A Development of Energy Load Prediction Equations for Multi-Residential Buildings in Korea

Hae Jin Kang*1 and Eon Ku Rhee2

1 Post-Doctoral Research Fellow, Taubman College, University of Michigan, U.S.A
2 Professor, Department of Architecture, Chung-Ang University, Korea

Abstract

The study intends to develop energy load prediction equations which can be easily used to estimate the energy consumption of multi-residential 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 312 (=531,441). 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 is the 9th largest CO2 emitter in the world, and is facing great pressure to reduce emissions in the Post-Kyoto negotiations. The building sector contributes about 25% of CO2 emissions in Korea. And uniquely in Korea, multi-residential buildings account for 85% of total residential building stock. Therefore, it is of the utmost importance for Korea to reduce energy consumption in multi-residential buildings in order to meet its CO2 emission reduction obligations.

Variations in the design and construction of multi-residential buildings in Korea 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 CO2 emissions. However, design parameters for energy consumption reduction in multi-residential 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 be easily used to estimate the energy consumption of multi-residential 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,3, 4, 7, 8, 12, 16 no attempt has been made yet to present a simple energy prediction equation for multi-residential 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 312 (=531,441). 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 to develop 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 multi-residential buildings at every stage. Based on intensive literature search, many parameters were narrowed down to ten factors which mainly affect the energy consumption of multi-residential buildings. These include the numbers of stories, orientation, unit area, type of balcony, number of units per story, window/wall ratio (façade, rear), insulation performance of walls, infiltration quantity (location of the insulation), and window performance. (Table 1.)

The insulation performance of walls was supposed to be determined by insulation thickness. Since the infiltration quantity depends on the location of insulation (outer/inner/middle), the location was set as the determinant variable for infiltration quantity. The thermal performance of the wall was considered not to be dependent upon the insulation location. For the window performance, only the thermal performance of the window was considered. Although shading devices affect the energy performance of a building considerably, they are seldom employed in multi-residential buildings in Korea, and their behaviors are too complicated to be included in a simple mathematical equation. Thus, they are excluded from the parameters.

2.2 Applicable Ranges of Each Parameter

In order to analyze the relative importance of the 10 parameters chosen above, 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 analyses are based on a comparison with it. A baseline building has been established from a survey of multi-residential buildings in Seoul. The characteristics of the baseline building were determined by careful examination of a typical design.

Most multi-residential buildings in Korea, as seen in Fig.1., are of a basic module type consisting of 4 units, and 2 households share one elevator. Fig.1. shows a simplified drawing of a model constructed for simulation. Generally, most buildings face south, and the balcony is found on the north side. What stands out is that the northward balcony is used like an interior space. A brief description of the baseline reference building and characteristics of operation are given in Table 3.

Table 1. Design Parameters Affecting CO₂ Emission

| Category                | Energy Strategies                                      |
|-------------------------|--------------------------------------------------------|
| Volume, Shape, Plan     | # of stories, unit area, # of units per story, type of balcony |
| Arrangement             | Orientation                                            |
|                         | Insulation performance                                 |
|                         | Infiltration quantity                                  |
| Others                  | Window performance                                     |
|                         | Window/wall ratio                                      |

Table 2. Applicable Performance Ranges of each Energy-Related Design Parameter

| Design Parameters | Ranges            |
|-------------------|-------------------|
| Area (m²)         | 58 ~ 122          |
| Stories           | 15 ~ 25           |
| # of Units per Story | 2 units – 6 units |
| Orientation (degree) | 0 ~ 90 (0: South) |

*Type of Balcony (Unit Plan)

|                      | Type A | Type B | Type C |
|----------------------|--------|--------|--------|
| Insulation Performance (mm) |       |        |        |
| Façade               | 65~250 |        |        |
| Side                 | 65~250 |        |        |
| Rear                 | 65~250 |        |        |
| Infiltration Quantity(ACH) |       |        |        |
| 0.5 (interior insulation) |    |        |        |
| 0.3 (exterior insulation) |       |        |        |
| Window Performance (W/ m²K) |       |        |        |
| Façade               | 3.0 ~ 1.0  |        |        |
| Rear                 | 3.0 ~ 1.0  |        |        |

*Type of Balcony (Unit Plan)

