

# Economical evaluation of damaged vacuum insulation panels in buildings

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**Abstract.** In Korea, thermal insulation standard of buildings have been tightened annually to satisfy the passive house standard from the year 2009. The current domestic policies about disseminating green buildings are progressively conducted. All buildings should be the zero energy building in the year 2025, obligatorily. The method is applied to one of the key technologies for high-performance insulation for zero energy building. The vacuum insulation panel is an excellent high performance insulation. But thermal performance of damaged vacuum insulation panels is reduced significantly. In this paper, the thermal performance of damaged vacuum insulation panels was compared and analyzed. The measurement result of thermal performance depends on the core material type. The insulation of building envelope is usually selected by economic feasibility. To evaluate the economic feasibility of VIPs, the operation cost was analyzed by simulation according to the types and damaged ratio of VIPs

## 1. Introduction

### 1.1. Background of study

The Korean government has pursued intensive building energy saving policies in the area of building that takes about 21% of total energy consumptions [1]. In addition, various kinds of related technology have been developed and utilized for application of passive house and zero energy building. One of the core technologies for such zero energy building is the application of high-performance thermal insulation [2-5]. Recently, Vacuum insulation panels (VIPs) are installed in building envelopes since VIPs have considerably high thermal performance compared to existing thermal insulation [6-8]. There are various kinds of core materials for VIPs such as glass wool, fumed silica, polyurethane, and polystyrene. Core materials keep the form of an envelope and block the movement of internal gas molecule, minimizing heat transfer. Glass wool and fumed silica are mainly used for the core material [9].

### 1.2. Application of VIPs in building

It is necessary to evaluate the performance variation of VIPs by vacuum condition of the panel since vacuum condition can be destroyed at the time of construction. When the vacuum of VIPs is destroyed, convective heat transfer inside of the insulation panel greatly increases, the thermal performance decreases.

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The insulation of building envelope is usually selected by economic feasibility which is based on life cycle cost [10, 11]. In case of VIPs, thermal performance which significantly influences the operation cost depends on the condition of vacuum condition of VIPs. In this paper, to evaluate the economic feasibility of VIPs, the initial and operation cost was analyzed by simulation according to the types and the ratio VIPs whose vacuum condition was destroyed.

## 2. Experimental methods

### 2.1. Measurement of Thermal Conductivity of VIPs

This study measured thermal conductivity of normal VIPs and damaged VIPs which vacuum is destroyed by boring a hole. GW VIP and FS VIP were measured and the core materials of the panels were glass wool and fumed silica respectively. The thermal conductivity was measured heat flux method according to KS L 9016 [12] with HFM 436/3/1E Lambda of NETZSCH Instruments, Inc. as shown in figure 1.



