A Modified Energy Evaluation Tool for Residential Complexes in South Korea to Reflect Total Electricity Consumption

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Abstract
This study suggests a new method to evaluate the CO₂ emissions from residential complexes in South Korea. The conventional method only reflects energy consumption for space heating, hot water, and lighting. The Korean government has mandated a 40% reduction in CO₂ emissions from these sources to achieve the 26.9% national CO₂ reduction requirement from the building sector. The modified method reflects electricity consumption for public use and total electricity consumption for private use. The suggested equation for public electricity consumption is established by analyzing the electricity consumption of 26 residential complexes. The results of the study can be summarized as follows: (1) the conventional evaluation method is appropriate for low-rise residential complexes and a 26.7% reduction in CO₂ emissions is expected. (2) However, the conventional method cannot meet the national CO₂ reduction goal in high-rise residential complexes. Only a 21.7% reduction in CO₂ emissions can be achieved and a modification of the energy calculation method and CO₂ reduction goal should occur.

Keywords: residential building; CO₂ emissions; energy evaluation tool; energy policy; high-rise building

1. Introduction
1.1 Background
A significant proportion of energy is consumed by the building sector in many countries¹²⁵. Thus, a reduction in energy consumption is currently a serious concern for climate change mitigation. Recently, the Korean government has revised the national CO₂ emissions reduction goal by 37% versus business-as-usual (BAU) emissions by 2030. The policy change reflects difficulties in reducing CO₂ emissions. In the previous South Korean CO₂ reduction plan, CO₂ emissions from buildings were required to be cut by 26.9%. For the building sector, an energy consumption reduction in residential buildings is essential, as residential buildings consume over 15% of all energy used in the country⁵. The amount of new construction in Korea is negligible. Therefore, energy savings from the existing building stock is crucial for the success of the national CO₂ reduction plan. In order to accomplish the CO₂ reduction goal for the building sector in Korea, about 90% of residential buildings and 65% of non-residential buildings should be retrofitted to be green buildings⁶.

South Korea has many high-rise residential buildings. The geometric features and energy consumption profiles of these high-rise residential buildings differ greatly from the detached houses common in the European Union and United States. The gross floor area of multi-family residential buildings comprises about 86.8% of the total floor area of residential buildings in the country⁶. Park et al. (2014) indicate that tall residential buildings consume 2.54 times more energy than low-rise residential buildings, and suggest that public electricity consumption comprises 20–30% of the gross electricity consumption in residential complexes⁶. Lee et al. also show that electricity consumption, both from private and public uses, equals 60.6% of the total primary consumption of residential complexes in Daejeon, South Korea⁷. A high-rise residential building consists of private areas (clusters of residential units) and public areas (community areas, transportation facilities, and so on). In order to reduce energy consumption effectively in this type of building, energy savings in both areas need to be achieved. Recently, the Korean government established policies to reduce energy consumption in the building sector, and newly constructed residential buildings, in particular, must reduce energy consumption and CO₂ emissions. Residential buildings or complexes having
a minimum of 30 residential units with an average floor area larger than 60 m² must reduce 40% of their primary energy consumption or CO₂ emissions. A 30% reduction in energy consumption or CO₂ emissions is required for the residential units with floor area smaller than 60 m². However, an existing evaluation tool for energy savings in residential buildings in South Korea focuses solely on the energy consumed in residential units⁹. In addition, the baseline energy consumption of residential units only includes the energy consumption from space heating, hot water, and lighting. In this situation, an overestimation of the CO₂ emissions reduction in the entire residential complex may result, the inaccuracies of which could negatively impact the national CO₂ emissions reduction plan. In contrast, Japan has a building code and method to evaluate detailed energy consumption⁹. Thus, in order to support energy savings in residential buildings in South Korea, the energy consumption in public areas of the buildings should be reflected in the energy evaluation tool for residential buildings.

