zealand has just invented a software-based tool for it (Isaac, *et al.*, 1993); USA has proposed, in the current ASHRAE Standards 90 (ASHRAE, 1989c), an energy cost budget approach using simulation methods.

Implications for Hong Kong

Hong Kong has just implemented her first BES for commercial buildings in July 1995 (Hong Kong Government, 1995; Building Authority Hong Kong, 1995) and an OTTV method similar to that in ASEAN has been specified. Evaluation of the HK-OTTV standard shows that the current stringent level is moderate as compared with ASEAN and ASHRAE, and that the solar component is predominant in the respective OTTV calculation. Analysis of the OTTV components and parameters indicates that the relative importance of the solar components is related to the latitude of the locations and that the solar factors in the OTTV equations resemble the theoretical patterns in ASHRAE (1993, Chp. 27). The significance of solar components in the HK-OTTV standard implies that the design parameters controlling solar heat gain, such as window area, shading coefficient and external shading devices, should be considered very carefully in building design. To justify the BES methods calls for a knowledge of the local information about the climate and building energy performance.

7.1.2 Climatic data

The investigation of the Hong Kong climatic data reveals that existing weather data for HVAC applications are sparse and limited. To ameliorate the situation, a weather database for HVAC applications and building energy analysis has been established for Hong Kong.

Design weather data and climatic analysis

Using the data in the weather database, outdoor design conditions for Hong Kong have been developed and analysed. It is found that there is scope for reducing cooling plant size and achieving better building energy efficiency if accurate design data are used and the risk levels are fully understood by designers. A brief comparison of the climatic cycles in ASEAN and Hong Kong shows that ASEAN requires cooling throughout the year while Hong Kong requires both cooling and heating.

It is found that graphical methods are useful for analysing and interpreting climatic data. Analysis of the DBT distributions reveals that the whole-year DBT is strongly influenced by the summer DBT distribution; analysis of the WBT data and humidity levels shows that high humidity during night time in spring and summer is a heavy burden of air-conditioning systems; analysis of GSR data indicates that there is large solar heat gains during summer and a short period in winter. It is shown in the frequency psychrometric charts that economiser-cycle operation of HVAC systems is feasible in about 30% of a year in Hong Kong. To achieve energy-efficient design and operation, building components and systems should be carefully designed to take full advantage of the behaviour and interactions of the weather parameters.

Typical weather for energy simulation

The ASHRAE Test Reference Year method and the Typical Meteorological Year method have been studied and the typical years for Hong Kong have been determined. It is found that although the TMY method is commonly used nowadays, its selection procedure and statistical basis are ambiguous. An attempt has been made to clarify the TMY method, extend it to hourly data and the whole year, and quantify the uncertainty in the selection using a new statistical index (the KS statistic). Weather files for building energy simulation have been developed for Hong Kong for the 16 years from 1979 to 1994. Analysis of the simulated performance of the typical years and the 16 years shows that the typical months and whole-years selected from the TMY and TRY methods may or may not produce results close to the long-term averages. The performance of the simulation results of the selected months or years depends not only on the building characteristics but also on the weather file format and simulation program used. The degree of uncertainty of the selected typical weather data has been quantified. It is believed that rethinking of the typical year approach is needed and development of multi-year simulation is a possible way to resolve the problems of weather input for simulation.

7.1.3 Building energy simulation

A base case model has been established for typical office buildings in Hong Kong. Comparison of this model with similar models and audit results in ASEAN shows that they have some similarities and some differences in the design features and energy use behaviour.

Sensitivity analysis

The simulation results for the base case model indicate that cooling energy requirements dominate the energy consumption at about 55.8% and heating energy use is small, only 2.5%; the most essential components determining the peak cooling load are occupancy (sensible 14.6% and latent 15%), lighting (19.3%), equipment (15%) and solar (17%). The sensitivity findings show that the most important design parameters are: internal loads (occupancy, lighting and equipment), window design (shading coefficient and window area), thermostat setpoint, HVAC fan efficiency and statistic pressure, chiller coefficient of performance (COP) and chilled water supply temperature. It is found that energy consumption and peak demand have similar behaviour in sensitivity but the monthly load profiles may vary differently for some parameters (such as outdoor air flow and chiller COP).

Regression analysis and energy equations

Regression techniques which are often used for studying building energy performance and developing OTTV standards are examined. Single-parameter and multiple regression models have been established for the important parameters identified in the sensitivity analysis. It is found that the term 'SC x WR' is significant in the envelope regression equations and the OTTV form of equation relates quite well to the building energy consumption. By comparing the regression coefficients developed for different locations, it is possible to assess the OTTV components in different climates.

A general form of energy equations, which includes variables from different parameter groups (building loads, HVAC system and HVAC refrigeration plant), has been proposed. Testing of the cross-parameter

models using randomised simulation input shows that they are quite good in energy estimation. To reduce the number of simulations required for generating the regression models (of many parameters), a method using randomised input has been suggested. Models with 12 parameters have been established using this concept and the non-linear regression techniques; analysis of these models indicates that a multiplying model for the general energy equation performs better than an adding model. This method has a good potential for helping develop simplified equations for expressing energy targets.

