Development of Load Prediction Equations of Office Buildings

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Key words: Design parameters, Multiple regression analysis, Load prediction equations

Abstract

The objective of this study is to evaluate the design parameters and to develop the cooling and heating load prediction equations of office buildings. The building load calculation simulation was carried out using the DOE-2.1E program. The results of the simulation were used as data for multiple regression analysis which could develop the load prediction equations.

1. Introduction

The energy-conscious building design is a consecutive decision-making process. During the early design stages, the main effort of architect is to determine the geometry of the building, such as mass, orientation, plan, window-to-wall area ratio, etc. The simulation analysis is possible at the final design stages, however energy simulation tools require detailed information for the unknown building at the early design stages. In most cases, architects use only the coarse rules of thumb as the energy-conscious building design guidelines at the early design stages. On the contrary, the main shortcoming of using accurate simulations only at the final design stages is that major drawbacks of the design cannot be corrected anymore.

Therefore, this study aims to develop the cooling and heating load prediction equations which can help architects to design the energy-conscious building.

The simulations for cooling and heating load calculations were undertaken by the DOE-2 building energy analysis program and a database was established using the simulation results. The systems of experimental design were used to decrease the number of simulations.

A multiple regression analysis was performed to evaluate the relative importance of each design parameter affecting the thermal performance of the buildings and to develop the load prediction equations.

2. Energy-related design parameters

An energy-conscious decision-making process includes the choice, coordination and assignment of appropriate values of many design parameters. The process is complicated by the high degree of interdependencies between various design parameters, because the choice of one design parameter influences the recommended range for the others. This process might be simplified if we knew which para-

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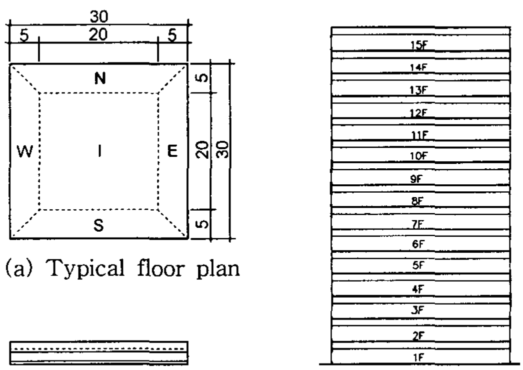
Table 1 Energy-related design parameters

	Design parameters	Evaluation elements
Sizing	Total floor area Number of floors	Total floor area Number of floors
Shape	Shape of buildings	S/V ratio Aspect ratio
Layout	Orientation	Orientation
Plan	Typical floor type Space planning	Core type Internal load density
Elevation & Section	Ceiling height Window/Wall area Overhangs Daylighting	Ceiling height Window-to-wall ratio Projection factor Lighting control(Auto)
Details	Wall - materials - layer - thickness Window - type	 Heat transmittance Insulation position Heat capacity Heat transmittance Shading coefficient

meters have significant influence on the thermal performance of office buildings. Table 1 shows the various energy-related design parameters should be considered.

3. Presenting the simulation model

The simulation model based on building data and SBOC (Standard Building Operating Conditions) was used to analyze the relative importance of the various design parameters and to develop the load prediction equations.



(a) Typical floor plan

(b) Elevation

(c) Section

Fig. 1 Typical floor plan, elevation and section of simulation model.

Table 2 Simulation model summary

Design parameters	Conditions
Typical floor area	30×30 m (900 m^2)
Number of floors	15
Aspect ratio	1 : 1
Orientation	south
Internal load density	35 W/m^2
Ceiling height	2.6(3.8) m
Window-to-wall ratio	0.4
Projection factor	0
Daylighting	500 lux
Insulation thickness	65 mm
Insulation position	internal
K-value of window	3.26 $W/m^2 \cdot K$
Shading coefficient	0.6
Core type : center core	
Core area : 20% of typical floor area	

3.1 Building data

The simulation model is the intermediate floor of an office building shown in Fig. 1.