1.2 Purpose
The purpose of this study is to suggest a modified calculation method for the baseline energy consumption in residential complexes that takes into consideration energy consumed in public areas as well private energy use. High-rise residential buildings in South Korea have many public spaces, such as underground parking, community areas, and others. These spaces and facilities also consume energy, mainly electricity. In addition, transportation equipment, such as elevators and pumps, also requires electricity for its operation. In order to establish a modified calculation method, first the proportion of public-use electricity consumption to gross electricity consumption was calculated. Second, an equation for the total energy consumed in a residential complex, including public-use energy, was established. Finally, the expected overestimation of CO₂ emissions from the current evaluation tool was evaluated. This study used the gross energy data acquired from the energy supplier that distinguishes between private and public use.

2. Methods
2.1 Energy Data Gathering
In general, residential buildings need heat energy for space heating and hot water in private residential units. In this study, it was assumed that heat energy is used only for private use, while electricity is used in both private and public spaces. In order to determine the energy consumption profile of residential complexes, the gross electricity and heat consumption of residential complexes were obtained from the electricity supplier. The energy data excluded the commercial part for the residential complexes. In addition, the community heating energy consumption was very small, and has been excluded in many previous studies⁹,¹⁰. Electricity consumption data were available for 26 residential complexes, including 20,635 residential units of 187 residential buildings. Heat energy consumption data were difficult to obtain, and data for only five residential complexes, which use heat energy from a district heat supplier, were available. The total gross heat energy consumption of the five residential complexes, including 3,562 residential units, was gathered. Fig.1. illustrates the geometric features of low-rise, mid-rise, and high-rise residential buildings.

2.2 Suggesting a Modified Evaluation Method
This study intended to provide a modified energy evaluation method for residential complexes considering the total energy consumption in both private and public spaces. It is assumed that energy consumption in public spaces increases proportionally with the number of stories in a residential complex. With the restricted energy consumption data and building information available, the ratio of public electricity consumption to private electricity consumption (hereafter, Rₚₚ value) was selected as a key factor. The calculation method for private electricity consumption of a conventional residential unit was provided in a previous study¹¹ and by the Korean national building code⁸. Public electricity consumption can be estimated using the relationship between public and private electricity consumption. The relationship between the Rₚₚ value and the average number of stories of the residential complexes was analyzed using the simple linear regression function in Microsoft Excel 2010.

Next, to evaluate the total energy consumption of residential complexes, the established estimation method for public energy consumption was integrated with the conventional energy simulation tool, Sustainable Housing Performance Evaluation Software, supported by the South Korean government ⁸. Finally,
the modified evaluation method for the total energy consumption of residential complexes was determined. Equations for CO₂ emissions estimation were also revised slightly. Fig.2 illustrates the concept and process of the newly proposed method.

2.3 Comparison of the Conventional and Altered Methods

The CO₂ emissions from residential complexes were evaluated using the conventional estimation method and the revised method. The effect of an overestimation of the reduction in CO₂ emissions resulting from the conventional calculation method was analyzed.

3. Conventional Energy Evaluation Tool

3.1 Outline

The official energy simulation tool for the energy consumption evaluation of residential complexes was developed by the Korea Land and Housing Corporation (LH). This tool is a simple Excel-based program. It evaluates the energy used for space heating, hot water, and lighting. Lee et al. (2010) explain the energy calculation methods for the base model in this tool. The bin method is used to calculate heating energy. The calculation method and the results for heating energy consumption were validated by actual heating energy consumption data and the dynamic simulation tool CAPSOL. Estimations for the energy consumption from hot water and electricity use in a current residential unit (baseline model) were performed with regression modeling of the measured energy consumption data. Fig.3 illustrates the starting page and results page of the conventional evaluation tool.

3.2 Energy Consumption Using the Baseline Model

The estimation of energy consumption in a current residential unit was based on actual energy consumption data. The relevant equations, outlined below, were defined by the building code of South Korea. For the estimation of electricity consumption from lighting for the baseline model, if the floor area of the residential unit was smaller than 50 m², then Equation 1 was applied. Otherwise, Equation 2 was used. These equations reflect that lighting energy consumption represents 11% of all electricity consumed in a residential unit. Space heating energy consumption was calculated by Equation 3. Energy consumption for hot water (Eₜₗ) was estimated using Table 1. The CO₂ emissions were calculated using Equations 4-5. The suggested calculation methods are for Seoul, the capital city. The coefficients used for t-CO₂ conversion in Equations 3 and 4 were 2.336 t-CO₂/TOE and 0.424 t-CO₂/MWh, respectively. Plant efficiency was taken from the definitions in the Korean building code.

