Heating energy cost analysis and economic evaluation of the airtightness level of multi-unit Residential building

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ABSTRACT [*major heading style: Bold 12 pt, UPPERCASE*]
Air infiltration increases the heat loss through the building envelope, which leads to a rise in energy costs. Increasing the airtightness of a building is an important means of reducing energy costs. However, the final construction costs and the increased airtightness can be confirmed through inspection only after construction has been completed. In this study, the relationship between the airtight construction costs and the consequential decreased energy consumption was analyzed using payback period analysis. It is expected that the result can be used as determining the desired airtightness value according to the airtight construction costs and the payback period in the construction planning or designing stage.

KEYWORDS
Airtightness construction, Payback Period Analysis, Energy cost, Cost-effectiveness Analysis

INTRODUCTION

Heat transfer through infiltration is a continuous process during the life span of a building, which increases the energy cost. Therefore, it is often recommended to improve the airtightness of the building envelope by applying airtightness measures as an energy conservation method. Previous studies on the cost-effectiveness of increasing airtightness by retrofitting existing buildings showed an 18% decrease in the air infiltration rate through the building envelope and a 10% decrease in energy consumption.(Steven Nabinger., 2011) Furthermore, a study on the economic benefits of improving the efficiency of building envelopes in residential buildings in the UK showed that increasing the airtightness resulted in about 9% contribution to the reduction in heating energy. (M.C. Gillott et al., 2016) Previous studies focused on the reduction in energy cost by improving the airtightness of existing buildings. In addition to research on reducing energy consumption by increasing airtightness, it is also necessary to study the effect of an increase in airtightness on the construction

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costs. In this study, areas suitable for improving airtightness in apartments and buildings were selected. The reduction in energy costs was calculated according to the increased airtightness and the investment in airtight construction. Additionally, the payback period for the initial investment was calculated according to the level of airtightness. The results of this study will be useful when determining the desired level of airtightness in the planning and designing stages.

METHOD

In order to assess the reduction in energy costs as a result of airtight construction and the payback period for the construction costs, representative unit households were selected and major areas susceptible to high air infiltration were targeted for airtight construction. The areas targeted for airtight construction were selected based on the results of previous studies. The projected construction costs were calculated and divided into case 1 and case 2, according to the construction materials and the methods used. In order to calculate the reduction in energy cost, the airtightness in the selected apartments was increased from the standard value of 3.0 ACH50 in increments of 0.5 units of measure. The annual heating load was assessed using HDD and the reduction in energy costs was calculated. In calculating the initial investment costs used to construct airtightness measures and the consequential yearly reduction in energy costs, inflation in the energy sector was taken into account. Payback period analysis, which is a method used to analyze economic feasibility, was used to calculate the payback period of the initial construction costs (airtight construction cost).

SELECTION OF AIRTIGHT CONSTRUCTION AREAS TO CALCULATE AIRTIGHT CONSTRUCTION COSTS

A Sample Unit of Multi-unit Residential Building

An apartment unit with a layout and area typical of those found in Korea was selected as the sample building. It had an exclusive using area of 84 m2, with a height of 3 m and volume of 316.6 m3.

Selecting Airtight Construction Areas

The airtightness of each area experiencing leakage in the multi-unit residential building was measured and categorized. (Park et al., 2007) The airtightness of apartment fittings was measured to establish the leakage distribution rate. (Shin et al., 2013) In this study, the areas targeted for airtight construction were selected based on previous research that studied the building envelope and openings as well as points where piping and cables penetrate the building. The areas selected for airtight construction were marked on the apartment unit blueprint as shown below.

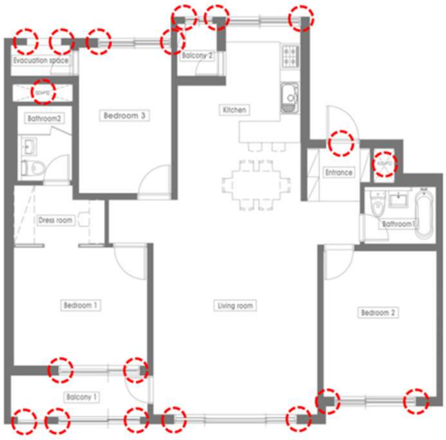
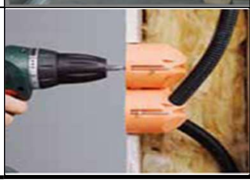


Figure 1. Air barrier strategies for a sample unit of multi-unit residential building.