The intermediate floor model was partitioned into five distinct thermal zones: four perimeter zones and an interior zone. Four perimeter zones surround an interior zone of 400 m^2 floor area. Each perimeter zone is 30 m wide and 5 m deep, and each faced east, west, south and north.

Table 2 shows the condition of each design parameter for the simulation model.

3.2 SBOC (standard building operating conditions)

SBOC is one of the most important factors affecting the building energy consumption. Internal loads arising from occupants, lighting and equipment were scheduled according to the typical usage patterns for office buildings. Daytime working hours were from 9 am to 6 pm on weekdays and from 9 am to 1 pm on sa-

Table 3 HVAC operating conditions

	Heating	Cooling
Temperature	20℃	26℃
Humidity	35%	55%
Start date	1, November	11, June
End date	31, March	10, September
Operation start time	weekday 8 : 00 saturday 8 : 00	weekday 8 : 00 saturday 8 : 00
Operation stop time	weekday 18 : 00 saturday 13 : 00	weekday 18 : 00 saturday 13 : 00

turday. 80% of the lighting load was added to each zone as a sensible heat gain.

A simple constant air volume variable temperature HVAC system was adopted for determining coil loads in response to the parametric variations. CAV system which is one of the basic HVAC systems is generally adopted as the HVAC system of office buildings in Korea. Thermostat setpoints were 20℃ and 26℃ during occupied hours for winter and summer, respectively. On the other hand, these were 12℃ and 32℃ during unoccupied hours for winter and summer, respectively. Air infiltration rate was fixed at a value of 1.0 airchange per hour.

Table 3 shows the HVAC operation conditions for the simulation model.

4. Simulation description

DOE-2.1E building energy analysis program was used in conjunction with the simulation model to establish a database. The Systems of Experimental Design which is one of the statistical methods was applied to decrease the number of simulations.

4.1 Simulations by the systems of experimental design

To analyze the relative importance of each design parameter, simulations should be performed in each case when one parameter is changed within possible ranges at fixed other parameter values. Therefore, if 14 parameters in Table 4 are changed with three levels, the total number of simulations would be 3^{14} (=4,782,969). However, if the Systems of Experimental Design is applied, the number of simulations (3^{14}) is reduced to 81. The simulation results are almost similar to the results of full-set simulations.

Table 4 Design parameters and values

	Design parameters	Level 0	Level 1	Level 2
A	Typical floor area (m^2)	400	900	1600
B	Number of floors	5	15	25
C	Aspect ratio	1 : 1	1 : 1.5	1 : 2
D	Orientation	S	SE	E
E	Internal load density (W/m^2)	15	25	35
F	Ceiling height (m)	2.4	2.6	2.8
G	Window-to-wall ratio	0.2	0.4	0.6
H	Projection factor	0	0.25	0.5
I	Daylighting (lux)	-	300	500
J	Insulation thickness (mm)	65	80	100
K	Insulation position	int	mid	ext
L	Concrete thickness (mm)	100	150	200
M	K-value of window ($W/m^2 \cdot K$)	2.56	2.91	3.26
N	Shading coefficient	0.4	0.6	0.8

The Systems of Experimental Design was executed using the Tables of Orthogonal Arrays which makes it easy to design experiments. The 14 design parameters and their values with three levels are shown in Table 4.[3,7]

4.2 Development of database

The simulations for cooling and heating load calculations were undertaken by the DOE-2 building energy analysis program and a database was established based on the simulation results. Seoul weather data made by the SAREK (Society of Air-Conditioning and Refrigerating Engineers of Korea) was converted into TRY (Test Reference Year) format which is one of the DOE-2 weather data type.

5. Development of load prediction equations

Energy simulation tools are required to evaluate the thermal performance of the buildings and to provide more flexible building energy standards. So, the statistical correlations between the annual cooling and heating loads of buildings and the physical characteristics of the design parameters were developed.

