Computer Simulation of Energy Performance of Commercial Buildings in Hong Kong

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ABSTRACT

Computer-based simulation methods offer a powerful and flerible tool for building energy analysis. This paper presents a research study on the thermal and energy perfomance of commercial buildings in Hong Kong using computer modelling techniques on a microcorrputer-based platform. A database of energy simulation results has been generated using a personal computer (PC) version of the DOE-2. ID building energy simulation programme with a generic base case model building and the weather files developed for Hong Kong A parametric analysis has then been conducted to explore the energy-related design factors of commercial buildings in Hong Kong. Research results showing the key parameters that influence the energy performance of commercial buildings in Hong Kong are Presented. Present situation of energy conservation activities in Hong Kong and the potential of detailed energy simulation methods for building energy analysis are also discussed.

INTRODUCTION

In Hong Kong, like many other modem cities, the rapidly growing economy and increase in living standard have brought about a significant increase in energy demand (mostly in the form of electricity). Figure 1 shows the energy requirements in Hong Kong for the 13-year period from 1979 to 1991 (Census and Statistics Department 1992). It can be seen that there was 139 % increase in the primary energy requirement (PER) during this period. And in 1991, the primary energy (mainly coal) required for electricity generation accounted for over 70 % of the PER. Figure 2 shows the growth of electricity consumption for the three main sectors (domestic, industrial and commercial) in Hong Kong during the past two decades. Another small

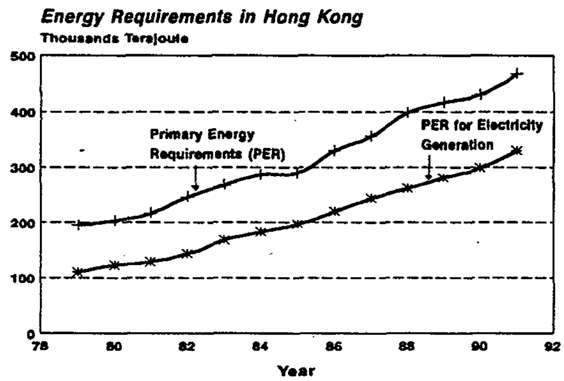

Figure 1. Energy Requirements in Hong Kong

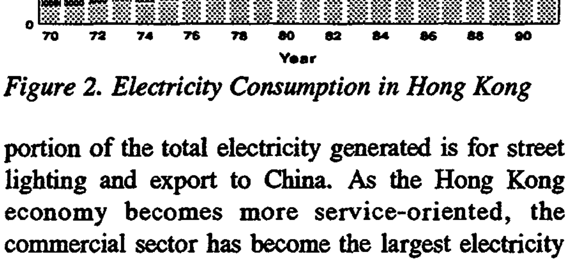

Figure 2. Electricity Consumption in Hong Kong

portion of the total electricity generated is for street lighting and export to China. As the Hong Kong economy becomes more service-oriented, the commercial sector has become the largest electricity end-user. In 1991, electricity consumed in the commercial sector represented 44.3% of the total electricity consumption (including export to China). It is believed that substantial energy savings can be achieved by promoting energy-conscious design in commercial buildings.

Attempt to achieve energy-efficient design in buildings by estimating the building energy requirements can be an arduous task. It has been recognised that

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computer simulation techniques can be a powerful and flexible design tool (Clarke 1985). With the advance in computing technology and the development in building energy simulation techniques, in-depth studies of design options and factors are now possible by detailed hour-by-hour building energy simulation programmes (BESPs) running on microcomputers.

This paper presents a research study of the thermal and energy performance of commercial buildings in Hong Kong using computer modelling techniques established on a personal computer (PC) based platform. A database of simulation results has been generated using an IBM PC version (an extended DOS 386 version) of the DOE-2.1D programme (Acrosoft International, Inc. 1990). A generic base case model building and the weather files for Hong Kong have been developed. And a parametric analysis has been conducted to explore the energy-related design factors of commercial buildings in Hong Kong.

COMPUTER SIMULATION TOOL

Problem solving for building energy analysis using computer simulation is not new. Since the late 1970s, BESPs developed on mainframe/mini- computers has been used for energy conservation activities. DOE-2 (LBL 1981) and BLAST (BLAST Support Office 1991) are examples of these BESPs that can perform detailed hour-by-hour load and energy calculations for each of the 8,760 hours in a year.