Type A: Both Balconies Enclosed (interior & exterior windows)
Type B: Both Balconies Open (interior window only)
Type C: Rear Balcony Enclosed, Front Balcony Extended (exterior window only)

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 ten variables presented in Table 4. are changed on only three levels, as many as 3¹⁰ (=531,441), simulations will be required, making the analysis almost impossible.
Table 3. Brief Description of Baseline Model

| Category       | Factors                        | Value          |
|----------------|--------------------------------|----------------|
| Climate Site   | Climate data                   | Seoul (TMY2)   |
|                | Heating/cooling period         | Heating        |
|                |                                | 1/1–3/30, 11/1–12/3 |
|                |                                | Cooling        |
|                |                                | 6/11–9/10      |
| Building       | Ceiling height (mm)            | 2300           |
|                | *WDR (%) Balcony              | 1:1            |
|                | *WWR (%) Façade               | Façade 80%, rear 40% |
|                | System Heating                | Floor radiant heating |
|                | System Cooling                | Package type AC |
|                | System Ventilation            | Unit ventilation |
| Operation      | Temperature control            | Heating        |
| Occupancy      |                                | 24°C           |
|                |                                | Cooling        |
|                |                                | 26°C           |
|                | Ventilation heating space     | 0.4 ACH        |
|                | Ventilation non-heating space | 2.0 ACH        |
|                | Mech. Ventilation             | 0.7 ACH        |
|                | Number of occupants           | 4              |
|                | Internal heat (W) Person      | Latent 70      |
|                |                                | Sensible 45    |
|                | Equipment                     | 314            |
|                | Lighting                      | 68             |

*WDR: Width/Depth Ratio, *WWR: Window/Wall Ratio

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 simulation to 81 (L8 [340]).

As an interaction may arise between balcony type (D) and window/wall ratio (E, F) due to placement of a window on the balcony wall, two new parameters (D*E, D*F) which reflect simultaneous influence among two variables were added. 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, 5, 9, 11, 15, 18, 20, 23, 25(26), 35(36), 40) of orthogonal array (Table 5.), 12 parameters are arranged as follows: 1 = Type of Balcony; 2 = WWR (Façade); 5 = WWR (Rear); 9 = Unit Area; 11 = Number of Units per story, 15 = Orientation, 18 = Thickness of Insulation, 20 = Location of Insulation; 23 = Window U-factor (Façade); 25(26) = Type of Balcony * WWR (façade); 35(36) = Type of Balcony * WWR (Rear); 40 = Window U-factor (Rear). 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 analysis of variance was established based on the simulation results (Table 6.). Seoul weather data made by the KMA (Korea Meteorological Administration) was 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 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 264.49MJ/m²·yr and 62.18MJ/m²·yr, respectively.

### 5. Analysis of Variance (ANOVA)

#### 5.1 Equation for Analysis

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

\[
P_{Ai} = \frac{Y_{i1} + Y_{i2} + \cdots + Y_{i27}}{27} - T_m \quad (Eq. 1)
\]

\[
P_{A1} = \frac{Y_{28} + Y_{29} + \cdots + Y_{54}}{27} - T_m \quad (Eq. 2)
\]

\[
P_{A2} = \frac{Y_{55} + Y_{56} + \cdots + Y_{81}}{27} - T_m \quad (Eq. 3)
\]

\[
P_{B0} = \frac{(Y_{1} + \cdots + Y_{25}) + (Y_{26} + \cdots + Y_{52}) + (Y_{53} + \cdots + Y_{80})}{27} - T_m \quad (Eq. 4)
\]

\[
P_{A,i} = \frac{S_{St}}{SST} * 100
\]

\[
\rho_T = \frac{S_{St}}{SST} * 100
\]

\[
S_{St} \text{ Percentage contribution of nominal}
\]

\[
SST \text{ Variation of nominal only}
\]

\[
SST \text{ Sum of squares (total variation)}
\]
The parameters which have significant contribution at the 5% significant level (p-value) in ANOVA were selected as contributing energy factors, and the non significant terms (p-value greater than 0.05) were eliminated. The results show all parameters were selected as significant factors for heating energy consumption. However, for cooling energy consumption, 4 parameters were found to be not significant. They are; number of units per story, window/wall ratio (rear), insulation performance of wall, window performance (rear), and D*F parameter.

