An evaluation of energy conservation measures for deteriorated single-family houses

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Abstract. The study analyzes the heating energy performance and water use reduction of the deteriorated single-family house with energy conservation measures (ECMs) such as double-glazing window, internal insulation, high-efficiency boiler, LED lightings, and water-saving closet. The building energy consumption and savings of each energy conservation measure are analyzed using the DesignBuilder program. The payback period and life cycle cost are analyzed to verify the indices of the cost effectiveness. As a result, the refurbishment of the internal insulation system is identified to be the most effective measure to save energy and cost. The simultaneous consideration of thermal insulation and high-efficient boiler helps the low-income bracket among the single-family houses of the old downtown area to increase their residential improvement.

1. Introduction
The large-scaled redevelopment of new town projects appears to cause the gentrification and disorganization of the local community. To avoid these side effects, the central government has implemented the Urban Regeneration New Deal Projects (URNDP) in South Korea. The URNDP focuses on refurbishing the deteriorated and declining residential environment. In this study, the priority analysis of energy conservation measures is identified to help the stakeholders understand the relevant types of building techniques to proceed the project with a limited budget.

2. Objectives
For the purpose, a single-family house is empirically selected as a reference model with different types of energy conservation measures. Based on the energy use calculated by the dynamic building energy program, the energy saving ratio, life cycle cost, and payback period are analyzed to determine the relative importance of the energy conservation measures.

3. Methods
3.1. Analysis of the input data
This study uses the reference model of Jung-Hwa Kim (2015) to simulate the building energy [1]. The reference model is based on the on-site survey data of 2,571 households living in detached houses among 3,061 households that received the subsidies of the construction costs for low-income households in 2013. The annual energy consumption of the reference model was calculated by using the simulation program, and different types of energy conservation measures have been applied to the reference model. The input data of energy simulation are shown in Table 1. The thermal insulation characteristics of the building envelope and the infiltration rate for the air tightness are as cited in the previous study [1].

Table 1. Input data of the reference model

[Table 1 content]

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| Classification          | Data     | Note (Source) |
|-------------------------|----------|---------------|
| Floor Area              | 44.5     | Jung-Hwa Kim (2015) [1] |
| Ceiling Height          | 2.3      | Jung-Hwa Kim (2015) [1] |
| Orientation             | South    |               |
| Thermal Transmittance   |          |               |
| Roof                    | 1.05     | Jung-Hwa Kim (2015) [1] |
| Wall                    | 1.05     | Jung-Hwa Kim (2015) [1] |
| Floor                   | 1.05     | Jung-Hwa Kim (2015) [1] |
| Window                  | 4.46     | Jung-Hwa Kim (2015) [1] |
| Door                    | 2.29     | Jung-Hwa Kim (2015) [1] |
| Location/Weather File   | Incheon  | IWEC          |
| Heating Setpoint (degrees Celsius) | 20  | KEA (2018) [11] |
| Infiltration for Air Tightness (ACH) | 1   | Jung-Hwa Kim (2015) [1] |
| Heating System (Oil-Fired) | Efficiency: 35% | Jung-Hwa Kim (2015) [1] |
| Lighting Density (W/m²) | 15       | Won-Seok Kim (2015) [8] |

Table 2. Initial investment and information of the energy conservation measures (100 KRW in Cutting)

| ECMs   | Items                      | Properties                                           | Unit Price [KRW/EA] | Quantity | Total [KRW] |
|--------|----------------------------|------------------------------------------------------|---------------------|----------|-------------|
| 1      | High Insulated Steel Door  | U-vale: 1.23 W/m²·K                                  | 324,000             | 1 EA     | 324,000     |
|        |                            | (Energy Saving Design Standards of Buildings, 2017)   |                     |          |             |
| 2      | Double-Glazed Window       | 5CL+12Air+ SLE w/PVC Framed U-vale: 1.58 W/m²·K      | 165,000             | 9 m²     | 1,485,000   |
|        |                            | (Energy Saving Design Standards of Buildings, 2017)   |                     |          |             |
| 3      | Internal Insulation System | EPS TYPE 2-2 100mm                                    | 16,000              | 78 m²    | 1,248,000   |
|        |                            | (Energy Saving Design Standards of Buildings, 2017)   |                     |          |             |
| 4      | LED Lighting               | Density : 10 W/m² [Power Consumption: 18W]           | 26,500              | 8 EA     | 212,000     |
|        |                            | (The construction of energy-saving, environmentally   |                     |          |             |
|        |                            | friendly housing standards, 2017)                    |                     |          |             |
| 5      | Condensing Gas-fired Boiler| Efficiency : 92.4% [Capacity: 18,000 Kcal/hour]      | 570,000             | 1 EA     | 570,000     |
|        |                            | (Energy Saving Design Standards of Buildings, 2017)   |                     |          |             |
| 6      | Stainless Oil-fired Boiler | Efficiency : 90% [Capacity: 17,000 Kcal/hour]       | 540,000             | 1 EA     | 540,000     |
|        |                            | (Energy Saving Design Standards of Buildings, 2017)   |                     |          |             |
| 7      | Condensing Oil-fired Boiler| Efficiency : 98% [Capacity: 16,400 Kcal/hour]       | 942,000             | 1 EA     | 940,000     |
|        |                            | (Energy Saving Design Standards of Buildings, 2017)   |                     |          |             |
| 8      | Water-Saving Closet        | 6 litter / flush                                     | 370,000             | 1 EA     | 370,000     |
|        |                            | (Water Supply and Waterworks Installation Act, 2017)  |                     |          |             |