The DOE-2 building energy simulation programme is used for the present study because it has been validated for accuracy and can offer great capability for simulating a wide range of features and energy conservation measures (Gale C. Corson Engineering 1990; Diamond et al. 1985). Developed by the Lawrence Berkeley Laboratory (Birdsall et al. 1990), the DOE-2 programme has been used in the United States and in many other countries to analyse the impact of energy-efficient technologies for buildings and to provide a technological basis for the development of energy conservation standards.

In order to standardise and facilitate the analysis process, efforts have been made to develop subroutines for automating the simulation process, extracting results, storing and manipulating the voluminous output generated from the simulation runs (Printouts are reduced to save our trees!). Figure 3 gives an overall picture of the simulation and analysis process.

WEATHER FILE FOR HONG KONG

Before energy simulations are carried out, it is necessary to obtain a weather file for the location under consideration. The weather file library of the DOE-2 programme covers only locations in the North America and does not have weather file for Hong Kong (at

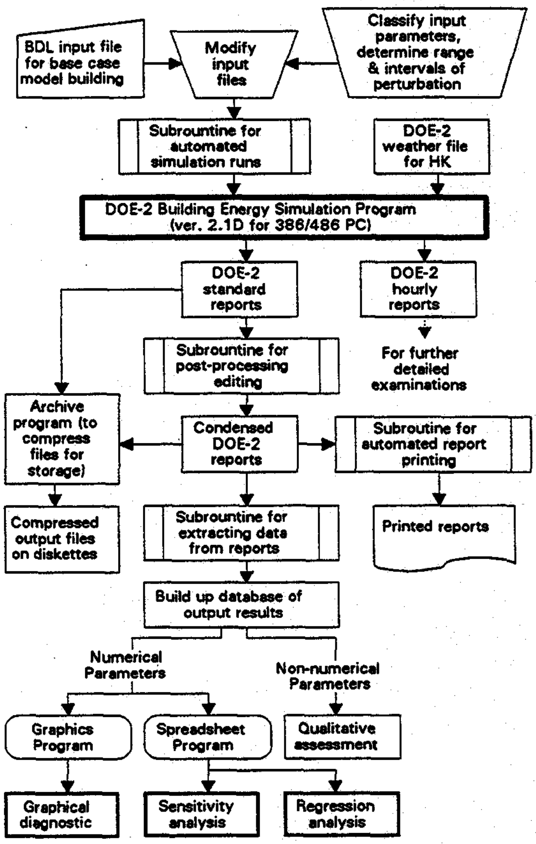

Figure 3. Simulation and Analysis Process

latitude 22.3 °N and longitude 114.2 °E).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Test Reference Year (TRY) procedure (LBL 1981) has been employed to select a typical weather year for Hong Kong for use in this comparative energy study. Weather data (including air temperature, solar radiation, etc.) for the 10-year period from 1980 to 1989 have been obtained from the Royal Observatory Hong Kong and have been analysed using the TRY selection procedure. Weather data for year 1989 was found to be the most representative of the prevailing local climatic conditions (Hui and Lam 1992). Figure 4 shows a summary of the three key climatic factors — dry-bulb temperature, wet-bulb temperature and global solar radiation.

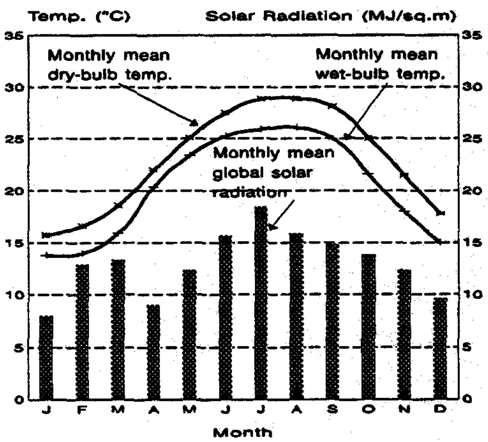

Figure 4. Summary of Key Climatic Factors Hong Kong 1989 Weather Data

In order to incorporate the local measured solar radiation data in Hong Kong, the 1989 weather file with 8,760 hourly records are compiled in a format called the Typical Meteorological Year (TMY) format, accessible by the DOE-2 weather processor to generate a binary weather file. In contrast to a TRY format weather file, the TMY format weather file contains user-supplied solar radiation data for use in simulation.

BASE CASE MODEL BUILDING

The most important factor in developing energy models for buildings is an intimate knowledge and understanding of the physical and operational characteristics of the building to be modelled. A base case model building has been developed to serve as a baseline reference for comparative energy studies.

