An Energy Evaluation of Multi-residential Buildings in South Korea Using Gas Utilities

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Abstract. The purpose of this study was to evaluate energy performance of existing multi-residential buildings and classify them according to their energy efficiencies. 200 households from four different aging multi-residential buildings were selected and analyzed. By applying monthly gas consumption of a whole year to Inverse Model Toolkit, the heating slope and change-point temperature coefficients were calculated and used for energy performance evaluation. As a result, the older buildings were classified to the category of the poor energy performer that needs to be remodeled for improving their energy efficiency.

1. Introduction
Over the past years, greenhouse gas emission and energy consumption in the building sector have been increasing and this has raised a concern in the world. The government of South Korea has put lot of efforts in the reduction of greenhouse gas emission through the inauguration of building energy related acts and the promotion of green building design [1]. According to Korean national statistics, as of 2018, only 2% of the existing buildings were newly built or remodeled to meet the building energy efficiency regulations [2]. Hence, an active encouragement for building remodeling is essential for the energy reduction acts to effectively reduce building energy consumption and greenhouse gas emission in South Korea. Generally, in South Korea, 30 years after the completion of a building, the building is considered as a deteriorated building. According to the survey conducted on Korean buildings, 45.7% of the existing residential buildings are deteriorated and need remodeling [3]. Nonetheless, a study has reported significant building energy performance degradation for buildings younger than 30 years old and the deterioration of heating and cooling equipment was the first and foremost factor influencing the building energy performance [4]. Therefore, more investigations are needed to develop relevant building aging classifications and remodeling criteria involving other factors related to building energy consumption and greenhouse gas emission. The purpose of this study was to evaluate the energy performance of existing multi-residential buildings and to classify deterioration buildings in the order of remodeling prioritization.

2. Methods
This study was conducted following the steps illustrated in Figure 1. The authors started by selecting the target buildings for this study and the selection was based on the building shape, height, type of heating system, location and the year of completion. The actual gas consumption for the whole year (2011) of the target buildings were obtained from the local utility agency. Given that the local billing system was structured that the billing was one month behind the actual energy recoding, the data were further modified to match the recorded gas amount and the month of actual usage period prior to applying them to Inverse Model Toolkit (IMT). In this study, monthly outdoor air temperature for the...
year 2011 in Ulsan provided by the Korea Meteorological Administration was used [5]. In addition, for appropriate comparison of energy performance of buildings with different floor area, the Energy Use Intensity (EUI, energy use per unit area) was used in this study.

Using the modified gas billing data and local outdoor temperature, the change-point regression model coefficients were calculated for each of the target building using IMT. A correlation coefficient, $R^2$, above 0.8 [6] was used to confirm the correlation between the monthly gas consumption and the outdoor air temperature. After that, quadrants were created by plotting the average heating slope and the average change-point temperature that are the coefficients calculated from the change-point regression model of each target building. Lastly, the energy performance of the target buildings was analyzed and compared.

![Figure 1](image.png)

**Figure 1.** The flow chart of the study.

### 3. Overview of Inverse Model Toolkit

Inverse Model Toolkit is a tool used to evaluate the building energy performance based on the actual energy consumption of the building [7]. The IMT model used in this study was a change-point regression model. Generally, a change-point regression model is a method used to statistically analyze the correlation between local monthly outdoor air temperature and building energy consumption. There are five different models depending on the building system, and each model type is shown in Figure 2, and explained as below.

(a) 1 parameter model (1P): 1P shows a constant building energy consumption regardless of the outdoor air temperature.

(b) 2 parameter model (2P): 2P applied to air-conditioned buildings where the energy consumed for adequate thermal conditions increases as the outdoor temperature increases.

(c) 3 parameter model heating (3PH): the building energy consumption decreases as the outdoor temperature increases until it reaches a certain temperature from which the building energy consumption becomes constant. The constant energy consumption, $C$, in the 3PH refers to the base energy used regardless of the outdoor thermal conditions such as the energy used for cooking, hot water, etc. In addition, $B_1$ refers to a heating slope that indicates energy efficiency of the building, and $B_2$ refers to a change-point temperature that indicates the starting temperature set-point for heating the building.

