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Regression analysis of high-rise fully air-conditioned office buildings

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Abstract

The building energy simulation computer program DOE-2 was used to carry out a parametric study of a generic high-rise air-conditioned office building in Hong Kong. A total of 28 design parameters related to the building load, the heating, ventilating and air-conditioning (HVAC) system and the HVAC refrigeration plant were found to correlate well with the predicted annual electricity consumption. Both linear and non-linear multiple regression techniques were used to develop regression models and energy equations for the prediction of annual electricity use. Twelve input design parameters (six from building load, four from HVAC system and two from HVAC refrigeration plant) were considered to be the most significant design variables and were used in the energy prediction equations. It is hoped that the resulting models and energy equations can be used as a simplified design tool for comparing the relative thermal and energy performance of different design schemes during the early design stage. This paper presents the methodology and the development work, and discusses the findings.

Keywords: Regression analysis; Energy equations; Randomized inputs

1. Introduction

Energy and the environment are the key issues that professions have to address in any building development project these days. In Hong Kong, there has been a marked increase in energy consumption in buildings, particularly commercial buildings [1,2], due mainly to the rapid economic growth and the shift of the local economy from manufacturing-based to service-oriented (e.g. banking, finance, etc.). Most of the industrial business has moved north into mainland China where both the labour costs and property prices are much lower. Electricity consumption in the commercial sector in Hong Kong rose at an average annual rate of 10% during the 25-year period from 1970 to 1994.

There has been increasing pressure on architects and engineers to design more energy-efficient buildings and building services systems such as lighting and air conditioning. Among the building professions, it is generally accepted that computer energy analysis techniques are valuable design tools for the design and analysis of buildings and building services installations, particularly for large office buildings. Examples of some hourly computer simulation packages that have gradually been introduced into the architectural and building engineering practices are BLAST [3], DOE-2 [4] and TRACE [5]. Discussions with architects and engineers, however, have revealed that most practitioners consider computer energy analysis techniques too complicated, time-consuming and costly. There is a need for some simplified approaches, particularly during the initial conceptual design stage when different building design schemes are being considered. This paper presents the work on the development of regression models and energy equations for the prediction of energy performance of large fully air-conditioned office buildings using single and multiple regression techniques. It is envisaged that the resulting models and energy equations could be used by architects and engineers as a simplified design tool for comparing the relative thermal and energy performance of different design schemes during the early design stage.

2. Methodology

2.1. Generic office building and parametric study

One of the important factors in developing energy models for buildings is an intimate knowledge and a good understanding of the physical and operational characteristics of the building to be modelled. A generic office building was developed to serve as a baseline reference for comparative energy studies. A survey of the existing commercial buildings in Hong Kong was conducted to find out the design character-

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Table 1
Summary of base case values and perturbations for building load

Abb.	Input parameter	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 $W/m^2.K$	10	1	9
UI	U-value of inter. walls	2.513 $W/m^2.K$	4	0.49	3.149
UR	U-value of roof	0.539 $W/m^2.K$	5	0.426	2.147
US	U-value of skylight	N/A	10	1	9
UW	U-value opaque wall	2.005 $W/m^2.K$	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 and space conditions					
AT	Space air temp.	25.5°C	6	21	29
EQ	Equipment load	15 W/m^2	6	5	25
IF	Infiltration rate	0.6 ach	6	0	2
LL	Lighting load	20 W/m^2	6	10	30
LT	Lighting type	Rec-F-NV	4	4 lighting types	
OC	Occupant density	3.68 psn/m^2	6	2	10
1.4 Building thermal mass					
FT	Furniture type	Heavy	2	Heavy and light	
FW	Floor weight	342 kg/m^2	11	146	634
RW	Roof weight	496.1 kg/m^2	5	483.1	502.6
WW	Wall weight	25.2 kg/m^2	6	25.2	794.9

istics common to most commercial buildings in Hong Kong [6]. Descriptions of a generic base case model building were then established for use in the building energy simulations. The base case reference building developed was a 40-storey office building (35×35 m) with curtain-wall design and a centralized heating, ventilating and air-conditioning (HVAC) system. The floor-to-floor and window heights were 3.4 and 1.5 m, respectively. This represents a window-to-wall ratio (WR) of 44%. The air-conditioning design is a variable air volume system with terminal reheat. The building and the HVAC plant operate on a 10-h day (08:00 to 18:00) and a 5 1/2-d week basis. Tables 1 and 2 show the data for the input design parameters used for the base case for the building load and the HVAC system/refrigeration plant, respectively. Further details can be found in Refs. [7,8].