INITIAL COST

The initial investment costs only covered costs related to airtight construction, which included materials and labor. The current market prices were used to calculate the material costs, and in the case of materials for which market prices were not readily available, the costs were calculated from a quotation by the manufacturing company. Regarding labor costs, the quantity per unit method for construction work was used to calculate the projected construction costs. The initial investment cost was thus analyzed for the two cases. Case 1 used a sealant on the airtight construction areas for caulking the infiltrating sections. Case 2 used certified materials for airtightness, such as airtight windows and doors (highest efficiency rating), airtight tape, and expanding sealing tape. Case 1 and case 2 had estimated construction costs of 500,000 won and 14,700,000 won, respectively.

Table 1. *Exterior Air barrier strategies and case*

Air barrier strategy	*Case*	
	1	*2*
• Air barrier of structure floor - external wall joint , Wall - wall joint Wall - window joint , Dry wall- dry wall joint AD/PD shaft voids/holes, pipe penetration		
• Air barrier of opening Front door , Front door frame joint windows and doors frame joint Windows and frame separation distance Ventilator grills		
• Others Electrical outlet Door interphone cable box Installed Lighting fixture penetration		

HEAT ENERGY DEMAND

In order to calculate the infiltration load, the infiltration load formula from ASHRAE (2003) was used. The heating load was calculated according to the air infiltration rate.

$$q = Q\rho C_p \Delta t \qquad (1)$$

Where q is heat load(W), Q is airflow rate(m^3/h), ρ is air density(kg/m^3), $C_p$is specific heat of air(J/kg가 가 K) and Δt is temperature difference between indoors and outdoors(K). The annual heating load was calculated as shown below.

$$q_{heat} = 24Q\rho C_p HDD \qquad (2)$$

For HDD, weather data recorded in Seoul over the last 10 years was used to calculate the average heating degrees and days. Previous studies on result of airtightness test for multi-unit residential building showed average values of 2.59 ACH50 and 3.37 ACH50. In this study, a standard value of 3.0 ACH50 for a typical apartment was selected based on previous studies. For comparison, ACH50 values of 2.5, 2.0, 1.5, and 1.0 were each selected, as well as 0.6, a standard value for passive houses. In converting the units to cost, each of the load calculations was represented as gas and electricity costs.

Table 2. *Average Heating degree days and Annual Heat Demand*

City	*Average Heating degree days (℃·days)*	*Annual Heat Demand (Kwh)*					
		ACH50 3.0	*ACH50 2.5*	*ACH50 2.0*	*ACH50 1.5*	*ACH50 1.0*	*ACH50 0.6*
Seoul	2590.4	4174.93	3479.11	2789.28	2087.46	1391.64	834.99

CALCULATION IF ENERGY COST

Inflation was taken into consideration in calculating the predicted yearly reductions in energy cost. The predicted average rate of inflation in the cost of electricity and gas in South Korea over the next 10 years was reflected in the calculations. The calculation formula is shown below.

$$\text{Future value} = R \times (1 + r)^{n-1} \qquad (3)$$

Where R is Present value, r is interest rate, n is year. The graph in Figure 1 shows the change of heating cost with airtightness efficiency. The slope of the graph shows a steep increase since the cost of gas increased by 5.03%, while the cost of electricity only increased by 1.11%.