The result of the study indicates that, in terms of the contribution to heating energy consumption, the type of balcony of the building was found to have the most significant effect.
contribution (25%) followed by the location of the thermal insulation (10.9%), WWR (façade) (10.3%), unit area (7.4%), and insulation thickness (6.1%). As for cooling energy consumption, it was found that the contribution is greater in the following order; the unit area (65%), WWR (façade) (12.6%) and orientation (5.0%). 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.

Table 7. Percentage Contribution to Heating Energy Consumption

| Strategy | Contribution Rate (%) | Performance Level of Heating Energy Consumption (MJ/m² yr) |
|----------|-----------------------|----------------------------------------------------------|
|          |                       | 0 1 2                                                    |
| A        | 7.4                   | -20.5 0 20.9                                             |
| B        | 2.4                   | 13.8 -3.8 -10.0                                          |
| C        | 5.0                   | -17.2 -2.1 19.3                                          |
| D        | 24.9                  | -38.1 36.8 1.3                                           |
| E        | 10.3                  | -24.7 0.4 23.9                                           |
| F        | 5.0                   | -18.0 2.1 15.9                                           |
| G        | 6.1                   | 20.1 -2.9 -17.2                                          |
| H        | 10.9                  | 24.3 1.3 -25.5                                          |
| I        | 5.3                   | 17.2 1.3 -18.4                                          |
| J        | 1.7                   | 10.9 -0.4 -10.5                                         |
| D*E      | 4.2                   | 18.4 7.5 -26.0                                         |
| D*F      | 1.5                   | -10.5 -5.0 15.5                                           |
|          |                       | -8.0 -2.5 10.5                                          |

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        | 65.0                  | 20.1 -2.9 -17.2                                          |
| C        | 5.0                   | -5.9 1.7 4.2                                             |
| D        | 9.3                   | -3.8 -4.6 8.4                                           |
| E        | 12.6                  | -8.8 1.3 7.5                                            |
| H        | 0.4                   | -1.7 0.4 1.3                                            |
| I        | 1.1                   | 2.9 -0.4 -2.5                                           |
| D*E      | 3.5                   | 3.8 1.3 -5.0                                            |
|          |                       | 1.7 -0.8 -1.3                                          |
|          |                       | -5.4 -0.8 6.3                                          |

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 simple and valuable tool for energy-conscious building design.

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

As a result of multi-regression analysis, a mathematical model is developed that 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 ($R^2 = 0.930$) prediction is relatively more accurate than the heating load ($R^2 = 0.876$) prediction.

Heating Load ($Y$)

$$= 9.90 + 5.94 X_1 + 0.29 X_2 - 0.16 X_3 + 0.08 X_4 + 0.49 X_5 - 0.05 X_6 + 0.10 X_7 + 4.51 X_8 + 0.20 X_9 + 2.86 X_{10} + 2.70 X_{11} + 0.10 X_{12}$$

$$X_1 : a_1 \text{ Location of the Insulation (Interior: 1, Middle: 0, Exterior: -1)}$$
$$X_2 : \text{WWR (Façade)}$$
$$X_3 : a_1 \text{ Balcony (A Type: 1, B Type: 0, C Type: -1)}$$
* WWR (Façade)
$$X_4 : a_2 \text{ Balcony (A Type: 0, B Type: 1, C Type: -1) * WWR (Façade)}$$
$$X_5 : \text{Unit Area}$$
$$X_6 : \text{Thickness of the Insulation}$$
$$X_7 : \text{Orientation}$$
$$X_8 : \text{U-value of the Window (Façade)}$$
$$X_9 : \text{WWR Rear}$$
$$X_{10} : a_1 \# \text{ of the Units (Two: 1, Four: 0, Six: -1)}$$
$$X_{11} : \text{U-value of the Window (Rear)}$$
$$X_{12} : a_2 \text{ Balcony (A Type: 0, B Type: 1, C Type: -1) * WWR (Rear)}$$