The 8760 measured hourly weather data for 1989 were used for this study. The year 1989 is considered the test reference year (TRY), in that it represents the prevailing weather conditions regarding comparative energy study in Hong Kong [9]. The simulation tool employed in the present study is the DOE-2.1E building energy simulation computer program from the Lawrence Berkeley Laboratory [4]. Simulation was carried out based on the generic office building with basic design features commonly found in office buildings in Hong Kong. The base case reference building design input parameters were then varied over chosen intervals. The aim of the parametric analysis was to assess the influence of each input parameter to the annual electricity consumption, enabling the important and critical characteristics of the influence of the input parameters to be identified. The input parameters for the computer simulation were categorized into three major groups—building load, HVAC system and HVAC refrigeration plant, as shown in Tables 1 and 2. Sixty-two design parameters were considered, 29 for the building

Table 2
Summary of base case values and perturbations for HVAC systems and plant

Abb.	Input parameter	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 h/d	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 Refrigeration and heat rejection					
CP	Chiller COP	1.2kW/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	

envelope, 17 for the HVAC system and 16 for the HVAC refrigeration plant. A total of 387 computer simulations were performed.

2.2. Regression-based techniques

Regression analysis is a statistical technique used to relate variables. The basic objective is to build a regression model relating a dependent variable to independent variables. Regression techniques have been used for studying the effects of various parameters on building energy performance [10,11] and for developing simplified equations for building energy standards [12]. By varying the input variables for the base case reference building, a large number of simulations are run to generate data for deriving algebraic expressions relating building performance to design parameters [13].

First of all, the regression procedure was conducted for the 62 input parameters in the single-parameter study to identify the principal form of relationships. A total of 28 input parameters were found to correlate well with the annual electricity consumption (AEC). Sensitivity analysis techniques were then used to select the most significant design variables. Twelve input parameters (six from the building load, four from the HVAC system and two from the HVAC refrigeration plant) were selected. Multiple linear regression analysis was conducted to derive simple prediction equations of the AEC for each of the three groups using their respective selected input parameters. A general form of energy prediction equation was then developed, which included all the 12 parameters from all three groups. To test the effectiveness of the models and to assess the relative importance of the parameters, test cases using randomized input were generated. A method was proposed which used randomized inputs to generate data for developing regression models. This reduced the number of simulations required for data generation during regression analysis of a large number of variables.

Linear regression techniques using the statistics package SPSS [14] were used for the single and multiple regression analysis. Non-linear regression techniques were used for developing the energy prediction equations for cross-parameter models which involve the multiplication of different groups of variables [15]. The statistical methods use the least-square approach to find the best fit to the data and the 'goodness of fit' of the model is measured by the coefficient of determination (R^2), which is equal to unity if a perfect fit is found. The standard error, which is the standard deviation of the residuals of the regression model, can also be used to draw statistical inference about the model performance.

3. Regression models

The annual building energy consumption (electricity) in MWh was used as the objective function for the regression analysis. Most of the air-conditioned office buildings in Hong Kong use only electrical energy.