A brief survey of the existing commercial buildings in Hong Kong has been conducted to find out the characteristics common to most commercial buildings in Hong Kong (Goodsall and Lam 1992). Descriptions of a generic base case model building are then established for use in the building energy simulation. The base case building selected is a 40-storeys square office building (35 m by 35 m) with curtain-wall construction and a centralised heating, ventilating and air-conditioning (HVAC) system. Figure 5 shows the plan & section of the base case model building which has a 3.4 m floor-to-floor height and a window height of 1.5 m. This represents a window-to-wall ratio (WWR) of 44%. The building and the HVAC plant operate on a 10-hour day (08:00 to 18:00) and 5½-day week basis. Base case values taken for the model building can be found in Tables 1 and 2.

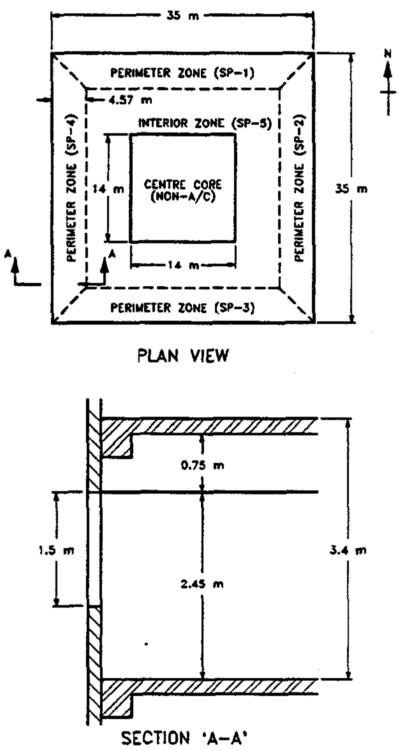

Figure 5. Plan & Section of Base Case Building

PARAMETRIC ANALYSIS PROCEDURE

Building descriptions and design involve many different and complex parameters. A parametric analysis has been conducted with the aim to explore and examine the energy-related design factors and to identify important parameters influencing building energy consumption in Hong Kong. In the analysis, all the major building characteristics and energy-related factors that affect building cooling and heating loads are first reduced as far as possible to simple "single" parameters. The input parameters to the BESP are then categorised into three main groups — building load, HVAC system and HVAC refrigeration plant. Each group is further divided into subgroups as shown in Figure 6.

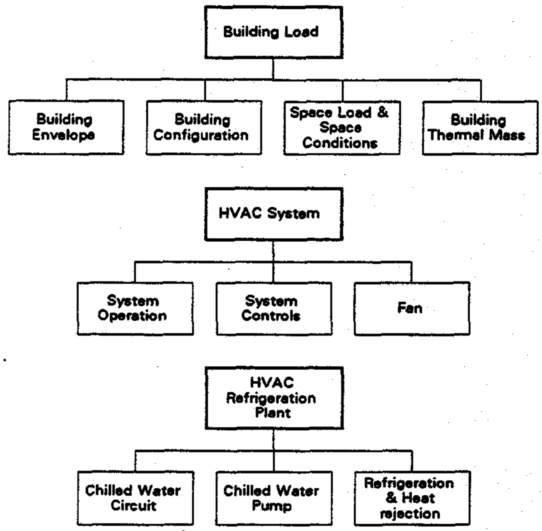

Figure 6. Categorisation of Input Parameters

Each of the input parameters is varied singly (one at a time) with respect to the base case situation by a few selected intervals (or perturbations). A series of simulations is then performed to study the effects on building energy consumption. A summary of the parameters, their base case values and the simulation runs performed is given in Tables 1 and 2. Some parameters such as system types and control settings are not numerical and they are assessed qualitatively.

Analyses have been carried out at this stage to find out the sensitivity of the annual energy consumption with respect to the variations in numerical input parameters. By simple regression methods the relationships between annual energy consumption and input parameters are established for understanding the respective energy behaviours.

At this initial stage of our study, a total of over 350 simulations have been performed in the parametric study — about 200 for building load, 90 for HVAC system and 60 for HVAC refrigeration plant. For modelling of the parameters in HVAC system and plant, simulation runs are based on the base case model building as described previously so that their load calculation results remain the same. This serves to isolate each parameter for the sake of analysis.