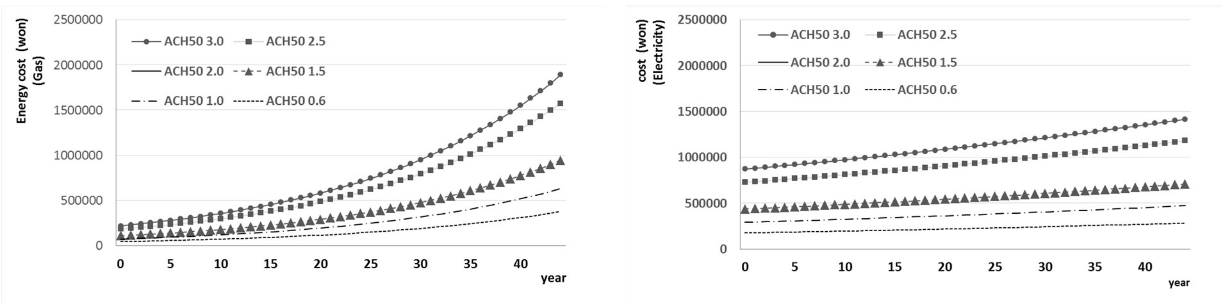


Figure 1. *Heating energy cost with increased airtightness (gas, electricity)*

RESULTS OF ECONOMIC EVALUATION

In this study, the payback period method, which is a method used to determine the economic evaluation of a building, was used to estimate the payback period for the airtight construction costs. Figures 2 and 3 show the accumulated reduction in the cost of gas and electricity with increased airtightness. From these figures, it was possible to deduce the payback period for the airtight construction costs.

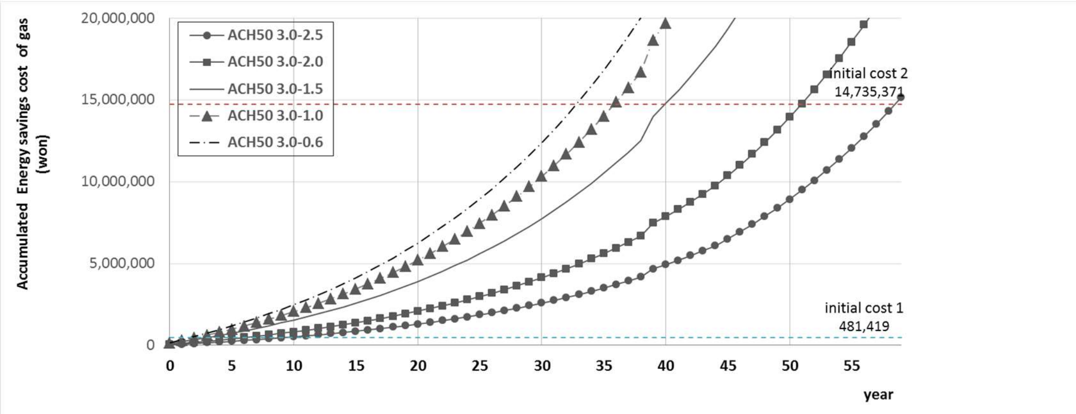


***Figure 2**. The reduction in energy costs and payback period for airtight construction cost with increased airtightness (Gas)*

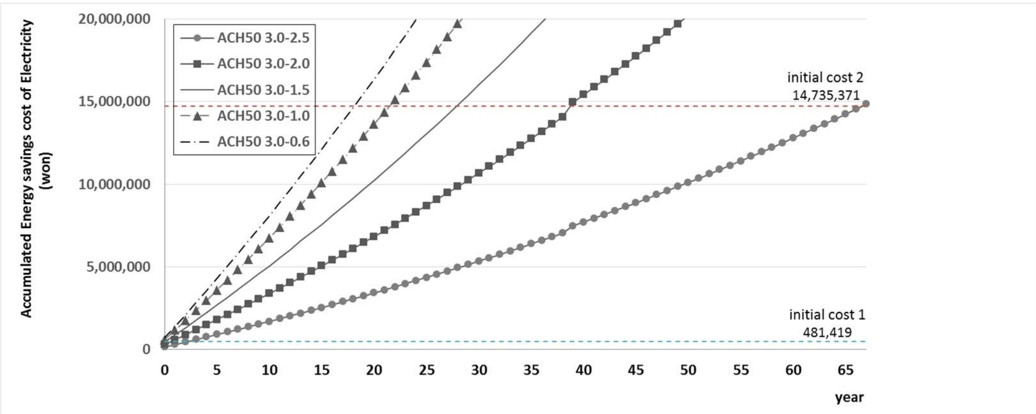


***Figure 3**. The reduction in energy costs and payback period for airtight construction cost with increased airtightness (Electricity)*