3.1. Single-parameter analysis

Before carrying out the regression analysis, it is important to decide what input design parameters are to be studied and to understand the implications. Regression techniques were applied to correlate the annual electricity consumption with the 62 input design parameters in the parametric study men-

Table 3
Summary of regression relationships for annual electrcity use in MWh

Abb.	Parameter	Unit	Linear regression $y=c+mx$			Quadratic regression $y=A+Bx+Cx^2$			
			c	m	R^2	A	B	C	R^2
1. Building load									
AR	Absorptance of roof		8037	12	0.999				
AW	Absorptance of wall		7874	249	0.999				
SC	Shading coeff.		7410	1674	0.998				
UF	U-value of window	W/m^2 K				8421	−102	6.2	0.999
UR	U-value of roof	W/m^2 K	8039	10	0.996				
UW	U-value of wall	W/m^2 K	7928	48	0.944				
WR	Wind.-to-wall ratio		7678	855	0.994				
FH	Floor-to-floor height	m	7480	168	0.998				
PZ	Perimeter zone depth	m				8208	−6.1	5.3	0.938
AT	Space air temp.	°C	8597	−22	0.999				
EQ	Equipment load	W/m^2	5975	138	1.000				
IF	Infiltration	ach	8078	−65	0.987				
LL	Lighting load	W/m^2	4606	172	1.000				
OC	Occup. density	psn/m^2	6383	6123	1.000				
2. HVAC system									
OA	Outdoor air flow	l/s/psn	7473	83	0.994				
QR	Min. cfm ratio					7874	293	952	1.000
TR	Throttling range	°C				8072	−2.6	3.9	0.987
TS	Therm. setpt. cooling	°C				23235	−958	14.3	0.996
FE	Inv. of fan efficiency		6825	672	1.000				
FS	Fan static pressure	Pa	6812	0.9	1.000				
3. HVAC refrigeration plant									
CH	Chw. supply temp.	°C				10495	−577	31.5	1.000
CR	Chw. thrott. range	°C	8071	−18	0.995	8075	−25	2.3	1.000
DT	Chw. design delta	°C				8628	159	9.6	1.000
PE	Chw. pump mot. eff.		8266	−245	0.997	8478	−733	279	1.000
PH	Chw. pump head	Pa	7776	13	1.000				
PI	Chw. pump imp. eff.					8615	−1122	494	1.000
CP	Inv. of Chiller COP		5145	8489	1.000				
NC	Number of chillers	nos.	7941	679	0.969	8717	−184	11.3	0.975

y = annual electricity use in MWh
x = input design parameter

tioned earlier. Since electricity use varies inversely proportional to some parameters (such as fan efficiency and chiller coefficient of performance), the inverses of these parameters were used in the regression analysis. Table 3 gives a summary of the relationships found for the DOE-2 simulations and the subsequent regression analysis. The regression coefficients and the R^2 values are shown for the 28 parameters which correlate well with the energy consumption MWh by either a linear or a quadratic relationship or both. All the R^2 values exceed 0.9. The results suggest that linear regression models provide a good fit between many of the building load parameters and the annual consumption, whereas many parameters of the HVAC system and plant can be fitted by quadratic equations.

3.2. Multiple regression models

Sensitivity analysis was conducted on the 28 parameters. Twelve input design parameters (six from building load, four from HVAC system and two from HVAC refrigeration plant) were found have high sensitivity coefficients, indicating that the annual energy consumption was most sensitive to the changes in these 12 design variables [8]. These 12 parameters were considered in the detailed analysis using multiple regression method. Table 4 gives the perturbation values of the parameters used for the simulations. Values for the annual MWh were extracted from the simulation results and submitted to the SPSS statistics package [14] for conducting the multiple regression analysis.

In order to get a better regression fit, it was found necessary to transform some of the parameters (such as inverse) and add new variables into the equation by combining two parameters (e.g. a product term of two parameters). Several different forms of regression models were tested by adding the product term one by one. The final regression models were selected based on a balance between accuracy (in terms of R^2 values and standard errors) and the ease of use (in terms of simplicity).