These correlations (load prediction equations) are useful in providing architects with a valuable tool for energy-conscious building design. They can be used quickly and easily to evaluate the energy impact of various design approaches and envelope characteristics.

5.1 Regression model and variables

A multiple regression analysis is a statistical analysis procedure finding relationships between the variables using the Least Squares Method. The Least Squares Method is a technique used for defining the best fit to data sets by minimizing the distance between the data and the line.

One of the most important tasks in regression analysis is the selection of appropriate independent variables to be used in subsequently defining the dependent variable.

In most cases, it is desired that the selected variables have physical meaning as well as being useful predictors.

Table 5 shows the independent variables for multiple regression analysis.

(1) Basic variables : Basic design parameters affecting the thermal performance

(2) Physical variables : Load components (conduction and solar radiation through glazing and internal load) based on physical groupings of parameters

Table 5 Independent variables

Independent variables			Explanation
Basic variables	V1	A	Typical floor area
	V2	B	Number of floors
	V3	C	Aspect ratio
	V4	D	Orientation
	V6	E	Internal load density
	V7	F	Ceiling height
	V8	G	Window-to-wall ratio
	V9	H	Projection factor
	V10	I	Daylighting
	V14	J	Insulation thickness
	V15	K	Insulation position
	V16	L	Concrete thickness
	V17	M	K-value of window
	V18	N	Shading coefficient
Physical variables	V19	(1-G)×J/A	((1-Window-to-wall ratio)×Insulation thickness)/Typical floor area
	V20	G×M/A	(Window-to-wall ratio×K-value of window)/Typical floor area
	V21	G×N/A	(Window-to-wall ratio×Shading coefficient)/Typical floor area
Mathematical variables	V5	1/A	1/Typical floor area
	V11	AT/A	Typical floor surface area/Typical floor area
	V12	AT/(A×F)	Typical floor surface area/(Typical floor area×Ceiling height)
Auxiliary variable	V13	H×I	Projection factor×Daylighting

(3) Mathematical variables : New variables established mathematically using simple functions

(4) Auxiliary variables : New variables representing the interaction effect between parameters

A series of linear regressions was performed using the STEPWISE procedure in the SAS statistical analysis computer program. It can be regressed to optimize the predictive capability of the regression model using the independent variables V1 through V21, dependent variables CL for cooling load and HL for heating load.

The criterion used for the improvement of the prediction was the coefficient of determination (R^2). R^2 represents the square of the correlation between the predicted value and actual value. It is expressed as a decimal number between 0.00 and 1.00. Here 1.00 represents perfect prediction in the model. The most plausible form of the model determined by the regression analysis is a plot of a straight line. Consequently, the model can be represented by the combination of independent variables.

5.2 Load prediction equations by the multiple regression analysis

Finally, it can be regressed all the independent variables V1 through V21 using the STEPWISE procedure. Table 6 and equation (1) and (2) are the results of multiple regression analysis.

Table 6 shows that the cooling load prediction is more accurate than the heating load prediction. Architects must be attentive to window-to-wall area ratio, typical floor area, internal load density and the utilization of daylighting, shading coefficient and heat transmittance of window for the energy-conscious building design.

$$\begin{aligned}\text{Cooling Load (CL)} \\ &= -11.97 + 1.51\times V3 + 0.41\times V6 \\ &+ 3.10\times V7 + 15.22\times V8 \\ &- 3.93\times V10 - 2.02\times V17 \\ &+ 14.73\times V18 + 21515\times V21 \\ &[4.186\times MJ/m^2\cdot year]\end{aligned} \quad (1)$$

