A Development of Heating and Cooling Load Prediction Equations for Office Buildings in Korea

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Abstract

The study intends to develop energy load prediction equations which can be easily used to estimate the energy consumption of office buildings in the central climatic zone in Korea during the early design stage. Based on an intensive literature search, energy strategies and performance levels which affect heating and cooling energy consumption were established for a reference baseline building. To analyze the sensitivity of each energy strategy to overall performance, the table of Orthogonal Array was used to decrease the number of experiments to 81 in spite of the fact that the required number for carrying out the simulation was $3^{24}$ ($= 282,429,536,481$). The computer simulation was performed using EnergyPlus. At the same time, the Analysis of Variance was conducted to estimate the relative importance of each energy factor. The results of the ANOVA were used as data for multiple regression analysis which could develop the load prediction equations. The proposed equation will provide architects with a simple and yet reliable tool to estimate the energy load of a building at the early design stage. At the same time, it will enable architects to develop the best design solution in terms of energy performance.

Keywords: energy consumption; design parameters; EnergyPlus; multiple regression; energy load prediction equation

1. Introduction

1.1 Background and Purpose of Study

Korea, the 9th largest CO$_2$ emitter in the world, is facing great pressure to reduce emissions in the Post-Kyoto negotiations. While the building sector contributes about 25% of CO$_2$ emissions, office buildings account for about 30% of total building stock in Korea. Therefore, it is of the utmost importance for Korea to reduce energy consumption in office buildings in order to meet its CO$_2$ emission reduction obligations.

Variations in the design and construction of office buildings are very small and limited relative to other building types. Therefore, once methods and technologies to reduce energy consumption are established, they can easily be disseminated, which will result in effective reduction of CO$_2$ emissions. However, design parameters for energy consumption reduction in office buildings are not fully established yet, and the selection criteria are insufficient due to lack of information regarding energy performance.

1.2 Method and Scope of Study

The study intends to develop energy load prediction equations which can easily estimate the energy consumption of office buildings in the central climatic zone in Korea during the early design stage. Although there have been a number of studies which developed simple load prediction models for office buildings and other building types, few equations have been updated on cutting-edge technologies and recent performance of parameters for office buildings in Korea. Based on intensive literature search, energy-related design parameters and performance levels which affect energy consumption were established for a baseline building. To analyze the sensitivity of each energy-related design parameter to overall performance, the table of Orthogonal Array was used to decrease the number of experiments to 81 in spite of the fact that the required number for carrying out the simulation was $3^{24}$ ($= 282,429,536,481$). Computer simulation was performed using EnergyPlus. At the same time, the Analysis of Variance was conducted to estimate the relative importance of each energy parameter. The results of the ANOVA were used as data for multiple regression analysis in developing the load prediction equations.
2. Energy-related Design Parameters and Applicable Performance Range Affecting Energy Consumption

2.1 Energy-related Design Parameters Affecting Energy Consumption

There are many design parameters that affect the energy consumption of office buildings at every stage. Based on intensive literature search, the number of parameters affecting the energy consumption of office buildings were narrowed down to 24. They include the gross floor area, numbers of stories, floor height, width/depth ratio, orientation, window/wall ratio (South, East, West, North), insulation performance of walls/roof/floors, window performance (U-value, SHGC (Solar Heat Gain Coefficient), VLT (Visual Light Transmittance), ventilation rate and dimming control (Table 1.). The window performance parameters including the thermal performance, solar heat gain, and visual light transmittance were considered. These parameters are related to architects' early design decisions and at the same time, are able to be defined in quantifiable objective values.

2.2 Applicable Ranges of Each Parameter

In order to analyze the relative importance of the chosen 24 parameters, the practically applicable ranges of each design parameter in the building have been set. These ranges are based on the investigated data which encompass performances from the minimum level regulated by the building code to commercialized cutting edge technologies. The ranges of each parameter can be found in Table 2.

3. Description of Baseline Building

The baseline building forms a very important part in the analysis because all the subsequent calculations and analysis are based on a comparison with it. A baseline building has been established from a survey of office buildings in Seoul. The characteristics of the baseline building were determined by careful examination of a typical design.

The majority of the office buildings in Korea, as seen in Fig.1., are of a basic module type consisting of a central building core. Fig.1. shows a simplified drawing of a model constructed for simulation. A brief description of the baseline reference building and characteristics of operation are given in Table 3.