For case 1, the payback period varied between 1 to 10 years depending on the airtightness. The fastest payback period occurred when the airtightness was increased from 3.0 to 0.6, resulting in 2.24 years when using gas for heating and 0.69 years when using electricity. The payback period for case 2 ranged from 18 to 48 years, depending on the airtightness. The fastest payback period also occurred when the airtightness was increased from 3.0 to 0.6, resulting in 33 years when using gas and 18 years when using electricity. Considering that the life span of a steel concrete building is 40 years, case 2 was found to be uneconomical, as the payback period when using gas for heating was over 30 years. It can be speculated that the difference in the rate of inflation for gas and electricity resulted in the difference in the rate of increase of the graph, which affected the payback period.

CONCLUSIONS

In this study, the reduction in energy costs and the airtight construction costs were analyzed using the payback period method in order to calculate the payback period for the airtight construction costs. The analysis on sample apartment units showed that the payback period for the investment cost shortens with an increase in airtightness. The payback period for case 2, depending on the airtightness method, was over 30 years and it was concluded that it is not economically feasible. The results from this study can be used to anticipate the payback period and target on the appropriate airtightness value in the construction, design, and planning stages. In this study, reference data on construction materials, costs, and hypothesized factors were used to currently obtainable data. In the future, when additional data can be secured, it will be possible to achieve results that are more accurate.

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REFERENCES

ASHRAE. 2013. 2013 ASHRAE Handbook-Fundamentals, Chapter 16: Ventilation and Infiltration. Atlanta: American Society of Heating, Refrigerating and

Air-Conditioning Engineers, Inc.

Steven Nabinger, Andrew Persily. Impacts of airtightening retrofits on ventilation rates and energy consumption in a manufactured home. Energy and Buildings 43(2011) 3059-3067

Korea Price information, Corp.

http://www.kpi.or.kr

Korean Statistical information Service. http:// Kosis.kr

Korea Energy Statistics Information System. http://kesis.net

Kyung Hwan JI. 2015. Characteristics and prediction of airtightness for high-rise reinforced concrete residential buildings. Department of architectural engineering, Inha University, Incheon

M.C. Gillott , D.L. Loveday , J. White , C.J. Wood , K. Chmutina , K. Vadodaria.

Improving the airtightness in an existing UK dwelling: The challenges, the measures and their effectiveness. Building and Environment 95 (2016) 227e239

Shin, Hyun-Kook, Cho, Hyun, Kim, Kwan-woo, Jo Jae-Hun. 2010 A study on Airtightness of Building Components in The High-rise Building. Journal of architectural engineering

Shin Hyun Kook, Jo Jae Hun. 2013 Air Leakage Characteristics and Leakage Distribution of Dwellings in High-rise Residential Buildings in Korea. Journal of Asian Architecture and Building Engineering 12(1), 87-92, Sun Hyo Park, Jong Seo Won, Jae Hun Jo, 2007. The present status of the building airtightness according to construction work manship. Journal of kieae 12 (2007-06)

The Construction Standard on Low-Energy Green House and Performance. Ministry of Land, Infrastructure and Transport, Korea, 2012-661

Article 2, section 3 of the Renewal District by built environment renewal development act

Fanger PO. 1970. *Thermal Comfort*. Copenhagen: Danish Technical Press.

Hanzawa H, Melikov AK, and Fanger PO. 1987. Air flow characteristics in the occupied zone of ventilated spaces, *ASHRAE* Transactions. 93 : 10-20.

Kimura K. and Tanabe S. 1993. Recommended air velocity against combinations of temperature and humidity for sedentary occupants in summer clothing, *Proceedings of the 6th International Conference on Indoor Air Quality and Climate – Indoor Air '93,* Helsinki: Indoor Air '93, Vol 6, pp 61-66.