\[
E_{\text{eul}}(\text{MJ}) = (0.72 \times A^2 - 0.25 \times A + 9112) \times L \quad (1)
\]
\[
E_{\text{eul}}(\text{MJ}) = (98.7 \times A + 5965) \times L \quad (2)
\]
\[
E_{\text{sh}}(\text{MJ}) = 456A + 2476 \quad (3)
\]
\[
tCO₂(\text{heat}) = \frac{N_{\text{units}} \times (E_{\text{sh}} + E_{\text{hw}})}{\text{plant efficiency}} \times \frac{1}{4.16 \times 10^5} \times 2.336 \quad (4)
\]
\[
tCO₂(\text{electricity}) = (N_{\text{units}} \times E_{\text{eul}}) \times 0.424 \times \frac{1}{3.6 \times 10^5} \quad (5)
\]

Where:
- \(E_{\text{eul}}\) = Baseline lighting electricity consumption for a residential unit (MJ)
- \(A\) = Floor area of target residential unit (m²)
- \(L\) = Proportion of lighting energy to total electricity consumption in a residential unit (11%)
- \(E_{\text{sh}}\) = Baseline heat consumption for space heating (MJ)
- \(E_{\text{hw}}\) = Baseline heat consumption for hot water (MJ)
- \(N_{\text{units}}\) = Number of residential units

Table 1. Baseline Energy Consumption for Hot Water (Eₜₗ) in the Model

| Floor area   | Eₜₗ (MJ) |
|--------------|----------|
| <59 m²       | 11290    |
| 59-84 m²     | 13818    |
| 84-125 m²    | 14504    |
| ≥125 m²      | 15530    |

4. Energy Consumption for Public Use

4.1 Measured Electricity Consumption

The electricity consumption for private and public use in 26 residential complexes is illustrated in Table 2 and Fig.4. The Korean building code and Lee et al. (2010) indicate that the baseline electricity consumption for a residential unit is proportional to the floor area, as indicated in Equations 1 and 2. However, Lee et al. (2014) indicate that the total electricity consumption in high-rise residential buildings is larger than in low-rise buildings when including public usage, due to an increased use of the elevator, pump, etc.

Thus, in order to estimate the public electricity consumption, the \(R_p\) value was used. This value is expressed as the ratio of public electricity consumption to private electricity consumption. Large private electricity consumption implies a larger floor area of the residential units, larger family sizes, and more frequent use of elevators and pumps. Fig.5 shows the...
The correlation coefficient between gross public electricity and the average number of building stories was 0.65. On the other hand, the correlation coefficient between $R_{pp}$ values and the average number of building stories was 0.93. These results indicate that $R_{pp}$ values have a stronger positive relationship with the average number of building stories than gross public electricity consumption. Residential complex 22 shows abnormally high electricity consumption. The purpose of the study is to establish a robust regression model for general residential complexes. For this reason, residential complex 22 was excluded in the regression model. Considering the simple linear regressions expressed in Fig.5., the $R_{pp}$ value is more appropriate for the public electricity consumption estimation. The coefficients of determination ($R^2$) for public electricity consumption were 0.42–0.54. However, the coefficient of determination ($R^2$) for the $R_{pp}$ value was 0.861. The $R^2$ ranges from 0 to 1. When the $R^2$ is 1, the curve fitting of the regression model to target data set is perfect. Considering the restricted independent variables available and the actual energy consumption data that can be influenced by uncontrolled occupant activities, an $R^2$ of 0.861 for $R_{pp}$ is acceptable. The ASHRAE Handbook specifies that $R^2$ should not be less than 0.75\(^1\). Considering these results, the simple linear regression effectively expresses the relationship between the $R_{pp}$ values and the average number of building stories. The derived equation follows.

$$R_{pp}(electricity) = (0.0148 \times S + 0.092) \ldots (6)$$

Where

- $R_{pp} =$ public electricity consumption/private electricity consumption
- $S =$ average number of building stories