The modelled regression equations are as follows:

Building Load

$$\mathrm{AEC}=1414+4407\mathrm{SC}\times\mathrm{WR}-27\mathrm{AT}+142\mathrm{EQ}+182\mathrm{LL}+7414\mathrm{OC} \quad (1)$$

(AEC = Annual Electricity Consumption in MWh, $R^2=0.9915$, standard error = 4.0%)

HVAC System

$$\mathrm{AEC}=5188+542\mathrm{OA}+2858\mathrm{FE}+4\mathrm{FS}+0.000427\mathrm{FS}\times\mathrm{FS}+4.62\mathrm{TS}\times\mathrm{TS}-18\mathrm{OA}\times\mathrm{TS}-113\mathrm{TS}\times\mathrm{FE}-0.23\mathrm{TS}\times\mathrm{FS}+0.731\mathrm{FS}\times\mathrm{FE} \quad (2)$$

($R^2=0.9674$, standard error = 9.9%)

HVAC Refrigeration Plant

$$\mathrm{AEC}=6222-120\mathrm{CH}+9883\mathrm{CP} \quad (3)$$

($R^2=0.9897$, standard error = 2.0%)

Table 4
Perturbation values for multiple regression analysis

Building load	SC	WR	AT (°C)	EQ (W/m²)	LL (W/m²)	OC (psn/m²)
($3^6=729$ runs)	0.1	0.1	21	0	0	1
	0.55	0.5	25.5	15	15	5.5
	1.0	0.9	30	30	30	10
HVAC system	OA (l/s/psn)	TS (°C)	FE	FS (Pa)		
($4^4=256$ runs)	2	21	0.1	0		
	8	24	0.4	1000		
	14	27	0.7	2000		
	20	30	1.0	3000		
HVAC refrig.plant:	CH (°C)	CP				
($4^2=16$ runs)	4	0.142				
	6	0.284				
	8	0.427				
	10	0.568				

Note: 1. SC = shading coefficient of windows; WR = window-to-wall ratio; AT = space air temperate; EQ = equipment load; LL = lighting load; OC = occupant density (in person/m²).
2. OA = outdoor air flow; TS = cooling thermostat setpoint; FE = inverse of fan efficiency; FS = supply fan static.
3. CH = chilled water supply temperature; CP = inverse of chiller coefficient of performance.

Details of the abbreviations and corresponding units for the 12 parameters in Eqs. (1) to (3) are the same as those given in Table 4. For parameters of building load (i.e. SC, WR, AT, EQ, LL and OC), it has been found that the term SC × WR has significant influence, in that the R^2 values are greatly improved by incorporating this term into the equation. The R^2 value calculated for the annual electricity consumption in MWh is 0.9915. For the parameters of the HVAC system (i.e. OA, TS, FE and FS) more product terms are needed to get a satisfactory fit for the regression equation and the fan efficiency (FE) is the most significant parameter. For the parameters of the HVAC refrigeration plant, the form of equation is quite simple, as there are only two parameters. Other parameters can either only give qualitative relationship or are not correlated at all. All the R^2 values are greater than 0.96, indicating that at least 96% of the variation in the annual electricity use resulting from changes in the 12 selected design parameters can be explained by the selected regression models.

3.3. Testing the regression models using randomized simulation input

To test the predictive power of the regression models, a method is proposed to generate a database using randomized input values for the parameters. The procedures for generating the randomized input data and subsequent analysis involve the following steps:

(a) Select the parameters to be studied.

(b) Determine the range of variations of each parameter.

(c) Establish the values of the parameters in the simulation input file by a random-number generator, the values should be within the ranges.

(d) Establish random input files, submit them to DOE-2 for simulations and obtain the simulated annual electricity consumption.

(e) Using the regression equation concerned, calculate the predicted annual electricity consumption of each set of the input design parameters.

(f) Compare the DOE-2 simulated results with those predicted by the regression models.

Tests have been performed for the 12 parameters used in the regression models. Twenty random simulation runs were performed for each of the three groups (i.e. building load, HVAC system and HVAC refrigeration plant) to generate the test data. Figs. 1–3 show the comparisons of the MWh predictions for the load, system and plant models, respectively. It can be seen that the regression models are quite good in predicting the electrical energy consumption for the 20 sets of randomized data. To assess the accuracy of the regression