TABLE 1
Summary of Base Case Values and Perturbations for Building Load

Input Parameter (Abbr. in front)	Base Case Value	Perturbation Nos.	Min. Value	Max. Value
1. Building Load				
1.1 Building Envelope				
AR absorptance of roof	0.7	7	0	1
AW absorptance of wall	0.7	7	0	1
EG egg-crate shading	0	17	0	3
FN side-fins projection ratio	0	17	0	3
OV overhang projection ratio	0	17	0	3
SC shading coeff. (windows)	0.4	8	0	1
SF skylight to roof ratio	0	7	0	1
SS shading coeff. of skylight	N/A	8	0	1
UF U-value of fenestration	5.6 W/m²·K	10	1	9
UI U-value of inter. walls	2.513 W/m²·K	4	0.49	3.149
UR U-value of roof	0.539 W/m²·K	5	0.426	2.147
US U-value of skylight	N/A	10	1	9
UW U-value of opaque wall	2.005 W/m²·K	6	0.513	4.208
WR window-to-wall ratio	0.44	7	0	1
1.2 Building Configuration				
AS aspect ratio of plan	1	8	1	5
FH floor-to-floor height	3.4 m	7	2.5	5
NS number of storeys	40 nos.	5	10	50
OR orientation	facing N,E,S,W	4	rotate 15° @	
PZ perimeter zone depth	4.57 m	11	2	8
1.3 Space Load & Space Conditions				
AT space air temp.	25.5 °C	6	21	29
EQ equipment load	15 W/m²	6	5	25
IF infiltration rate	0.6 ACH	6	0	2
LL lighting load	20 W/m²	6	10	30
LT lighting type	Rec-F-NV	4	4 light. types	
OC occupant density	3.68 psn/m²	6	2	10
1.4 Building Thermal Mass				
FT furniture type	Heavy	2	Heavy & light	
FW floor weight	342 kg/m²	11	146	634
RW roof weight	496.1 kg/m²	5	483.1	502.6
WW wall weight	25.2 kg/m²	6	25.2	794.9

TABLE 2
Summary of Base Case Values and Perturbations for HVAC Systems and Plant

Input Parameter (Abbr. in front)	Base Case Value	Perturbation Nos.	Min. Value	Max. Value
2. HVAC System				
2.1 System Operation				
AC type of air side system	VAV reheat	4	4 A/C types	
EC economizer control	Yes	5	5 settings types	
OA outdoor air flow rate	7 cfm/psn	7	2	30
OH operation hours	10 hr/day	4	4 op. hrs.	
2.2 System Controls				
OL outdoor air control	Temp.	3	3 control types	
QR min. cfm ratio	0.3	6	0.1	0.5
RD reheat delta temp.	5 °C	15	2	15
SR supply air temp. reset	Yes	4	4 reset settings	
TR throttling range	1.1 °C	11	0.1	2.77
TS thermo. setpt. (summer)	25.5 °C	10	21	29
TT thermostat type	Rev. action	3	3 thermo. types	
TW thermo. setpt. (winter)	21 °C	10	19	27
2.3 Fan				
FC fan control method	IGV	3	3 methods	
FE fan efficiency	0.55	5	0.1	0.9
FM fan motor placement	In air flow	2	outside airflow	
FP fan placement	Draw-thru'	2	blow thru'	
FS fan static pressure	1369 Pa	7	500	3000
3. HVAC Refrigeration Plant				
3.1 Chilled Water Circuit				
CH chw. supply temp.	6.7 °C	7	4	9
CR chw. throttling range	1.39 °C	5	0.6	2.5
DT chw. design delta temp.	5.56 °C	5	4	7
3.2 Chilled Water Pump				
PE pump motor eff.	0.9	4	0.8	0.95
PH pump head	20 m Aq	4	10	40
PI pump impeller eff.	0.77	5	0.6	0.9
PL fraction of pump loss	0.01	4	0.005	0.02
PS pump sizing option	sys. peak	2	inst. demand	
PT pump speed control	fixed	2	var. speed	
3.3 Refrig. & Heat Rejection				
CP chiller COP	1.2 kW/TR	5	0.5	2
HG hot gas bypass PLR	0.25	11	0.2	0.7
HR heat rejection method	direct a/c	2	cooling tower	
MA min. entering air temp.	18.33 °C	4	12	21
NC number of chillers	6 nos.	6	1	10
PC ratio of cond. fan elec. power to chiller cap.	0.03	6	0.02	0.1
RF type of refrig. plant	herm. recip.	4	4 comp. types	

RESULTS OF PARAMETRIC ANALYSIS

Base Case Building

A summary of the load and energy use characteristics of the base case model building is given in Table 3. Key features observed are summarised as follows:

(a) Cooling requirements dominate the annual building energy consumption at about 52% (including chillers, fans and pumps). As expected for the subtropical climate in Hong Kong, heating energy requirements are insignificant at only 0.1%.