Fig.4. Electricity Consumption Profiles of 26 Residential Complexes

trends in public electricity consumption and $R_{pp}$ values with the number of floors in the residential complexes. The correlation coefficient between gross public electricity and the average number of building stories was 0.65. On the other hand, the correlation coefficient between $R_{pp}$ values and the average number of building stories was 0.93. These results indicate that $R_{pp}$ values have a stronger positive relationship with the average number of building stories than gross public electricity consumption. Residential complex 22 shows abnormally high electricity consumption. The purpose of the study is to establish a robust regression model for general residential complexes. For this reason, residential complex 22 was excluded in the regression model. Considering the simple linear regressions expressed in Fig.5., the $R_{pp}$ value is more appropriate for the public electricity consumption estimation. The coefficients of determination ($R^2$) for public electricity consumption were 0.42–0.54. However, the coefficient of determination ($R^2$) for the $R_{pp}$ value was 0.861. The $R^2$ ranges from 0 to 1. When the $R^2$ is 1, the curve fitting of the regression model to target data set is perfect. Considering the restricted independent variables available and the actual energy consumption data that can be influenced by uncontrolled occupant activities, an $R^2$ of 0.861 for $R_{pp}$ is acceptable. The ASHRAE Handbook specifies that $R^2$ should not be less than 0.75\(^1\). Considering these results, the simple linear regression effectively expresses the relationship between the $R_{pp}$ values and the average number of building stories. The derived equation follows.

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Fig.5. Variations of (1) Public Electricity Consumption and (2) $R_{pp}$ Values as the Number of Building Stories Increases

Table 2. Electricity Consumption for Private and Public Use of 26 Residential Complexes (187 Buildings)

| No. | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Number of residential units | 628 | 498 | 2,269 | 229 | 246 | 1,322 | 408 | 2,811 | 87 | 533 | 1,136 | 1,495 | 661 |
| Number of buildings | 22 | 13 | 6 | 3 | 3 | 14 | 7 | 21 | 1 | 7 | 15 | 31 | 10 |
| Average number of stories | 5 | 5 | 15 | 15 | 15 | 16 | 17 | 18 | 20 | 20 | 20 | 20 | 20 |
| Public electricity consumption (MWh) | 521 | 358 | 1,360 | 230 | 313 | 1,303 | 607 | 2,575 | 70 | 498 | 1,130 | 1,334 | 2,308 |
| Private electricity consumption (MWh) | 2,241 | 1,842 | 6,066 | 882 | 883 | 4,666 | 1,578 | 10,005 | 287 | 2,040 | 4,026 | 5,151 | 4,644 |
| $R_{pp}$ value (Public/Private) | 0.23 | 0.19 | 0.22 | 0.26 | 0.35 | 0.28 | 0.38 | 0.26 | 0.24 | 0.24 | 0.28 | 0.26 | 0.50 |

Fig.4. Electricity Consumption Profiles of 26 Residential Complexes
Table 3. Difference in $R_{wp}$ Values between Low-rise and High-rise Residential Complexes

| Type of building | F-test | T-test |
|------------------|--------|--------|
|                  | F     | P-critical | P-value (1-tailed) | Mean | Std. error | P-value (1-tailed) |
| All buildings (n=26) | -    | -         | 0.545             | 0.296 | -          | -                |
| Group A (under 30 stories, n=13) | 4.467 | 2.687     | 0.007*            | 0.286 | 0.082     | 1.03E-08*        |
| Group B (over 30 stories, n=13)  |        |           |                   | 0.804 | 0.172     |                  |

* P < 0.05

Table 4. Detailed Annual Energy Consumption Profiles of Individual Residential Units for 26 Residential Complexes