(d) 4 parameter model heating (4PH): 4PH corresponds to buildings with VAV systems where the base energy changes depending on the outdoor temperature.

(e) 5 parameter model (5P): 5P combines the base energy (C), heating slope (B1), cooling slope (B2), and indoor thermal set-points B3 and B4 for heating and cooling, respectively. The model is appropriate for building with only one source energy.
In this study a 3PH model was used and the building energy consumption for this model is estimated by Equation (1). In addition, the heating energy and the base energy consumption of the building can be calculated using this model as shown in Figure 3.

$$E = C + B_1(B_2 - T)^+$$  \hspace{1cm} (1)

**Figure 2.** Change-point regression models for energy consumption in buildings.

**Figure 3.** Energy consumption of 3 parameter change-point regression model.

The heating slope on Figure 3 was used as the building energy performance index. Kissok et al. [8] has investigated the correlation between heating slope and building equipment performance as shown in Equation (2).

$$HS = HC/\eta_h$$  \hspace{1cm} (2)
Where, HS, HC and $\eta_0$ indicate the heating slope, heating coefficient, and equipment performance, respectively. Figure 4 illustrates how building heating slope changes as $\eta_0$ changes. HS represents the heating slope for a given equipment performance ($\eta_0$) whereas $HS'$ is the resulted heating slope when the equipment performance has decreased ($\eta_0'$.)

![Figure 4. 3PH models change with decreased equipment performance.](image)

4. Results and discussion

4.1. Target building

South Korea. The majority of the multi-residential buildings in this area was built between 1988 and 2011 and is classified as plate and tower building types with the number of floors varying from 3 to 30. The selected buildings were plate-shaped buildings of 14 to 20 floors and with individual heating system that uses gas as the energy source. In order to evaluate the deterioration factor’s impact on building energy performance, four multi-residential buildings with 5 years difference in their year of completion were selected. The whole year (January to December 2011) monthly recordings of gas consumption for each household of the targeted multi-residential buildings were applied to 3PH with the year 2011 monthly average outdoor air temperature of Ulsan.

| Targeted residential buildings | Completion Year | Area (m²)  | Building unit location | Household location | Number of Households |
|-------------------------------|-----------------|-----------|------------------------|--------------------|---------------------|
| A                             | 1991            | 86.41     | Side                   | Lower Level 4 (8%) | 50                  |
|                               |                 |           |                         | Middle Level 5 (10%) |                     |
|                               |                 |           |                         | Upper Level 3 (6%) |                     |
| B                             | 1996            | 84.28     | Side                   | Lower Level 4 (8%) | 50                  |
|                               |                 |           |                         | Middle Level 9 (18%) |                     |
|                               |                 |           |                         | 16 (32%) | 13 (26%) |
| C                             | 2001            | 106.32    | Side                   | Lower Level 5 (10%) | 50                  |
|                               |                 |           |                         | Middle Level 16 (32%) |                     |
|                               |                 |           |                         | 8 (16%) | 12 (24%) |
| D                             | 2006            | 87.26     | Side                   | Lower Level 4 (8%) | 50                  |
|                               |                 |           |                         | Middle Level 14 (28%) |                     |
|                               |                 |           |                         | 10 (20%) | 11 (22%) |

Prior to data modification, only 10% of the households in the targeted multi-residential buildings showed a correlation between gas consumption and outdoor temperature demonstrated by a correlation coefficient, $R^2$, above 0.8. This was caused by the fact that the local billing system was one month behind the actual recordings. In other words, for instance, the gas bill for March 2011 indicated the
amount of gas used during the month of February 2011. Therefore, these gas billing data were first adjusted before being applied to the outdoor air temperature in 3PH. After data adjustment, more than 75% of the households had a correlation coefficient above 0.8, indicating a significant correlation between building gas consumption and outdoor temperature.

After confirming the correlation between gas consumption and outdoor temperature, 50 households with low CV-RMSE (Coefficient of Variance of the Root Mean Squared Error) [9] were selected from each of the targeted multi-residential buildings. To account for building location effect on energy consumption, the households were evenly selected from both the side and middle building units and for each building unit households were selected from lower, middle and upper floor levels. Table 1 summarizes the details of the selected households for each multi-residential building.