(b) The basic system loads i.e. lights and equipment, which are non-weather-dependent, account for almost 48% of the total electricity consumption.

(c) An energy budget of 164 kWh/m²/annum (based on gross floor area) is obtained. It lies within the range of surveyed data in Hong Kong (Yip and Hui 1991). (Other energy consuming equipment e.g. lifts and water pumps are excluded in the energy estimate.)

(d) The cooling load intensity for the refrigeration plant is estimated to be about 133 W/m² (or 285 ft²/TR) based on gross floor area. This figure is close to the general check figures used in Hong Kong.

Sensitivity Analysis

Sensitivity analysis compares changes in output with changes in input. The main objective is to assess the significance of each input parameter to the annual energy consumption. A knowledge of the influence that the individual input parameter has on the outputs is useful for identifying the important and critical characteristics. The results from the sensitivity analysis also provide information about the response of the simulation tool and model to the input parameters.

Individual sensitivity and influence coefficients (Spitler et al. 1989; Stoecker 1989) with respect to the

TABLE 3
Summary of Load and Energy Characteristics of Base Case Building

1. Building Load Breakdowns (from load calculation reports)

Components	Building Peak Load				Annual Energy from Building Load			
	Cooling Load		Heating Load		Cooling Energy		Heating Energy	
	(kW)	(%)	(kW)	(%)	(MWh)	(%)	(MWh)	(%)
Walls	254.88	7.4%	-312.06	22.1%	114.65	1.2%	-550.47	43.5%
Roofs	5.19	0.1%	-7.12	0.5%	5.62	0.1%	-6.87	0.5%
Glass cond.	199.32	5.8%	-774.74	54.9%	-561.63	-6.0%	-1329.05	105.0%
Glass solar	490.82	14.2%	34.90	-2.5%	1367.25	14.7%	304.78	-24.1%
Internal walls	38.28	1.1%	38.28	-2.7%	329.10	3.5%	6.24	-0.5%
Occupant (sen.)	659.56	19.0%	26.87	-1.9%	1851.13	19.9%	136.36	-10.8%
Occupant (lat.)	669.41	19.3%	(*)	---	1741.38	18.7%	(*)	---
Lights	648.35	18.7%	79.99	-5.7%	2207.85	23.7%	254.57	-20.1%
Equip.	497.73	14.4%	28.70	-2.0%	1306.29	14.0%	84.52	-6.7%
Infiltration (sen.)	---	---	-526.14	37.3%	-78.48	-0.8%	-165.36	13.1%
Infiltration (lat.)	---	---	(*)	---	1017.70	10.9%	(*)	---
Total	3463.55	100.0%	-1411.33	100.0%	9300.86	100.0%	-1265.29	100.0%
Sensible	2794.15	80.7%			6541.78	70.3%		
Latent	669.41	19.3%			2759.08	29.7%		
Peak time	17:00 Jul 6		01:00 Jan 29					
Load intensity								
- in W/m^2	84.15 (based on NFA							
- in ft^2/TR	449.59 of 41160 m^2)							

(*) latent loads from occupants & infiltration are not included in heating.

2. System and Plant Summary

Total fan supply flow rate = 187,349 L/s
Max. cooling load = 6499 kW (**)
Peak time = 09:00 May 30
Cooling Energy for Plant Load (**) :
Total = 8391.924 MWh (100 %)
Sensible = 5175.888 MWh (61.7 %)
Latent = 3216.036 MWh (38.3 %)

	Load Intensity (Plant) Based on	
	NFA of 41160 m^2	GFA of 49000 m^2
- in W/m^2	157.90	132.64
- in ft^2/TR	239.60	285.23

Chiller plant size :
1.106 MW x 6 nos. [Total = 6.636 MW]
(315 TR x 6 nos.) (1887 TR)
Chiller total load = 8748 MWh
Chiller total elec. = 3197 MWh

(**) cooling load given at system level are in fact heat extraction rates.