Table 6 Selected independent variables

Load	Step	Variables		Partial R-square	R square	Significant probability (Prob>F)
Cooling	1	V21	G×N/A	0.7232	0.7232	0.0001
	2	V6	E	0.1238	0.8471	0.0001
	3	V10	I	0.0366	0.8836	0.0001
	4	V18	N	0.0372	0.9209	0.0001
	5	V8	G	0.0498	0.9707	0.0001
	6	V3	C	0.0043	0.9749	0.0007
	7	V7	F	0.0029	0.9778	0.0028
	8	V17	M	0.0028	0.9806	0.0019
Heating	1	V5	1/A	0.5471	0.5471	0.0001
	2	V8	G	0.1867	0.7338	0.0001
	3	V10	I	0.0779	0.8117	0.0001
	4	V18	N	0.0484	0.8601	0.0001
	5	V17	M	0.0432	0.9033	0.0001
	6	V6	E	0.0180	0.9213	0.0001
	7	V7	F	0.0162	0.9375	0.0001
	8	V14	J	0.0044	0.9419	0.0225
	9	V19	(1-G)×J/A	0.0032	0.9451	0.0460

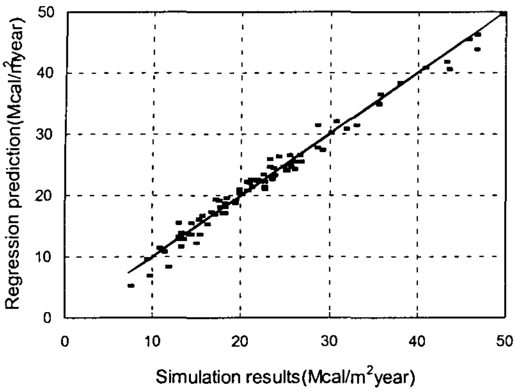


Fig. 2 Cooling load comparison.

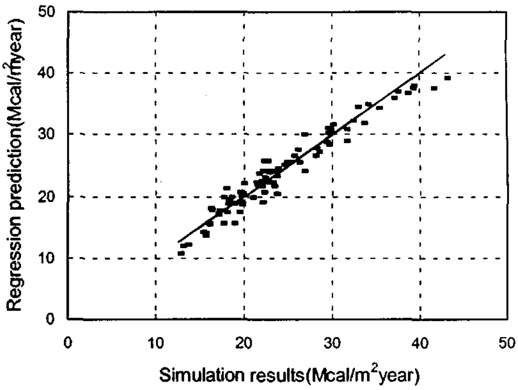


Fig. 3 Heating load comparison.

$$\begin{aligned} \text{Heating Load (CL)} &= -24.22 + 6517.75\times V5 + 0.12\times V6 \\ &+ 5.46\times V7 + 18.52\times V8 \\ &+ 4.14\times V10 + 6.00\times V14 \\ &+ 5.94\times V17 - 9.43\times V18 \\ &[4.186\times MJ/m^2\cdot year] \end{aligned} \quad (2)$$

where,
V3 : aspect ratio
V5 : 1/(typical floor area) $[m^{-2}]$
V6 : internal load density $[W/m^2]$
V7 : ceiling height [m]
V8 : window-to-wall ratio
V10 : daylighting
V14 : heat transmittance of wall $[4.186\times kJ/hm^2℃]$
V17 : heat transmittance of window $[4.186\times kJ/hm^2℃]$
V18 : shading coefficient
V21 : solar radiation load $(=V8\times V18/V1)$

5.3 Validation

Table 6 also shows that the coefficients of determination (R^2) were 0.98 for the cooling load prediction and 0.94 for the heating load prediction. Thus, it was proven that the regression model is appropriate.

A comparison of DOE-2.1E simulation results and the regression prediction is shown in Figs. 2 and 3.

6. Conclusions

This paper shows that annual cooling and heating load calculated by DOE-2.1E can be represented as a simple regression model. It can be used to evaluate the thermal performance of office buildings at the design stage.

The application of the model is subject to the following limitations. The database was not expanded to include the effects of varying the schedules of building operation, the effects of core types and the effects of the climate.

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