| No. | Number of residential units | Average number of stories | Site energy consumption (kWh/a) | CO$_2$ emissions (t-CO$_2$/a) |
|-----|-----------------------------|---------------------------|--------------------------------|-------------------------------|
|     |                             |                           | Electricity (public)            | Electricity (private)          |
| 1   | 628                         | 5                         | 830                            | 3,568                         |
| 2   | 498                         | 5                         | 719                            | 3,699                         |
| 3   | 2,269                       | 5                         | 599                            | 2,673                         |
| 4   | 229                         | 15                        | 1,004                          | 3,852                         |
| 5   | 246                         | 15                        | 1,272                          | 3,589                         |
| 6   | 1,322                       | 15                        | 986                            | 3,530                         |
| 7   | 408                         | 16                        | 1,488                          | 3,868                         |
| 8   | 2,811                       | 17                        | 916                            | 3,559                         |
| 9   | 87                          | 18                        | 805                            | 3,299                         |
| 10  | 533                         | 19                        | 593                            | 3,827                         |
| 11  | 1,136                       | 20                        | 959                            | 3,544                         |
| 12  | 1,495                       | 20                        | 1,348                          | 7,027                         |
| 13  | 1,964                       | 20                        | 1,420                          | 4,473                         |
| 14  | 322                         | 33                        | 1,870                          | 5,239                         |
| 15  | 646                         | 34                        | 1,474                          | 5,397                         |
| 16  | 450                         | 34                        | 1,164                          | 5,496                         |
| 17  | 663                         | 37                        | 1,720                          | 6,946                         |
| 18  | 407                         | 39                        | 1,273                          | 5,465                         |
| 19  | 579                         | 41                        | 1,070                          | 5,596                         |
| 20  | 742                         | 42                        | 960                            | 7,097                         |
| 21  | 253                         | 44                        | 859                            | 7,077                         |
| 22  | 1,307                       | 49                        | 716                            | 7,072                         |
| 23  | 815                         | 50                        | 555                            | 7,072                         |
| 24  | 1,179                       | 58                        | 554                            | 7,071                         |
| 25  | 468                         | 60                        | 551                            | 7,070                         |
| 26  | 481                         | 69                        | 548                            | 7,069                         |

The Korean building code defines a "high-rise building" as any building over 30 stories, and a building over 50 stories is defined as a "tall building". Most residential complexes with fewer than 30 stories (i.e., Nos. 1–13) had slightly lower $R_{wp}$ values, from 0.19 to 0.38, with No. 13 being an exception. On the other hand, the public/private electricity consumption ratio of residential complexes with more than 30 stories abruptly increased, with a range from 0.59 to 1.09.

Table 5 shows the results of an F-test and t-test on $R_{wp}$ values between the two building groups: buildings under 30 stories (Group A) and those over 30 stories (Group B). The F-value is higher than the F critical value, and the P-value is lower than the significance level of 0.05. Thus, the variances of the two groups are unequal. The result of a one-tailed t-test indicates that the $R_{wp}$ value for Group B is higher than for Group A. These results confirm the existence of different $R_{wp}$ values for low-rise and high-rise residential complexes.

4.2 Total Energy Consumption Profiles of Representative Residential Complexes

Annual site energy consumption data were only available for 15 residential complexes. The energy consumption profile per residential unit in each residential complex is described in Table 4 and Fig.6.

CO$_2$ emissions from low-rise building complexes were calculated using Equations 4 and 5.

A plant efficiency of 0.93 for district heat was applied for the calculations. High-rise residential complex 23 emitted about 10 times more CO$_2$ for public use electricity than low-rise residential complex 2. Fig.6. indicates that the ratio of CO$_2$ emissions from public-use electricity reaches 32% in high-rise residential complex 23. CO$_2$ emissions from public-use electricity comprised only 6% of the total CO$_2$ emissions per residential unit in low-rise residential complex 2. These results confirm that the energy consumption from public use should not be disregarded and should be reduced to achieve national CO$_2$ emissions reduction goals.

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Table 3 shows the results of an F-test and t-test on $R_{wp}$ values between the two building groups: buildings under 30 stories (Group A) and those over 30 stories (Group B). The F-value is higher than the F critical value, and the P-value is lower than the significance level of 0.05. Thus, the variances of the two groups are unequal. The result of a one-tailed t-test indicates that the $R_{wp}$ value for Group B is higher than for Group A. These results confirm the existence of different $R_{wp}$ values for low-rise and high-rise residential complexes.