**Figure 1.** Equipment for thermal conductivity measurement.

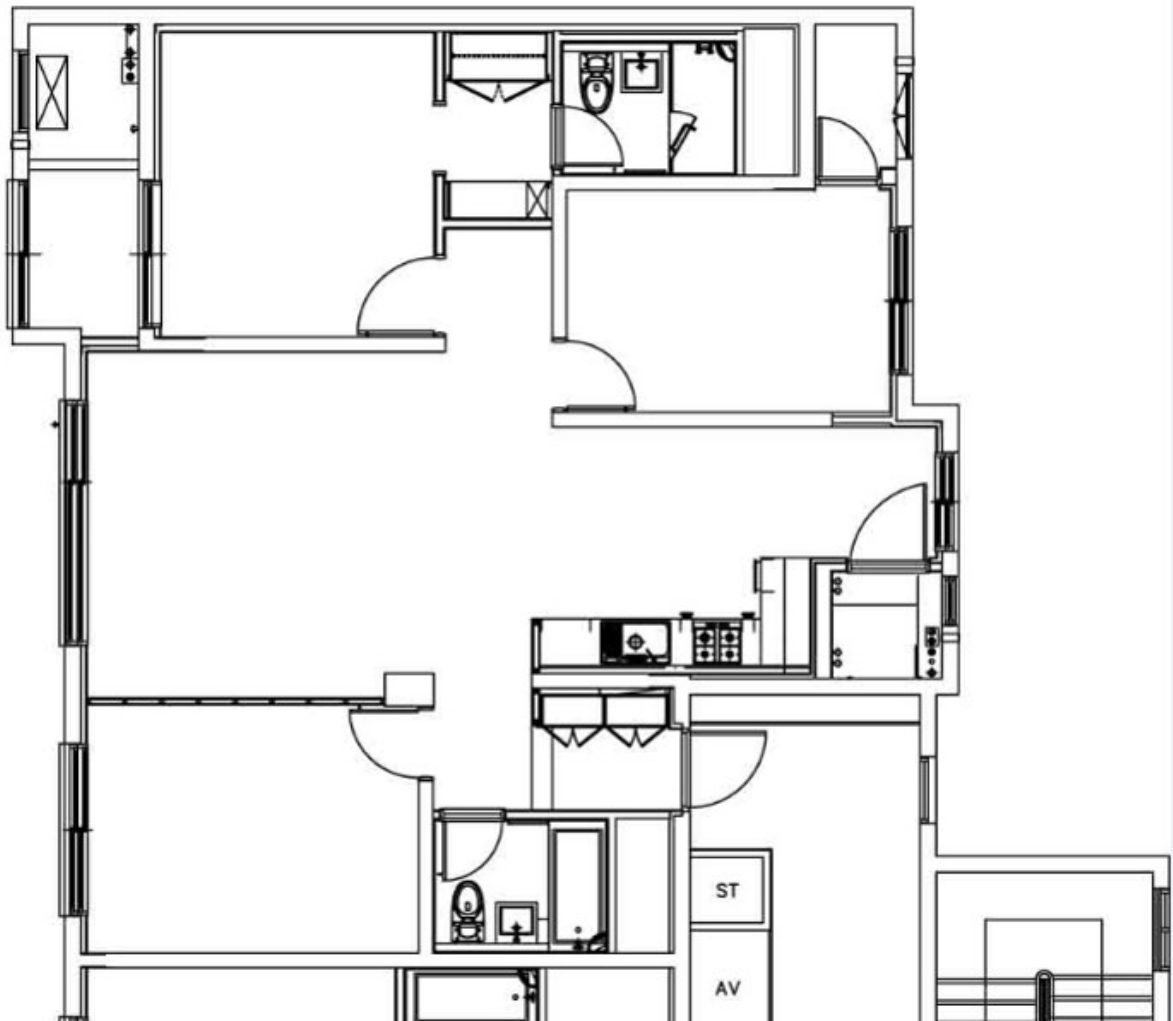
### 2.2. Energy simulation and economic feasibility

TRNSYS software was used to simulate heating energy consumption of apartment housing according to the types and ratio of damaged VIPs. 9 cases of damaged ratio from 0 to 100% were applied to the simulation and the damaged ratio was calculated by dividing the number of the VIPs whose vacuum condition was destroyed by the total number of VIPs which were installed.

VIPs for building envelope are usually installed as external insulation system and other heat bridge was not considered in this simulation. The condition of the simulation is listed in table 1 and the floor plan of the housing is shown in figure 2. Because the heating load is dominant in housing buildings and the cooling load depends on the lifestyle of occupants in Korea, the simulation was focused on the heating load.

**Table 1.** Conditions of simulation.

| Contents                           | Condition  | Remark               |
|------------------------------------|--|----------------------|
| Weather                            | Seoul(TMY2)  |                      |
| Gloss area                         | 80 m <sup>2</sup>                                  |                      |
| Wall area which VIPs are installed | 74.389 m <sup>2</sup>                              |                      |
| Occupants                          | 3 persons  | 2 adults and 1 child |
| Set temperature for heating        | 23°C   |                      |
| Operating Schedule                 | Weekday : 19:00 – 08:00<br>Weekend : 17:00 – 11:00 |                      |
| Ventilation rate                   | 0.5 Air change rate per hour                       |                      |
| Infiltration rate                  | 0.2 Air change rate per hour                       | Constant             |
| Heating source                     | City gas   |                      |
| Efficiency of the boiler           | 87%  | Typical boiler       |