3.2. Selection of the energy conservation measures
The following energy conservation measures are selected: highly insulated steel door, double-glazed window, LED lighting, and condensing gas-fired boiler. To improve the application of the research findings, renewable energy systems such as photovoltaics and geothermal heat pump systems are excluded due to the high initial cost. The selected ECMs were derived in accordance with Appendix Table 1 of the establishment of standards of the long-term repair plans, article 7 of Apartment Housing Management Act Enforcement Regulations [2] and the precedent study of Sung Wan Kim (2017) [3]. The cost of each energy conservation measure is based on the price quotes from the suppliers and the standard estimating costs for construction work. The detailed information of the energy conservation measures is as shown in Table 2.

3.3. Indices for the cost effectiveness analysis
The annual energy usage is classified by the heating, domestic water heating, lighting, etc. The monthly data of the heat source was used to calculate the energy rate. The main heating source for energy conservation is the lamp oil excluding the condensing gas-fired type. The energy rate of each heat source was calculated as follows.
Electric energy rate (KRW/Year) = (Basic Rate [KRW/Year] + Energy Rate [KRW/Year]) +
(Basic Rate [KRW/Year] + Energy Rate [KRW/Year] × 3.7% (Power industry fund part)) +
(Basic Rate [KRW/Year] + Energy rate [KRW/Year] × 10%(Value added tax))

(1)

Energy consumption reduction [%] = ((Reference Model Energy consumption [kWh/year] – Alternative Energy Consumption [kWh/year]) ÷ Baseline Energy consumption [kWh/year]) × 100

(2)

Payback Period [year] = Initial investment of each Energy Conservation Measures [KRW] ÷ Life Cycle Cost Reduction [KRW]

(3)

Life Cycle Cost [KRW] = Initial investment of each Energy Conservation Measures [KRW] +
\[\frac{1}{1+i}(\frac{1+i}{1+r})^{n-1} \times Energy cost \ (KRW/year)\]

(4)

| Table 3. Electric rates (KEPCO Residential Low Power 2016.12.01.) |
|---------------------------------------------------------------|
| Basic Rate [KRW/Household] | Energy Rate [KRW/kWh] |
|-----------------------------|-----------------------|
| Below 200 kWh               | 910                   |
| 201 ~ 400 kWh               | 1,600                 |
| Exceed 400 kWh              | 7,300                 |

| Table 4. Price of lamp oil (Oil Price Information Service, Opinet, Korea National Oil Corporation 2018.07) |
|--------------------------------------------------------|
| Classification | Unit Price [KRW/litres] |
|----------------|-------------------------|
| Lamp Oil       | 942.2                   |

| Table 5. Price of LPG (Residential, Korea LPG Association) |
|---------------------------------------------------------|
| Classification | Unit Price [KRW/kg] |
|----------------|--------------------|
| LPG            | 1,945              |

In terms of the cost effectiveness indices, the payback period and life cycle cost were analyzed based on the annual energy consumption and energy cost. Each investment of energy conservation measures refers to the construction cost and operating cost for the building’s life cycle, which define the energy rate. The life cycle cost is calculated based on formula (6). The inflation rate (i) is 3.19% on average, which represents the consumer price index for 10 years from 2001 to 2010 [4]. The interest rate is 6.30% based on the average data for 10 years from 2001 to 2010 by the Bank of Korea. The life cycle of a single-family house is set at 40 years. The unit price of each energy conservation measure is calculated based on the national currency (KRW).