3. Building Energy Performance

	Annual Elec. MWh	
Space heat	8.56	0.1%
Space cool	3196.98	39.7%
HVAC aux. (fan)	779.31	9.7%
HVAC aux. (pump)	206.80	2.6%
Lights	2462.26	30.6%
Equip.	1390.80	17.3%
Total	8044.71	100.0%

Energy budget (#) :-

(a) based on GFA of 49000 m^2 : 164.20 $kWh/m^2/annum$
(b) based on NFA of 41160 m^2 : 195.40 $kWh/m^2/annum$

(#) other energy consuming equipment e.g. lifts & water pumps are not included.

4. Peak Electricity Demand

	Peak Elec. Demand (KW)	
Sys. load (##)	1748.51	41.1%
Circ. pumps	79.01	0.2%
Chillers	2430.97	57.1%
Total	4258.49	100.0%
Peak time	16:00 Aug 15	

(##) sys. load includes lights and equipment.

annual energy (electricity) consumption are determined for each numerical input parameter. Input parameters with significant influence to the building energy consumption are then identified in each parameter group. The results of the sensitivity analysis are summarised as follows:

(a) For building load — The internal basic loads including lighting, equipment and occupants are the most significant. Other important parameters include the design variables of the building envelope such as window-to-wall ratio, shading coefficient, U-value of window glass and absorptance of opaque wall.
(b) For HVAC system — Summertime thermostat setpoint, supply fan efficiency and fan static pressure are essential.
(c) For HVAC refrigeration plant — Coefficient of performance of chillers, chilled water supply temperature, chilled water design temperature difference and chilled water pump impeller efficiency are influential to the energy consumption.

Regression Analysis

Regression analysis serves to establish mathematical relationships between output and input variables (Sullivan et al. 1985). In the present study, only linear and quadratic regressions are applied. And the coefficients of determination (R^2) are calculated to decide whether simple regression models are applicable for the correlations between output and input parameters. The analyses are performed on regression worksheets written on a PC spreadsheet programme so that the procedure can be standardised and streamlined with the simulation process. Table 4 on the next page gives a summary of the regression relationships found.

Results of the regression analysis suggest that many parameters of building load are, to a good approximation, linearly related to the annual electricity consumption (in MWh). Whereas many parameters of HVAC system and plant can be fitted by quadratic equations. These observations may be explained from the algorithms and equations employed in the building energy simulation programme.

For instance, Figure 7 shows the energy consumption varies almost linearly with shading coefficient (SC) and WWR. That is interesting to see that, in Figure 8, energy consumption increases with increase in U-value of opaque wall, but decreases with U-value of windows. This is mainly due to the fact that windows help lose some of the heat during the night and during mid-season when the outdoor temperature falls below the indoor design air temperature.

TABLE 4
Summary of Regression Relationships

Input Parameter (Abbr. in front)	Linear Regr. $y = mx + c$			Quadratic Regr. $y = A + Bx + Cx^2$			
	c	m	R^2	A	B	C	R^2
1. Building Load							
1.1 Building Envelope							
AR absorptance of roof	8037	12	0.999	–	–	–	–
AW absorptance of wall	7874	249	0.999	–	–	–	–
EG egg-crate shading	Decay curve						
FN side-fins projection ratio	Decay curve						
OV overhang projection ratio	Decay curve						
SC shading coeff. (windows)	7410	1674	0.998	–	–	–	–
SF skylight to roof ratio	8052	148	0.986	–	–	–	–
SS shading coeff. of skylight	8035	235	1.000	–	–	–	–
UF U-value of fenestration	–	–	–	8421	-102	6.2	0.999
UI U-value of inter. walls	Scattered pts.						
UR U-value of roof	8039	10	0.996	–	–	–	–
US U-value of skylight	8150	-4	0.937	–	–	–	–
UW U-value of opaque wall	7928	48	0.944	–	–	–	–
WR window-to-wall ratio	7678	855	0.994	–	–	–	–
1.2 Building Configuration							
AS aspect ratio of plan	Dip curve at AS=1.5						
FH floor-to-floor height	7479.7	168	0.998	–	–	–	–
NS number of storeys	3.3	201	1.000	–	–	–	–
PZ perimeter zone depth	–	–	–	8208	-61	5.3	0.938
1.3 Space Load & Space Conditions							
AT space air temp.	8596.9	-22	0.999	–	–	–	–
EQ equipment load	5975.3	138	1.000	–	–	–	–
IF infiltration rate	8078	-65	0.987	–	–	–	–
LL lighting load	4605.6	172	1.000	–	–	–	–
OC occupant density	6383	6123	1.000	Inverse (m^2/psn) is regrd.			
1.4 Building Thermal Mass							
FW floor weight	8173.4	0	0.997	–	–	–	–
RW roof weight	Scattered pts.						
WW wall weight	Scattered pts.						
2. HVAC System							
2.1 System Operation							
OA outdoor air flow rate	7472.7	83	0.994	–	–	–	–
2.2 System Controls							
QR min. cfm ratio	–	–	–	7874	293	951.6	1.000
RD reheat delta temp.	Sharp rising curve						
TR throttling range	–	–	–	8072	-26	3.9	0.987
TS thermo. setpt. (summer)	–	–	–	23235	-958	14.3	0.996
TW thermo. setpt. (winter)	Sharp dropping curve						
2.3 Fan							
FE fan efficiency	6825.1	672	1.000	Inverse of FE is regrd.			
FS fan static pressure	6812.3	1	1.000	–	–	–	–
3. HVAC Refrigeration Plant							
3.1 Chilled Water Circuit							
CH chw. supply temp.	–	–	–	10495	-577	31.5	1.000
CR chw. throttling range	8070.9	-18	0.995	8075	-25	2.3	1.000
DT chw. design delta temp.				8628	159	9.6	1.000
3.2 Chilled Water Pump							
PE pump motor eff.	8265.5	-245	0.997	8478	-733	279.0	1.000
PH pump head	7776.1	13	1.000	–	–	–	–
PI pump impeller eff.	–	–	–	8615	-1122	493.8	1.000
PL fraction of pump loss	7988.2	5636	1.000	–	–	–	–
3.3 Refrig. & Heat Rejection							
CP chiller COP	5144.6	2417	1.000	–	–	–	–
HG hot gas bypass PLR	Sharp rising curve						
MA min. entering air temp.	Sharp rising curve						
NC number of chillers	7940.7	679	0.969	8717	-184	11.3	0.975
PC ratio of cond. fan elec. power to chiller cap.	7747.9	9894	1.000	–	–	–	–