7.2 Significance and Limitations

The significance of the results from this research is highlighted and the limitations of the present study are discussed.

7.2.1 Significance of the results

The author hopes that the present study can contribute to a better understanding of the methodology for analysing building energy performance and to the realisation of highly energy-efficient building design and operation through the stimulus of building energy standards. The significance of the research results can be divided into three areas:

- *Strengthen building energy standards* – Useful information and experience from other more advanced countries will be a good reference for future standard development in Hong Kong and other developing countries. A clear understanding of the current HK-OTTV standard and its limitations will form a base for its effective use and future enhancements (such as towards a performance-based approach).

- *Understand local climate* – The basic climatic data and the weather database for Hong Kong will be useful for both HVAC design and building energy analysis. An appreciation of the local climate and the methods (graphical

and statistical) for evaluating the climatic data will be instructive for designers who want to understand the climatic design principles.

- *Facilitate building energy performance analysis* – The approach and methods for building energy simulation and analysis demonstrated in this thesis will give designers greater control of the design and performance of buildings, if applied and interpreted properly. The supporting programs (the ear') will be useful for mechanising the simulation process and facilitating detailed, intensive analyses. The general energy equations suggested can be an effective means for characterising energy targets for practical situations not economical for detailed simulation.

7.2.2 Limitations of this study

There are some (or many) deficiencies and gaps of this study that the author would like to point out.

- *Lack of real energy consumption data for buildings* – This is probably the biggest constraint in Hong Kong which makes alidation' and calibration of energy models difficult. Although the models in this thesis has been compared with some brief surveys and overseas examples, they are indicative and not in any way sufficient for prediction of real energy use.

- *Only office buildings have been examined* – Although office buildings contain many key features in building design, not all of these features can be extrapolated to other building types. The simulation results in this thesis should not apply too far from office use, whereas the climatic analysis is believed to have more general application.

- *Only two simulation programs have been used* – The two programs employed (DOE-2 and BLAST) are coloured by America technology and do not reflect all the simulation approaches available nowadays. To generalise the philosophy, the author has designed the methodology in this research such that the simulation ngine' can be replaced easily if the need comes.

- *Limited weather data in Hong Kong* – The typical year analysis is based only on 16 years of full hourly weather data. The results are not representative enough for the long-term climatic conditions and the simulation exercises based on this weather database will be confined to comparative evaluations.

- *Information on BES are rapidly changing* – The descriptions and evaluation of BES are based on the author knowledge accumulated through inquiry and references. As the BES status in the world is obscure and changing rapidly, some of the information provided here may be inaccurate and out of date.

- *Indoor environment has not been addressed* – The present study assumes that with the respective building performance, the indoor environmental criteria have been satisfied. This may not be the case and there is scope for energy optimisation if indoor conditions are considered effectively.

7.3 Recommendations for Future Work

Future research and development work is recommended to facilitate the study of building energy performance and to strengthen the technical basis in Hong Kong.

7.3.1 General recommendations

The general recommendations are:

- *International source of BES information* – It is beneficial to have a site which contains the essential BES information for searching and reviewing. The information may be maintained by a research body who can disseminate it in appropriate media and forms (such as on Internet).

- *International and regional databases of weather files* – Lack of weather data files, particularly for developing countries, is a serious problem nowadays. Creation of weather databases for collection of weather files for energy

simulation will be useful. Internet ftp and web sites will be an effective medium for keeping the weather files.

- *Regression analysis using randomised input* – There is a good potential for making use of this technique to facilitate the regression analysis process and generate energy equations. Automation of the parametric simulations is necessary to make the best use of the method.

- *Multi-year simulation* – It is too early to say that the multi-year simulation method will replace the usual typical year approach. But its advantages in resolving the problems of design and typical weather is worth the effort to rethink the present approach and explore the method for future generations of simulation tools.

- *Relationship between energy standards and indoor air quality standards* – The correlation between energy conservation and indoor air quality is a common concern nowadays. How these two standards should be coordinated and designed to achieve optimal energy savings without damaging indoor conditions is an urgent research area.

7.3.2 Suggested work for Hong Kong

The suggested further work for Hong Kong includes:

- *Extensive energy audit and surveys for buildings* – They will serve not only to identify the characteristics of building energy use, design practices, etc. for existing buildings, but also to find out the energy conservation opportunities for the buildings themselves.

- *Weather database and climatic analysis* – The weather data and climatic properties related to building energy performance can be built up to form a technical base for designers and energy analysts.

- *Analyses for other types of buildings* – The approach and methodology in this thesis can be applied to study other building types and the results can be compared to determine the effective energy conservation strategies.

- *Analyses using different simulation programs* – Some other simulation engines can be used to perform the analysis so as to study the characteristics of each tool and the effect on the simulation results.

- *Study of energy conservation measures* – The simulation methods and models established in this study can be used to assess the various energy conservation measures and technologies available in the market (such as daylighting controls and thermal storage system).

- *Improved solar data* – Since the solar component is predominant in this climate, it is essential to establish more accurate solar data and to study carefully the characteristics of solar design in Hong Kong.

- *Technology transfer and updates* – Close eyes should be kept on the latest energy technology in the world and to ensure that the most effective methods can be learned and applied to Hong Kong.