4. Results

4.1. Indoor water use reduction through the water-saving closet

The economic feasibility of the water-saving closet is analyzed. The cost effectiveness of the water-saving closet with 6 litres per flush is analyzed in comparison with the existing water closet. In a single-family house, only one water-saving closet has been replaced. Based on the literature survey, the specification of the existing water closet is shown in Table 6. The water rate is shown in Table 7.

Toilets Bowl Water Usage [year] = Water Usage (liters/flush) × Number of Uses (Daily) × 30day × 12months

(5)
\[
W_{rates \ [year]} = \{Basic \ Rate \ + \ (Annual \ Water \ Usage \ (m^3)) \times (Water \ Utility \ Bill \ (Usage \ Fee) \ (KRW/ m^3)) + Sewage \ Bill \ + Allotted \ Charge \} \times 12 \ months
\]

(6)

Table 6. Information of the water rates (Source: Office of Waterworks, Seoul Metropolitan Government, 2018)

| Classification                  | Water Rate (Korean Won) |
|---------------------------------|-------------------------|
| Basic Rate                      | 1,080                   |
| Water Utility Bill (Usage Fee) (KRW/m³) | 550                     |
| Sewage Bill (KRW/m³)            | 850                     |
| Allotted Charge (KRW/m³)        | 170                     |
| Total charges = 1) Water Utility Bill + 2) Sewage Bill + 3) Allotted Charge |

Table 7. Economic analysis of the water closets

| Classification             | Baseline 1 | Baseline 2 | Water-saving toilet |
|----------------------------|------------|------------|---------------------|
| Water Usage (litter/Flush) | 13         | 19         |                     |
| Daily Usage (Frequency)    | 20         | 20         |                     |
| Usage (m³)                 | Daily      | 0.260      | 0.380               |
|                            | Monthly    | 7.3        | 11.4                |
|                            | Yearly     | 93.6       | 136.8               |
| Water Bill (KRW/year)      | Basic      | 12,960     | 12,960              |
|                            | Water Utility | 51,480     | 75,240              |
|                            | Sewage     | 79,560     | 116,280             |
|                            | Allotted Charge | 15,912     | 23,256              |
| Total Water Bill (KRW/year)| 159,912    | 227,736    | 80,784              |
| Proposed Water Usage Saving Ratio (%) | Compared to Baseline 1 | 54 |
| Proposed Yearly Reduced Cost (KRW) | Compared to Baseline 1 | 79,128 |
| Payback Period (year)      | Compared to Baseline 1 | 4.7 |

According to the calculation results, the cost of the annual water rate is 159,912 KRW if the water consumption of the existing water closet in baseline 1 is 13 litres per flush. With the water-saving closet, the annual water rate is 80,784 KRW. The water rate saving is 79,128 KRW compared to baseline 1. In terms of economics, the expected payback period values of the water-saving closet are 2.5 years and 4.7 compared to baseline 1 and baseline 2, respectively. In an enforcement regulation of the Housing Act, the entire replacement time of a water closet is every 20 years. Thus, replacing the existing water closet with the water-saving closet has a distinct effect on the water consumption saving and water charge.

4.2. Heating energy performance of the energy conservation measures

The energy performance of the reference model is shown in Table 8. The analysis results are shown in Table 9. The negative saving ratio indicates that the energy consumption increases compared to the reference model. The energy conservation measure with the highest energy-saving ratio is the internal insulation system. For the high-insulated steel door, the energy saving ratio is 0.16% compared to the baseline. In terms of the area of the door in comparison with the wall, the door-to-wall ratio except the roof and floor is only 1.87%. However, this study did not consider the effect of the improved air tightness of the high-insulated steel door due to the shortage of information of the deteriorated single-family houses before and after the airtightness. This process was developed to further analyze the improvement of the high-insulated steel door for the outdoor air load and heat load by transmittance. The condensing gas-fired boiler has good energy-efficient performance by reusing the latent heat of vapor, which
corresponds to the temperature range of 40-50 degree Celsius. It has shown 14% of energy saving compared to the reference model.