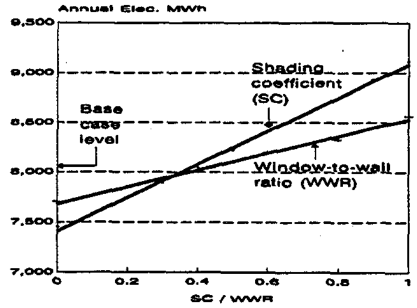

Figure 7. Effects of Shading Coefficient (SC) and Window-to-wall Ratio (WWR) on Building Energy Consumption

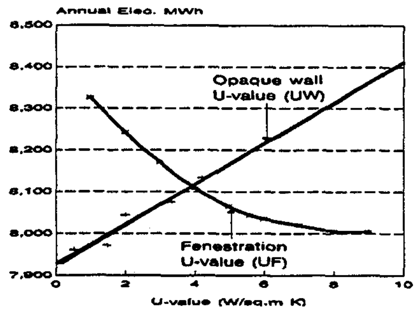

Figure 8. Effects of Envelope U-values on Building Energy Consumption

As shown in Figure 9 in below, the summer thermostat setpoint vs annual MWh may be fitted by a flat quadratic curve, going downward. That means energy might be saved by adjusting thermostat temperature to the upper comfort limit in summer. Also, the benefit of increasing the number of multiple chillers, as indicated in Figure 10, diminishes as the total chiller number reaches about six or seven. Other interesting results can be observed from the relationships so obtained from the simulation results.

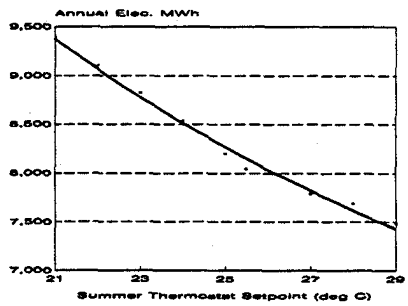

Figure 9. Effects of Summer Thermostat Setpoint on Building Energy Consumption

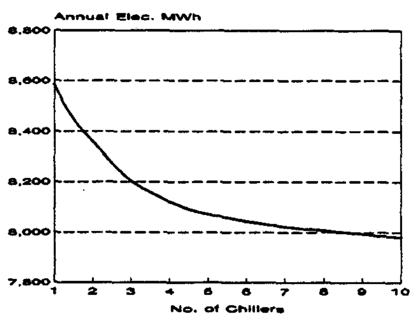

Figure 10. Effects of Number of Chillers on Building Energy Consumption

DISCUSSION

In Hong Kong, building stocks account for about half of the total energy consumption. There is growing concern about their effectiveness in energy use and its implications for the environment. Despite having one of the world's fastest building development programmes, there are no specific standards to promote energy efficiency in the design and operation of buildings. Attempts to study energy efficiency in buildings are often hindered by the complexity involved and the lack of reliable performance assessment tools and techniques. Urgent needs now in Hong Kong are to establish energy conservation guidelines and to promote R&DD (research & development plus demonstration) works for fortifying the technical basis in building energy technology.