4. Energy Simulation

4.1 Experimental Design

In order to determine the relative importance of each parameter on energy consumption, all other parameters should be fixed and one variable should be manipulated diversely to review how the results change. However, even if the twenty-four variables presented in Table 4. are changed on only three levels, as many as 3^{24} (= 282,429,536,481) simulations will be required, making the analysis almost impossible.

However, if an experimental design called Orthogonal Arrays is used, the same results from the calculation of an entire simulation can be induced by implementing a small number of simulations only. According to the Orthogonal Arrays, it is possible to reduce the number of simulations to 81 (L_81 [3^{4}]).

The total number of experiments conducted with the combination of variables was 81, and the conditions of
every case are depicted in Table 5. In each column (1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 15, 17, 18, 21, 23, 25, 27, 29, 32, 35, 38, 40) of orthogonal array (Table 5), 24 parameters are arranged as follows: 1 = SF Ratio; 2 = WWR (East); 3 = VLT (East); 4 = SHGC (West); 5 = WDR (%); 6 = VLT (South); 7 = Orientation; 9 = Gross Floor Area; 12 = Floor to Floor; 13 = Daylighting; 15 = SHGC (South); 17 = WWR (West); 18 = WWR (South); 21 = WWR (North); 23 = Surface U-factor (Roof), 25 = Surface U-factor (Wall), 27 = Surface U-factor (Ground Floor), 29 = Window U-factor (South); 32 = Window U-factor (East); 35 = Window U-factor (North); 38 = Window U-factor (West); 40 = SHGC (East). The rest of the columns are dummies.

4.2 Simulation Results

The simulations for cooling and heating load calculations were undertaken by using the EnergyPlus program and a database for the ANOVA was established based on the simulation results (Table 6.). Seoul weather data made by the KMA (Korea Meteorological Administration) were converted to TMY2 (Typical Meteorological Year version 2) format which is one of the EnergyPlus weather data types. There are three distinct climatic zones in

| Category                  | Factors          | Value          |
|---------------------------|------------------|----------------|
| Climate Site              | Climate Data     | Seoul (TMY2)   |
| Heating/                    | Heating          | 1/1-3/15,      |
| Cooling Period             | Cooling          | 3/15-10/31     |
| Building                   | Floor Area       | 40,000m²       |
|                           | Ceiling height   | 2700mm         |
|                           | Plenum Height    | 1400mm         |
| *WDR (%)                  | 1:1              |
| *WWR (%)                  | 40%              |
| Wall                      | 2.48W/m²K       |
| Window U-Value             | 2.1W/m²K        |
| SHGC                      | 0.2              |

Table 3. Brief Description of Baseline Model

| Parameters | Performance Level |
|------------|-------------------|
| A          | 0                 |
| B          | 1                 |
| C          | 2                 |

Table 4. Performance Levels of the 24 Parameters for Orthogonal Arrays

| A            | Gross Floor Area (m²) | 30,000 | 40,000 | 50,000 |
|--------------|-----------------------|--------|--------|--------|
| B            | SF Ratio              | 0.07   | 0.11   | 0.14   |
| C            | Floor to Floor        | 3.7m   | 4.1m   | 4.4m   |
| D            | WDR (%) (Width-Depth) | 1:1    | 1:2    | 1:1.5  |
| E            | Orientation           | S      | E      | SE     |
| F            | WWR (%)               | E      | 20     | 40     | 60     |
| G            | W                      | W      | 20     | 40     | 60     |
| H            | S                      | S      | 20     | 40     | 60     |
| I            | N                      | N      | 20     | 40     | 60     |
| J            | Roof U-factor         | 0.56   | 0.25   | 0.15   |
| K            | Surface U-factor      | 2.48   | 1.36   | 0.24   |
| L            | Ground Floor          | 0.69   | 0.35   | 0.19   |
| M            | Window U-factor       | E      | 2.4    | 1.55   | 0.7    |
| N            | W                      | W      | 2.4    | 1.55   | 0.7    |
| O            | S                      | S      | 2.4    | 1.55   | 0.7    |
| P            | N                      | N      | 2.4    | 1.55   | 0.7    |
| Q            | SHGC U-factor         | E      | 0.6    | 0.4    | 0.2    |
| R            | W                      | W      | 0.6    | 0.4    | 0.2    |
| S            | S                      | S      | 0.6    | 0.4    | 0.2    |
| T            | VLT U-factor          | E      | 15%    | 40%    | 70%    |
| U            | W                      | W      | 15%    | 40%    | 70%    |
| V            | S                      | S      | 15%    | 40%    | 70%    |
| W            | Ventilation Rate      | 2.4    | 1.55   | 0.7    |
| X            | Daylighting           | 2.4    | 1.55   | 0.7    |