Table 8. Energy performance results of the reference model

| Classification | Monthly Energy Performance Results | Usage (kWh) | Energy Rate (KRW) |
|----------------|-----------------------------------|-------------|------------------|
|                | Electricity | Fuel | Electricity | Fuel |
| JAN.           | 204         | 3,674| 23,880      | 364,374       |
| FEB.           | 184         | 2,994| 16,000      | 296,918       |
| MAR.           | 202         | 2,406| 23,450      | 238,657       |
| APR.           | 191         | 1,333| 16,740      | 132,213       |
| MAY            | 193         | 591  | 16,950      | 58,626        |
| JUN.           | 185         | 46   | 16,100      | 4,562         |
| JUL.           | 189         | 16   | 16,520      | 1,566         |
| AUG.           | 190         | 32   | 16,640      | 3,132         |
| SEP.           | 184         | 107  | 16,000      | 10,572        |
| OCT.           | 195         | 783  | 1,160       | 77,629        |
| NOV.           | 194         | 1,912| 17,060      | 189,678       |
| DEC.           | 204         | 1,197| 23,880      | 171,123       |
| Sum            | 2,314       | 5,009| 220,380     | 1,695,051     |
| Normalize by floor area | | 52.6 | 388.43 | 8,524 |

4.3. Priority analysis of the energy conservation measures through the cost efficiency indicators

Based on the initial construction cost and annual energy saving save, the priority analysis results are shown in Table 9. The energy conservation measure with the highest energy usage saving is the internal insulation reinforcement. The condensing oil-fired boiler shows the shortest period of payback. In case of ECMs 5, the high-efficiency condensing gas fired boiler using LPG exceeds the payback period. When the condensing gas-fired boiler is applied, the region where the LNG supply pipe is installed is adequate. Because LNG is much cheaper than LPG in South Korea, to analyze the correlation of the cost among energy conservation measures, the index for the required additional cost for 1% energy consumption saving was investigated. As shown in Table 9, the condensing oil-fired boiler most effectively achieves the highest energy saving with the lowest cost.

Table 9. Priority analysis of the energy conservation measures

| ECMs | Energy & Water Saving Ratio | Initial Expense | Energy Rate by Energy Source (KRW/year) | Total Energy Rate | Energy Rate Savings | Payback Period | Increasing Cost per Energy Saving Ratio | Life Cycle Costing |
|------|-----------------------------|-----------------|------------------------------------------|-------------------|---------------------|----------------|----------------------------------------|-------------------|
|      | %                           | KRW             | Electricity                              | Fuel              | KRW/year            | KRW/year       | KRW %                                  | KRW               |
| Reference Model | - | 220,380 | 1,695,051 | 159,912 | 2,075,343 | - | - | - | - | 47,863,788 |
| 1    | 0.16 | 324,000 | 220,380 | 1,692,127 | 159,912 | 2,072,419 | 0.14 | 110.8 | 2,314,286 | 48,120,356 |
| 2    | 4.34 | 2,310,000 | 220,710 | 1,579,150 | 159,912 | 1,959,772 | 5.57 | 12.9 | 266,607 | 46,683,376 |
| 3    | 8.64 | 2,624,000 | 213,020 | 1,579,150 | 159,912 | 1,414,129 | 19.95 | 1.0 | 62,556 | 39,580,708 |
| 4    | -0.03 | 212,000 | 140,590 | 1,754,192 | 159,912 | 2,054,694 | 0.99 | 10.3 | 212,000 | 47,599,567 |
| 5    | 5.70 | 570,000 | 224,110 | 1,874,656 | 159,912 | 1,435,335 | -71.47 | -0.2 | 3,778 | 82,344,070 |
| 6    | 4.89 | 540,000 | 220,380 | 1,600,881 | 159,912 | 1,981,178 | 4.54 | 5.7 | 118,843 | 46,231,951 |
| 7    | 19.16 | 942,000 | 220,380 | 1,326,388 | 159,912 | 1,706,680 | 17.76 | 2.6 | 53,041 | 40,303,306 |
| 8    | 54.00 | 370,000 | 224,110 | 1,695,051 | 159,912 | 1,999,945 | 3.81 | 4.7 | 97,113 | 46,408,852 |

5. Conclusion
This study results in the following key findings. First, the energy conservation measure with the highest energy-saving ratio is the internal insulation system. Second, the annual energy saving rates of the internal insulation and high-efficiency condensing oil-fired boiler are 19.95% and 17.76%, respectively. Third, the high-efficiency condensing oil-fired boiler has the shortest payback period among the energy conservation measures. In terms of life cycle cost, the internal insulation system is the most effective in the long term. For future study, the field measurements and on-site testing in single-family houses or test-beds must be performed in accordance with the empirical validation of this study. Additional research methodology is required to consider the option D calibrated simulation of determining energy and water saving volume 1 by the international performance measurement & verification protocol. The analysis of the residential environment improvement in the small-scaled urban redevelopment appears to be important for the Urban Regeneration New Deal Projects and zero energy building plan in South Korea.

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