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5. Modification of the Evaluation Tool

5.1 Suggested Modified Calculation Method

The modified calculation method for energy consumption in residential complexes can be established by making two suggested changes to the conventional evaluation tool: reflecting the total electricity consumption in a residential unit and including the electricity consumption for public use. First, in order to calculate the total electricity consumption in a residential unit, Equations 7 and 8 are suggested. Equations 7 and 8 have already been established in previous studies.\(^8,11\)

Equation 6 clearly shows the relationship between \(R_{pp}\) values and the average number of stories of the residential complexes. Thus, electricity consumption was calculated by multiplying \(R_{pp}\) values and electricity consumption in private use \((E_{eu})\) using Equation 9. Equation 5 was modified and expressed as Equation 10 by reflecting all electricity consumed, both private and public.

\[
\begin{align*}
E_{eu}(MJ) &= (0.72 \times A^2 - 0.25 \times A + 9112) \quad \text{(7)} \\
E_{eu}(MJ) &= (98.7 \times A + 5965) \quad \text{(8)} \\
E_{ep}\text{(electricity)} &= (0.0148 \times S + 0.092) \times E_{eu} \quad \text{(9)} \\
tCO_2\text{(electricity modified)} &= \left[N_{units} \times (E_{eu} + E_{ep})\right] \times 0.424 \times \frac{1}{3.6 \times 10^2} \quad \text{(10)}
\end{align*}
\]

Where
- \(E_{eu}\) = Baseline electricity consumption in an individual residential unit (MJ)
- \(E_{ep}\) = Baseline electricity consumption in public spaces per individual residential unit (MJ)

5.2 Verification of the Calculation Method for Electricity Consumption in Public Spaces

Equation 6 was established based on the electricity energy consumption data of all 26 residential complexes. Previous analyses indicated that \(R_{pp}\) values had a stronger positive relationship with the average number of building stories (correlation coefficient: 0.93). In addition, the simple linear regression model of Equation 6 had a higher \(R^2\) of 0.861. In this section, the error of the \(E_{ep}\) estimated by Equation 9 is evaluated. The mean absolute error (MAE) and the coefficient of variation of the root mean square error (CV (RMSE)) were calculated. The evaluation used actual electricity consumption in a residential unit instead of the baseline electricity consumption given in Equations 7 and 8 \(^8,11\). The MAE was 1,784 MJ and CV (RMSE) was 20.5%. Even though the CV (RMSE) was a little high, the suggested method gives meaningful results for a baseline of public electricity consumption in a residential complex based on actual energy consumption data. Fig. 7 illustrates the relationship between measured and estimated public electricity consumption in 26 residential complexes.

\[
\begin{align*}
\text{MAE} &= \frac{1}{n} \sum_{i=1}^{n} |E_i - M_i| \quad \text{(11)} \\
\text{CV(RMSE)} &= \sqrt{\frac{1}{n} \sum_{i=1}^{n} (E_i - M_i)^2} \times 100 \quad \text{(12)}
\end{align*}
\]

Where
- \(M\) = Measured electricity consumption in public spaces per individual residential unit (MJ)
- \(E\) = Estimated electricity consumption in public spaces per individual residential unit (MJ)
- \(M\) = The mean of measured electricity consumption in public spaces per individual residential unit (MJ)

Fig. 7. Measured and Estimated Public Electricity Consumption

6. Difference in the Evaluated CO\(_2\) Reduction Ratios from the Conventional and Modified Methods

6.1 Outline

The difference in CO\(_2\) emissions reduction ratios between the conventional and modified methods for residential building energy consumption estimation was evaluated. For the evaluation, several assumptions were made. Seoul was the location of the target residential complex. The floor area of a target residential unit was set at 100 m\(^2\). In addition, it was assumed that 500 residential units were included in the residential complexes. Three residential complexes with 5 stories, 25 stories, and 55 stories, respectively, were considered for the evaluation. A total reduction target of 40% in space heating, hot water, and electricity energy consumption was set.