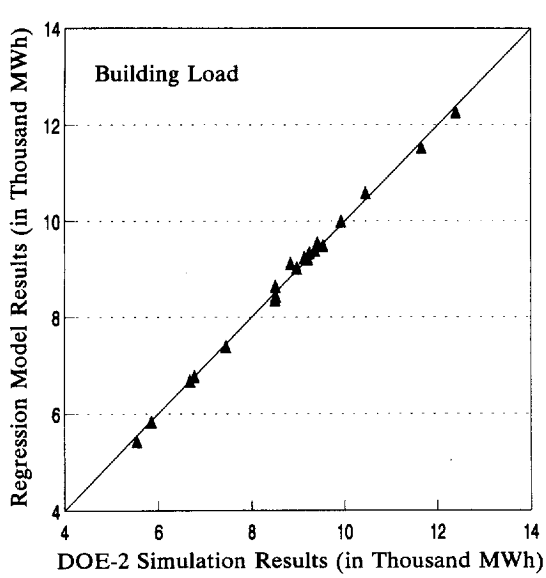

Fig. 1. Comparisons of annual electricity consumption from DOE-2 simulation and those from regression model (building load).

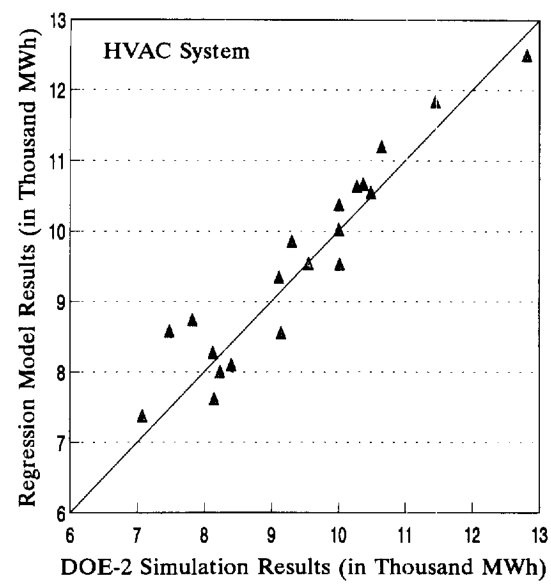

Fig. 2. Comparisons of annual electricity consumption from DOE-2 simulation and those from regression model (HVAC system).

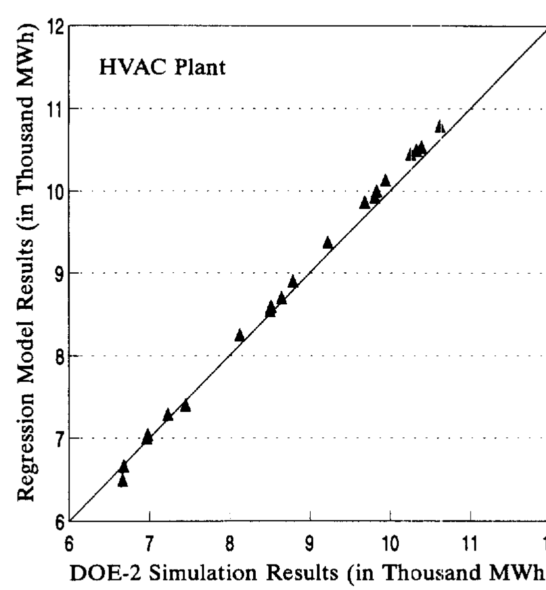

Fig. 3. Comparisons of annual electricity consumption from DOE-2 simulation and those from regression model (HVAC refrigeration plant).

models as compared with the DOE-2 simulation results, mean bias errors (*MBE*s) and root-mean-square errors (*RMSE*)s were calculated as follows:

$$MBE = \frac{\sum_{i=1}^{20} (y_{R,i} - y_{DOE,i})}{20} \quad (4)$$

$$RMSE = \left[\frac{\sum_{i=1}^{20} (y_{R,i} - y_{DOE,i})^2}{20} \right]^{1/2} \quad (5)$$

where $y_{R,i}$ = annual electricity consumption (in MWh) from the regression model and $y_{DOE,i}$ = annual electricity consumption (in MWh) from the DOE-2 simulation.