4.2 Simulation Results

The simulations for cooling and heating load calculations were undertaken by using the EnergyPlus program and a database for the ANOVA was established based on the simulation results (Table 6.). Seoul weather data made by the KMA (Korea Meteorological Administration) were converted to TMY2 (Typical Meteorological Year version 2) format which is one of the EnergyPlus weather data types. There are three distinct climatic zones in

Table 5. Orthogonal Array Table L₈(3^40)
Korea, and the analysis was carried out for Seoul, the representative location for "central climatic zone". The results of simulations show that the average annual heating and cooling load are 26.55 kWh/m²·yr and 42.03 kWh/m²·yr, respectively.¹⁰

Table 6. Simulation Results (kWh/m²·yr)

| No. | Heating Load | Cooling Load | No. | Heating Load | Cooling Load |
|-----|--------------|--------------|-----|--------------|--------------|
| 1   | 36.70        | 44.33        | 42  | 31.27        | 38.70        |
| 2   | 20.90        | 46.23        | 43  | 42.31        | 39.32        |
| 3   | 7.65         | 48.31        | 44  | 16.96        | 40.58        |
| 4   | 19.02        | 42.42        | 45  | 31.62        | 49.07        |
| 5   | 41.39        | 48.69        | 46  | 19.43        | 43.99        |
| 6   | 30.06        | 51.01        | 47  | 13.40        | 40.23        |
| 7   | 37.17        | 35.98        | 48  | 35.31        | 44.16        |
| 8   | 18.90        | 36.69        | 49  | 28.53        | 41.83        |
| 9   | 41.70        | 40.33        | 50  | 28.57        | 38.86        |
| 10  | 20.74        | 42.36        | 51  | 15.25        | 41.16        |
| 11  | 17.50        | 41.39        | 52  | 16.40        | 49.32        |
| 12  | 21.21        | 39.43        | 53  | 29.69        | 52.10        |
| 13  | 42.95        | 36.13        | 54  | 31.98        | 46.58        |
| 14  | 32.96        | 33.31        | 55  | 27.55        | 39.50        |
| 15  | 15.66        | 33.56        | 56  | 24.41        | 34.74        |
| 16  | 24.15        | 39.85        | 57  | 44.86        | 38.93        |
| 17  | 38.21        | 52.00        | 58  | 28.82        | 41.91        |
| 18  | 29.41        | 51.30        | 59  | 20.76        | 40.10        |
| 19  | 15.52        | 39.31        | 60  | 15.42        | 38.06        |
| 20  | 18.41        | 40.26        | 61  | 13.98        | 38.51        |
| 21  | 27.94        | 49.86        | 62  | 33.73        | 41.21        |
| 22  | 44.00        | 45.52        | 63  | 26.45        | 37.40        |
| 23  | 26.30        | 44.92        | 64  | 13.59        | 37.40        |
| 24  | 36.71        | 54.57        | 65  | 33.85        | 41.00        |
| 25  | 45.35        | 39.92        | 66  | 29.22        | 39.85        |
| 26  | 29.39        | 45.91        | 67  | 23.09        | 54.96        |
| 27  | 14.50        | 41.24        | 68  | 9.82         | 56.32        |
| 28  | 19.70        | 34.65        | 69  | 24.8         | 53.73        |
| 29  | 34.66        | 39.18        | 70  | 34.07        | 40.45        |
| 30  | 32.62        | 34.64        | 71  | 24.31        | 42.04        |
| 31  | 29.06        | 44.24        | 72  | 21.06        | 36.20        |
| 32  | 18.54        | 37.68        | 73  | 29.10        | 39.29        |
| 33  | 50.06        | 42.09        | 74  | 22.79        | 40.78        |
| 34  | 29.26        | 45.50        | 75  | 18.07        | 39.50        |
| 35  | 23.74        | 45.70        | 76  | 18.01        | 37.81        |
| 36  | 18.30        | 41.59        | 77  | 38.06        | 43.08        |
| 37  | 27.67        | 36.95        | 78  | 19.33        | 45.19        |
| 38  | 19.18        | 35.42        | 79  | 31.91        | 42.65        |
| 39  | 15.67        | 34.24        | 80  | 19.39        | 39.70        |
| 40  | 14.64        | 41.00        | 81  | 34.58        | 41.43        |
| 41  | 41.11        | 39.32        | Avg | 26.55        | 42.03        |