4.2. Energy performance of target building

First, the data for gas consumption was converted from the flow rate to kWh and the Energy Use Intensity (energy consumption per unit area) for each household was calculated and applied to 3PH. The building base energy, heating slope and change-point temperature were calculated, and used in this study. In addition, for a comparison of energy performance, reference change-point temperature (X-axis) and heating slope (Y-axis) values were set to 23.12 and 0.76, respectively. The reference values were obtained from the average change-point temperature and heating slope of 3PH of the 200 households selected.

Although the two reference values were used in this study, the evaluation of the household energy performance was based on the heating slope rather than the change-point temperature. The energy performance of a household was classified as low if its calculated heating slope was greater than the reference values (quadrant 1 and 2 on Figure 5), whereas the household with lower heating slope were classified as high energy performance (quadrant 3 and 4 on Figure 5). Note that the households in quadrant 1 had both the heating slope and change-point temperature greater than the reference values, and they can be regarded as the households in need of green remodeling to enhance their energy performance, while the households in quadrant 3 had both the heating slope and change-point temperature smaller than the reference values; the best building energy performers. Therefore, the analysis of the overall energy performance of the targeted multi-residential buildings were conducted based on the percentages of the households in quadrant 1 and 3 representing the number of households in need of green remodeling and the best energy performance, respectively.

For multi-residential building A, B, C and D, 30%, 42%, 12% and 18% of the total households respectively were classified as poor energy performers. 20%, 4%, 30% and 42% of the total households in building A, B, C and D, respectively had the best building energy performance. It is important to mention that the energy performance of these buildings varied according to the year of completion which is 1991, 1996, 2001 and 2006 for building A, B, C and D, respectively. Table 2 summarizes the results of the energy performance evaluation.
Moreover, as the heating slope is more influential on the building energy efficiency, the heating slope based energy efficiency classification indicated that the percentage of households in poor energy performance category (quadrant 1 and 2) were 62%, 92%, 48%, and 42% for A, B, C, and D buildings, respectively. Whereas, the percentages for households in the category of relatively good building energy performance (quadrant 3 and 4) were 38%, 8%, 52%, and 58% for A, B, C and D building, respectively. The results indicated that B building (completed in 1999) had the worst energy performance among the target buildings.

Table 2. Quadrant distribution of multi-residential buildings.

| Multi-residential building | Quadrant 1 | Quadrant 2 | Quadrant 3 | Quadrant 4 |
|---------------------------|------------|------------|------------|------------|
| A                         | 15 (30%)   | 16 (32%)   | 10 (20%)   | 9 (18%)    |
| B                         | 21 (42%)   | 25 (50%)   | 2 (4%)     | 2 (4%)     |
| C                         | 6 (12%)    | 18 (36%)   | 15 (30%)   | 11 (22%)   |
| D                         | 9 (18%)    | 12 (24%)   | 21 (42%)   | 8 (16%)    |
| Sum                       | 51 (25.5%) | 71 (35.5%) | 48 (24%)   | 30 (15%)   |

5. Conclusion
This study evaluated the energy performance of existing multi-residential buildings using 3PH. The heating slope and change-point temperature of 200 households selected from four different multi-residential buildings located in Ulsan were used for the assessment of energy performance. The results indicated that the number of households with poor energy performance and in need of green remodeling increased as the building age increased. Around 42% of the total households in the older buildings had poor energy performance, whereas only 18% of the households in the most recently built building among the analyzed buildings had poor energy performance. 8% and 42% of the total households in the older and most recent building, respectively, had the best energy performance. The study induced that the currently applied 30 years timespan for building remodeling in South Korea is ineffective as a 15 years aged building showed significant degradation in its energy performance. In addition, it is important to mention that the building energy performance was
evaluated based on the average heating slope and change-point temperature from 200 households; thus the authors’ future work will further investigation how to set a reference values which can be applicable to a wider range of multi-residential buildings.

6. References

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Acknowledgments
This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT, Ministry of Science and ICT) (No. 2018R1C1B5083359).