The calculated *MBE*s for the building load, the HVAC system and the HVAC plant models are 14.8, 141.7 and 90.3 MWh, respectively. These represent 0.2, 1.5 and 1% of their corresponding mean simulated annual electricity consumption. The *RMSE*s for the building load, HVAC system and HVAC plant models are 107.7, 471.3 and 127.1 MWh, respectively, representing 1.2, 5 and 1.5% of the mean annual electricity consumption from the DOE-2 simulation. All the *MBE*s are positive, indicating that the regression modelled equations tend to overestimate the annual electricity consumption. The HVAC system has the largest *RMSE*, indicating more scattered data compared with either the building load or the HVAC plant (see also Figs. 1 to 3).

4. The development of energy equations

If the regression equations are extended to include all the design parameters, a set of energy equations can be developed to provide an effective means for analysing building energy performance, particularly during the initial design stage when different design schemes and concepts are being considered.

4.1. Forms of equation

If the parameters of load, system and plant are considered as three group functions, the general form of the energy equation can be expressed as follows:

$$E = Function[(Load), (System), (Plant)] \quad (6)$$

where E = energy or load index, such as annual MWh and peak kW, $Load = f$ (envelope, internal loads, etc.), such as f (SC,WR,AT,EQ,LL,OC), $System = g$ (system operations, controls, fans), such as g (OA,TS,FE,FS), $Plant = h$ (chilled water circuit, refrigeration plant), such as h (CH, CP)

Two simple forms were used to develop energy equations incorporating parameters belonging to different groups. These are the addition and the multiplication functions as follows:

$$E = constant + (Load) + (System) + (Plant) \quad (7)$$

$$E = (Load) \times (System) \times (Plant) \quad (8)$$

The addition function (Eq. (7)) can be established using multiple regression as described in the Section 3.2. The multiplication function (Eq. (8)), however, needs non-linear regression techniques to develop the prediction equation. The non-linear regression procedure in the statistical software solves the regression problem by iteration [15].

4.2. Generate database for regression using randomized inputs

When the number of parameters is large, a large number of simulations have to be carried out to generate data input for the regression analysis. The total number of simulations for all the combinations of the perturbations of the input parameters may be unacceptably large. For instance, if there are 12 parameters and each of them has 3 perturbation values, then the total number of simulations required for all the combinations will be equal to 3^{12} (i.e. 531 441) simulations. To overcome this, randomized simulation inputs for the parameters were adopted so that a manageable number of simulations could be run to generate the database for the regression analysis.

The process is similar to the randomized testing mentioned in Section 3.3. It is believed that the number of simulations required depends on the number and the properties of the parameters involved. Generally speaking, as the number of simulations increases (more data point), the more representative the regression model will be. However, it is difficult to determine the minimum number required for every situation, unless a feedback mechanism can be installed in the simulation cycle to check for the necessity of including more cases. A feedback mechanism was not considered in the present work. Only the R^2 values of the regression analysis were monitored.

A total of 100 simulations were conducted to generate results for the linear (addition function) and non-linear (multiplication function) regression analysis. Since the primary concern is energy estimation using simple energy equations, only the annual electricity consumption was considered. The energy equations incorporating the 12 design parameters developed from the regression analysis are as follows:

Addition Form

$$\begin{aligned} AEC = & -4107 + (4757SC \times WR - 20.5AT + 166EQ \\ & + 223LL + 9120OC) + (-415OA + 4315FE \\ & + 6.79FS + 0.000672FS \times FS + 2.26TS \times TS \\ & + 0.000672FS \times FS + 2.26TS \times TS + 18.9OA \\ & \times TS - 193TS \times FE - 0.367TS \times FS \\ & + 1.09FS \times FE) \times (-304CH + 13680CP) \end{aligned} \quad (9)$$