Building energy simulation methods offer a powerful and flexible tool to energy conservation programmes. When coordinated with energy surveys and building data monitoring, computer modelling techniques can provide a valuable instrument for energy analysis and demand-side management. Putting these techniques into practice under the respective local context, a perspective view of the value of building performance simulation can be examined.

CONCLUSION

Computer simulations of energy performance for a generic commercial building in Hong Kong have been carried out. It has been found that cooling requirements account for more than half of the total energy consumption in the building. Results from the regression analysis suggested that most parameters related to building load (e.g. WWR and SC) vary linearly with the total building energy consumption, whereas parameters related to HVAC systems and plants can be fitted by quadratic equations.

The emergence and development of computer-based energy simulation methods have presented unique opportunities and problems to building energy analysts. The methods have distinctive requirements, properties and limitations. With the quest for higher building energy efficiency, it is envisaged that energy simulation techniques will come into more widely used in the design process by the building professionals. It should be noted that energy modelling in buildings is extremely complex and is subject to errors and misinterpretation. Its real value and usefulness depend on an insight to the energy modelling process and a rigorous quality control for the simulation procedures.

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REFERENCES

Acrosoft International Inc. 1990. "Micro-DOE2 User's Guide: Version 2.1D (Extended DOS)." Denver, CO (Jan.).

Birdsall, B.; W. F. Buhl; K. L. Ellington; A. E. Erdem; and F. C. Winkelmann. 1990. "Overview of the DOE-2 Building Energy Analysis Program: Version 2.1D." LBL-19735 Rev. 1. Simulation Research Group, Lawrence Berkeley Laboratory, University of California, Berkeley, CA (Feb.).

BLAST Support Office. 1991. "BLAST User Reference." Volume 1 & 2. Department of Mechanical & Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, IL.

Census and Statistics Department. 1992. "Hong Kong Annual Digest of Statistics." (Published annually). Government Printer, Hong Kong.

Clarke, J. A. 1985. *Energy Simulation in Building Design*. Adam Hilger, Bristol.

Diamond, S. C.; B. D. Hunn; and C. C. Cappiello. 1985. "The DOE-2 Validation." *ASHRAE Journal*, Vol. 27, No. 11 (Nov.), 25-32.

Gale C. Corson Engineering. 1990. *A Comparative Evaluation of Commercial Building Energy Simulation Software*. Bonneville Power Administration, OR (May).

Goodsall, C. J. and J. C. Lam. 1992. "Energy Efficiency in Buildings in Hong Kong: a Survey of Existing Construction." Research Report BC/91/02. Department of Building & Construction, City Polytechnic of Hong Kong, (May).

Hui, S. C. M. and J. C. Lam. 1992. "Test Reference Year for Comparative Energy Study." *The Hong Kong Engineer*, Vol. 20, No. 2 (Feb.), 13-16.

LBL. 1981. "DOE-2 Reference Manual (Version 2.1A)." Part 1 & 2. LBL-8706 Rev. 2. Los Alamos National Laboratory, Los Alamos, NM (May). (distributed by NTIS).

Spitler, J. D.; D. E. Fisher; and D. C. Zietlow. 1989. "A Primer on the Use of Influence Coefficients in Building Simulation." In *Proceedings of the IBPSA Building Simulation '89 Conference* (Vancouver, 23-24 June 1989). IBPSA, 299-304.

Stoecker, W. F. 1989. *Design of Thermal Systems*. Third Edition. McGraw-Hill, New York, Chp. 14.

Sullivan, R.; S. Nozari; R. Johnson; and S. Selkowitz. 1985. "Commercial Building Energy Performance Analysis Using Multiple Regression." *ASHRAE Transactions*, Vol. 91 Pt. 2A, 337-353.

Yip, P. C. and S. C. M. Hui. 1991. "Selection of Heat Rejection Methods for Air Conditioning Systems in Hong Kong." In *Proceedings of the CIBSE National Conference 1991* (University of Kent, Canterbury, 7-9 April 1991). CIBSE, U. K., 73-