Cooling Load ($Y$)

$$= 20.82 - 0.43 X_1 + 0.10 X_2 - 0.02 X_3 + 0.03 X_4 + 0.05 X_5 + 0.65 X_6 + 2.30 X_7 - 0.37 X_8$$

$$X_1 : \text{Unit Area}$$
$$X_2 : \text{WWR (Façade)}$$
$$X_3 : a_2 \text{ Balcony (A Type: 0 B Type: 1 C Type: -1) * WWR (Façade)}$$
$$X_4 : \text{Orientation}$$
$$X_5 : a_1 \text{ Balcony (A Type: 0 B Type: 1 C Type: -1) * WWR (Façade)}$$
$$X_6 : \text{U-value of the Window (Façade)}$$
$$X_7 : a_1 \text{ Balcony (A Type: 1 B Type: 0 C Type: -1)}$$
$$X_8 : \text{Location of the Insulation}$$

6.3 Validation

A comparison of EnergyPlus simulation results and the regression models is shown in Fig.4. and Fig.5. As shown below, the coefficient of determination ($R^2$) were 0.876 for the heating load prediction and 0.930 for the cooling load prediction, indicating 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 multi-residential 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: number of stories, orientation, unit area, type of balcony, number of units per story, window/wall ratio (façade, rear), insulation performance, infiltration quantity (location of insulation), window performance.

2) By using orthogonal arrays, the number of simulations was reduced to 81. With the results of simulations, analysis of variance was conducted. Type of balcony (heating) and unit area (cooling) were found to have the most contribution: followed by filtration volume, performance of insulation and orientation for heating; and orientation 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 0.876 for the heating load prediction and 0.930 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 location of the insulation, window/wall ratio, the type of balcony, unit area, the performance of insulation, orientation, and the performance of windows concerning energy-conscious multi-residential 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 multi-residential buildings effectively.

Acknowledgement
This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2012-0000136).

References
1) ASTM. (2005) Committee E06 on Performance of Building and Subcommittee E06.71 on Sustainability Standard Guide for General Principles of Sustainability Relative to Buildings.
2) Boughey, J. (2000) Proceedings from Cutting Edge 2000: Environmental valuation real property and sustainability. London: RICS Research Foundation.
3) Freire, R. et al. (2008) Development of Regression Equations for Predicting Energy and Hygrothermal Performance of Buildings. Energy and Buildings, 40(10), pp.810-820.
4) Ho-Tae, S. (1997) A Study on the development of load prediction equation and design guidelines for the energy conservation of office buildings. Ph D Dissertation Department of Architecture Graduate School Seoul National University, p.55.
5) Hoseon, Y. (2002) Effects of Various Factors on the Energy Consumption of Korean-Style Apartment Houses. Journal of Air-Conditioning and Refrigeration, 40(10), pp.972-980.
6) Korea Power Exchange. (2006) Survey on Electricity Consumption Characters of Home Appliances, pp.50-75.
7) Lam, J. et al. (1997) Regression Analysis of High-rise Fully Air-conditioned Office Buildings. Energy and Buildings, 26(2), pp.189-197.
8) Min-Chul, K. (2007) A Study on the Character of Changes in Unit Plans prepared Apartment Balcony Extension. The Graduate School of Kyungpook University, p.34.
9) Ministry of Knowledge Economy. (2007). The Study of the Development of Energy Performance Assessment Method and Policy in Buildings, p.340.
10) Peterson, J.L. et al. (1989) The Correlation of Annula Commercial Building Coil Energy with Envelope, Internal Load, and Climatic Parameters, ASHRAE Transactions, p.95, Part 1.
11) Pil-Hurn, K. (2000) Study on the energy consumption analysis and retrofit measures of apartment. Graduate School of Information Industry Hannam University, p.12.
12) Robert, D. and Henze, G. (2004) Statistical Analysis of Neural Networks as Applied to Building Energy Prediction. Journal of Solar Engineering, 126(1), pp.592-601.
13) Seung-Bok, L. et al. (2005) An Energy Management Process and Prediction of Energy Use in Office Building. Journal of Asian Architecture and Building Engineering, 4(5) , pp.501-508.
14) Shaviv, E. and Capeluto, I.G. (1992) The relative importance of various geometrical design parameters in a hot, humid climate, ASHRAE Trans., 98, pp.589-605.
15) Sullivan, R. et al. (1985) Commercial Building Energy Performance Analysis Using Multiple-Regression, ASHRAE Technical Data Bulletin.
16) Wilcox, B.A. (1991) Development of the Envelope Load Equation of ASHRAE Standard 90.1. ASHRAE Transaction, p.97, Part 2.