5. Analysis of Variance (ANOVA)

5.1 Equation for Analysis

ANOVA was conducted using the results of the simulations. The relative importance of each parameter was obtained by the following equation

\[ P_{A_{o}} = \frac{Y_{55}+Y_{56}+\ldots+Y_{87}}{27} \cdot T_{m} \]  

(Eq. 1)

\[ P_{A_{o}} = \frac{Y_{o}+Y_{20}+\ldots+Y_{84}}{27} \cdot T_{m} \]  

(Eq. 2)

\[ P_{A_{o}} = \frac{Y_{55}+Y_{56}+\ldots+Y_{84}}{27} \cdot T_{m} \]  

(Eq. 3)

\[ P_{B_{o}} = \frac{(Y_{1}+\ldots+Y_{2})+(Y_{20}+\ldots+Y_{84})+(Y_{55}+\ldots+Y_{84})}{27} \cdot T_{m} \]  

(Eq. 4)

\[ \rho_T(\%) = \frac{SS_T}{SST} \times 100 \]  

(Eq. 5)

5.2 Percentage Contribution to the Energy Consumption

The parameters which have significant contribution at the 5% significant level (p-value) in ANOVA were selected as the contributing energy factors, and the non-significant terms (p-value greater than 0.05) were eliminated. Only 8 parameters were selected as significant factors for heating energy consumption. For cooling energy consumption, 13 parameters were found to be significant. They are; Gross Floor Area, Surface Floor Ratio, Floor-to-Floor Height, Width Depth Ratio, Window Wall Ratio (South), Ventilation Rate, Window U-factor (North), SHGC (South), Orientation, and Wall U-factor (Wall) parameter.

The result of the study indicates that, in terms of the contribution to heating energy consumption, U-value of wall was found to have the most contribution (57.7%) followed by SHGC (West) (6.3%), WDR (3.2%) WWR (South) (2.3%) and Orientation (1.9%). As for cooling energy consumption, the hierarchy of the contribution is as follows: SHGC (West) (15.9%), SHGC (East) (14.5%), Dimming Control (8.2%) Gross Floor Area (6.7%), Wall U-factor (5.9%), WDR (5.6%), Floor-to-Floor height (4.9%) and VLT (West) (4.1%). It was found that the other variables’ contributions are small enough to be negligible.

In Table 7. and Table 8., the contribution rates are illustrated as the gradient in the graph. The more variables contribute to energy consumption, the steeper the gradient is. In the graph, 0 corresponds to the average heating and cooling energy consumption. Positive (+) values indicate that values are larger than the average intensity, and negative (-) values mean that values are smaller than the average intensity.

6. Development of Load Prediction Equations

Energy simulation tools are required to evaluate the energy performance of buildings and to provide more flexible building energy design standards. The load prediction equations derived from statistical correlations are useful in providing architects with a
Table 7. Percentage Contribution to Heating Energy Consumption

| Strategy | Contribution Rate (%) | Performance Level of Heating Energy Consumption (MJ/m²·yr) |
|----------|------------------------|----------------------------------------------------------|
|          |                        | 0       | 1       | 2       |
| C        | 1.8                    | -1.86   | 0.22    | 1.64    |
| D        | 3.2                    | -2.37   | 1.10    | 1.56    |
| E        | 1.9                    | -1.24   | -0.83   | 2.07    |
| H        | 2.3                    | 2.14    | -0.43   | -1.71   |
| W        | 1.4                    | 1.77    | -0.50   | -1.26   |
| K        | 57.7                   | 7.98    | 1.47    | -9.45   |
| P        | 1.5                    | 1.81    | -0.44   | -1.37   |
| S        | 6.3                    | -3.41   | 1.10    | 2.31    |

Table 8. Percentage Contribution Rate to Cooling Energy Consumption

| Strategy | Contribution Rate (%) | Performance Level of Heating Energy Consumption (MJ/m²·yr) |
|----------|------------------------|----------------------------------------------------------|
|          |                        | 0       | 1       | 2       |
| A        | 6.7                    | 1.28    | 0.68    | -1.96   |
| B        | 1.7                    | 1.11    | -0.49   | -0.62   |
| C        | 4.9                    | -1.72   | 0.62    | 1.10    |
| D        | 5.6                    | -1.81   | 0.65    | 1.11    |
| F        | 2.6                    | -0.94   | -0.33   | 1.27    |
| G        | 2.6                    | -1.10   | -0.03   | 1.13    |
| X        | 8.2                    | 2.19    | -1.05   | -1.14   |
| K        | 5.9                    | 1.19    | 0.61    | -1.80   |
| O        | 2.3                    | 1.26    | -0.63   | -0.63   |
| R        | 15.9                   | 2.69    | -0.16   | -2.52   |
| Q        | 14.5                   | 2.87    | -1.33   | -1.54   |
| U        | 4.1                    | -0.86   | -0.73   | 1.59    |
| V        | 1.9                    | -1.15   | 0.42    | 0.72    |