6.2 Results and Discussion

In order to compare the conventional and modified methods for energy consumption in residential complexes, CO\(_2\) emissions were determined for each case. Tables 5. and 6. show the calculated CO\(_2\) emissions and reduction ratios using the conventional method and the modified method. The conventional method reflects only electricity consumption for lighting in a residential unit. The calculated result using the conventional method shows an underestimated CO\(_2\) emissions baseline and an identical CO\(_2\) reduction.
of 792 t-CO$_2$, regardless of the number of stories. The modified method reflects two factors: the total electricity consumption for private use in a residential unit and the electricity consumption for public use. Table 6 shows that the modified method results in both higher and more variable CO$_2$ emission baselines as the number of stories increases. In order to achieve a 40% reduction in total CO$_2$ emissions from tall residential complexes (55 stories), 1,462 t-CO$_2$ should be reduced when considering the total electricity consumption. This result is 1.85 times larger than that obtained using the conventional method. The actual CO$_2$ reduction rate using the conventional method in respect to the total CO$_2$ emissions amount is evaluated in Table 7. Table 7 also indicates the difference in CO$_2$ reductions from the conventional and modified methods. The results show that a 26.7% CO$_2$ reduction can be achieved in a low-rise residential complex using the conventional calculation method, considering a 40% energy reduction for space heating, hot water, and lighting. The results are very close to the national CO$_2$ reduction goal of 26.9%. In addition, the results are very similar to the study by Kim et al. (2015), which indicates that energy consumption for space heating, hot water, ventilation, and lighting in residential units comprises only 64.37% of the total primary energy consumption of residential complexes based on the energy consumption data of 181 residential complexes, including 173,258 residential units. Considering the data of Kim et al. (2015), a 26% reduction of total energy consumption in residential complexes in Seoul can be achieved by reducing 40% of the energy consumed for space heating, hot water, ventilation, and lighting. Energy consumption for ventilation is negligible in Korean residential buildings and, hence, the energy statistics do not address it. According to the results of this study and the study by Kim (2015), it seems that the current policy and energy calculation methods are only appropriate for low-rise residential complexes.

However, the estimated CO$_2$ reduction ratio using the conventional method decreases to 21.7% for high-rise residential buildings over 55 stories when the increased electricity consumption for public use is taken into consideration. Therefore, it is necessary to correct the energy estimation method and policy goal for CO$_2$ reductions from high-rise residential complexes.

7. Conclusions and Discussion

This study suggested a new method to evaluate CO$_2$ emissions from residential complexes. The modified method reflects the electricity consumption in public areas of a building. In South Korea, calculation methods for baseline energy consumption of a residential complex were established based on actual energy consumption. Thus, the new calculation method for public electricity was also established by analyzing the actual electricity consumption of 26 residential
complexes. The results of the study can be summarized as follows:

(1) The conventional evaluation method for energy consumption in residential complexes focusing on space heating, hot water, and lighting energy consumption is appropriate for use with low-rise residential complexes. When a 40% reduction in energy is performed for space heating, hot water, and lighting, a 26.7% reduction in total CO$_2$ emissions can be achieved for low-rise residential complexes. This value is very close to the national CO$_2$ reduction goal for the building sector (26.9%) in South Korea.

(2) However, the conventional method cannot meet the national CO$_2$ reduction goal for high-rise residential complexes due to the omission of data covering electricity consumption for plug load, cooling equipment, and public usage. Only a 21.7% reduction in CO$_2$ can be achieved, and an amendment of the energy calculation method and CO$_2$ reduction goal should be conducted.

Considering the results of this study, two options are available to meet the nationally mandated CO$_2$ reduction of 26.9% in the residential building sector: first, increasing the CO$_2$ reduction requirement slightly for high-rise residential buildings while maintaining the conventional evaluation method; or second, adopting the modified evaluation method reflecting realistic electricity consumption and adjusting the CO$_2$ reduction target for residential complexes to 26.9%.

This study deals with the number of building stories as a major variable for the regression model of actual public electricity consumption in Seoul. Thus, the suggested model can only be applied to residential complexes in South Korea. In addition, many other variables of residential complexes, such as stories of underground parking and lobby size, are not considered in the regression model for this study. In future studies, it is necessary to consider other potential variables that can impact total energy consumption in residential complexes for improving the energy estimation model developed in this paper.

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Notes

1 The Bin method defines the relation between the outside temperature or climate and the indoor heating cooling load.
2 CAPSOL is a thermal building simulation module of PHYSIBEL. This program is validated for ISO 13792, EN 15255, EN 15265. (http://www.physibel.be/v0n2cp.htm)

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