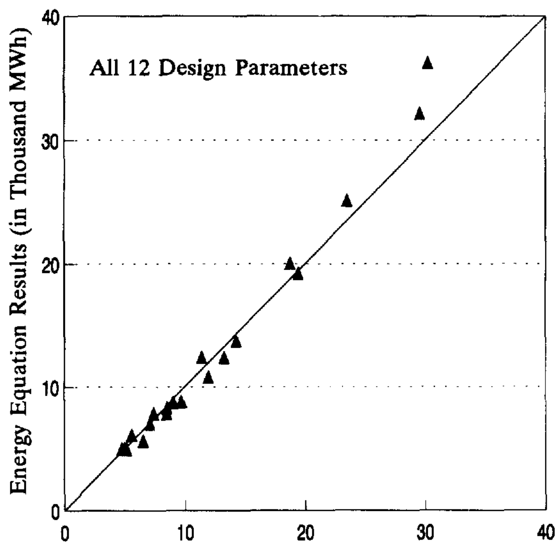

Fig. 4. Comparisons of annual electricity consumption from DOE-2 simulation and those from the multiplication energy equation.

Multiplication Form

$$AEC = (-1.38 - 7.3SC \times WR - 0.0151AT - 0.167EQ - 0.206LL - 9.6OC) \times (-340 - 73.7OA - 412FE - 0.406FS - 0.0000384FS \times FS - 0.644TS \times TS + 2.49OA \times TS + 16.7TS \times FE + 0.0215TS \times FS - 0.0872FS \times FE) \times (0.508 - 0.0109CH + 1.093CP) \quad (10)$$

The R^2 values for the addition and multiplication energy equations are 0.9202 and 0.988, respectively, indicating that the latter is a more representative prediction equation for annual electricity consumption.

4.3. Testing the multiplication energy equation using randomized simulation input

Similar to the testing of accuracy for the multiple regression models described in Section 3.3, 20 randomized input design parameters were generated for DOE-2 simulations. The simulated results were then analysed and compared with those predicted by the multiplication energy equation (i.e. Eq. (10)) using the same input design parameters. It can be seen in Fig. 4 that the annual electricity consumption data predicted from the energy equation are close to those from the DOE-2 simulation. The *MBE* and *RMSE* are 382 and 1633 MWh, respectively, representing 3.1 and 13.1% of the mean simulated annual consumption. The relatively large *RMSE* of 13.1% is mainly due to the two extreme cases with large simulated annual electricity consumption of about 30 GWh. This represents a normalized energy performance index of 612 kWh per unit gross floor area per year. It is envisaged that most air-conditioned office buildings will have electricity consumption much lower than the 612 kWh/m^2 level. If these two cases are excluded, then the *MBE* and the *RMSE* are −52.8 and 731 MWh, respectively. These represent 0.6 and 7.8% of the mean simulated annual consumption.

5. Conclusions

The building energy simulation computer program DOE-2 was used to carry out a parametric study of a generic high-rise air-conditioned office building in Hong Kong. A total of 387 computer simulations were conducted. Regression analysis was carried out to correlate the annual energy consumption with the 62 input design parameters used in the computer simulations. Out of the 62 input parameters, 28 design variables related to the building load, the heating, ventilating and air-conditioning (HVAC) system and the HVAC refrigeration plant were found to correlate well with the predicted annual electricity consumption. Sensitivity analysis was conducted on the 28 parameters. Twelve input design parameters (six from building load, four from HVAC system and two from HVAC refrigeration plant) were found have high sensitivity coefficients, indicating that the annual energy consumption was most sensitive to the changes in these 12 design variables. Multiple regression method was then used to develop an energy equation in multiplication form, which correlate the annual energy consumption with the 12 most significant design parameters. The mean bias error and the root-mean-square error are 0.6 and 7.8% of the mean simulated annual energy consumption.

The regression analyses in this study demonstrate the benefits and potentials of an approach to expressing building energy performance in terms of a number of design variables which will be considered critical at the early design stage. What has been suggested is a simplified and flexible method which can offer the possibility of developing equations and criteria for the assessment of the energy performance of the building and the building services systems. It is believed that the modelled regression equations for the building load, the HVAC system and the HVAC plant, and the developed energy equation can be used to compare the thermal and energy performance of different design schemes. This will be particularly useful to the architects and engineers during the initial design stage when different design schemes and concepts are being considered. Although the work has been conducted for a generic office building in Hong Kong, it is believed that the methodology, techniques and procedures developed here can be applied to other locations, particularly those with similar climate and building development in southern China.

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