Fig. 3. Percentage Contribution of Cooling Energy Saving

Fig. 2. Percentage Contribution to Heating Energy Saving

6.1 Regression Model and Parameters

A series of linear regressions were performed using the STEPWISE procedure. 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. 1.00 means perfect prediction in the model.

### 6.2 Development of the Multi-regression Equation

A mathematical model is developed through multiple regression analysis, which illustrates the relationship between the parameters and energy consumption. The model results indicate that the model is significant (Tables 9., 10., 11., 12.). The cooling load \( (R^2 = 0.845) \) prediction is relatively more accurate than the heating load \( (R^2 = 0.735) \) prediction.

#### Heating Load

\[
\begin{align*}
\text{Heating Load (Y)} &= 30.692 + 1.75X_1 + 1.78X_2 - 1.65X_3 - 1.93X_4 + 1.47X_5 + 1.514X_6 - 8.17X_7 - 1.59X_8 + 2.86X_9 \\
X_1 & : \text{Floor to Floor Height} \\
X_2 & : \text{WWR (Façade)}
\end{align*}
\]

#### Cooling Load

\[
\begin{align*}
\text{Cooling Load (Y)} &= 46.94 - 1.62X_1 - 0.80X_2 + 1.41X_3 + 1.49X_4 - 1.10X_5 - 1.12X_6 - 1.62X_7 - 1.53X_8 + 0.94X_9 - 2.60X_{10} - 2.10X_{11} + 0.06X_{12} - 0.79X_{13} \\
X_1 & : \text{Gross Floor Area} \\
X_2 & : \text{Surface Floor Ratio} \\
X_3 & : \text{Floor Height} \\
X_4 & : \text{WDR} \\
X_5 & : \text{WWR (East)} \\
X_6 & : \text{WWR (West)} \\
X_7 & : \text{Daylighting} \\
X_8 & : \text{U-value of Wall} \\
X_9 & : \text{U-value of Window (South)} \\
X_{10} & : \text{SHGC-West} \\
X_{11} & : \text{SHGC-East} \\
X_{12} & : \text{VLT-West} \\
X_{13} & : \text{VLT-East}
\end{align*}
\]
6.3 Validation
A comparison of EnergyPlus simulation and the regression models is shown in Fig.4. and Fig.5. As shown below, the coefficient of determination ($R^2$) was 0.845 for the heating load prediction and 0.735 for the cooling load prediction. This indicates that the regression model is reasonably well fitted with the computer-simulated values. Therefore, the regression equations were found to have a considerable predictive power.

7. Conclusion
The study intends to develop the energy load prediction equations for office buildings which can be simply used to estimate the energy consumption in the central climatic zone in Korea during the early design stage. The ANOVA and multiple regression analysis were conducted and the following conclusions were drawn.

1) Through an intensive literature search, the main factors affecting energy consumption reduction were selected. The factors examined for the analysis include: the gross floor area, numbers of stories, floor height, width/depth ratio, orientation, window/wall ratio (S, E, W, N), insulation performance of walls/roof/floors, window performance ($U$-value, SHGC (Solar Heat Gain Coefficient), VLT (Visual Light Transmittance), ventilation rate and dimming control.

2) By using orthogonal arrays, the number of simulations was reduced to 81. With the results of simulations, ANOVA was conducted. U-factor of Wall (heating) and SHGC (West) (cooling) were found to have the most contribution to energy consumption: followed by SHGC (East), SHGC (West), SHGC (East), dimming control, gross floor area and wall U-factor for cooling.

3) Multiple regression analyses were conducted using the data set, and the load prediction equations were derived. The coefficient of determination ($R^2$) between the regression models and EnergyPlus simulations was 0.845 for the heating load prediction and 0.735 for the cooling load prediction. As a result, the regression equations were found to have a considerable predictive power.

Therefore, architects must be attentive to the gross floor area, SHGC (west/east/south), U-factor (south), dimming control, WDR, floor-to-floor height and VLT (West) for energy-efficient office building design. They should also give priority to the design variables selected in this research and use the developed equations during the early design stage, if they are to design energy conscious office buildings effectively.

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