**Figure 2.** Floor plan of the typical apartment housing.

In life cycle cost analysis, the unit price of gas for heating was 72.02 \$/MWh [13]. To calculate the initial cost, the cost of VIPs and installation cost of VIPs were surveyed. The costs of GW VIP and FS VIP were 36.36 \$/m<sup>2</sup> and 32.73 \$/m<sup>2</sup> respectively and the cost of installation was 13.64 \$/m<sup>2</sup> for both types of VIPs.

The nominal interest rate was applied to the average of the interest on a loan for the last ten years of public and other parts. The inflation rate and gas price increase rate was applied to the average of the last ten years by Consumer Price Index and Korea Gas Safety Corporation, respectively. The discount rate is determined by the equation (1). Table 2 shows the nominal interest rate, the inflation rate, and gas price increase rate. The present value ( $P_v$ ) is determined by the equation (2).

**Table 2.** Variables for economic analysis.

| Period   | The nominal interest rate, % | The rate, % | inflation | The increase rate of gas price, % | The discount rate, % |       |
|----------|------------------------------|-------------|-----------|-----------------------------------|----------------------|-------|
|          |                              |             |           |                                   | Price                | Gas   |
| 20 years | 6.13                         | 2.96        |           | 10.94                             | 3.08                 | -4.34 |

$$i = \frac{(1 + i_n)}{(1 + f)} - 1 \quad (1)$$

$$P_v = \frac{N_v}{(1 + i)^n} \quad (2)$$

### 3. Results and discussion

#### 3.1. Measurement results

As a result of measurement, thermal conductivity of GW VIPs and FS VIPs before vacuum condition is destroyed was 0.0020, 0.0035 W/mK respectively. To examine thermal performance change of damaged VIPs, we artificially destroyed internal vacuum of VIPs and measured thermal conductivity. As a result of measuring thermal conductivity in 5 days after destroying the vacuum condition of VIPs, change rate depended on the type of core material of VIPs. Thermal performance of GW VIPs and FS VIPs decreased 18.3 times and 5.9 times respectively after the panels were damaged. Table 3 shows the results of thermal conductivity of VIPs before and after damage. To apply thermal conductivity of VIPs obtained from the measurement to building simulation, U-value was calculated for the walls which VIPs are installed. Table 4 shows the composition of the walls and thermal conductivity and thickness of each material. U-values of the walls which the VIPs are installed were calculated as shown in table 5.

**Table 3.** Results of measured thermal conductivity.

|                    | GW VIPs<br>(Normal) | GW VIPs<br>(Damaged) | FS VIPs<br>(Normal) | FS VIPs<br>(Damaged) |
|--------------------|---------------------|----------------------|---------------------|----------------------|
| Conductivity, W/mK | 0.002               | 0.037                | 0.120               | 0.279                |

**Table 4.** Properties of materials applied in external insulation system.

| Materials        | Thickness, m | Thermal Conductivity, W/mK  | Thermal Resistivity, mK/W |
|------------------|--------------|-----------------------------|---------------------------|
| Internal surface | -            | -                           | 0.110                     |
| Concrete         | 0.180        | 1.600                       | 0.113                     |
| Polyester        | 0.030        | 0.038                       | 0.789                     |
| Glass wool 64K   | 0.025        | 0.034                       | 0.735                     |
| VIPs             | 0.020        | Values from the measurement |                           |
| Glass wool 64K   | 0.025        | 0.034                       | 0.735                     |
| Air              | 0.100        | 1.163                       | 0.086                     |
| Masonry          | 0.030        | 2.800                       | 0.011                     |
| External surface | -            | -                           | 0.043                     |

**Table 5.** U-value of external insulation system according to the types of VIP.

|                             | GW VIPs<br>(Normal) | GW VIPs<br>(Damaged) | FS VIPs<br>(Normal) | FS VIPs<br>(Damaged) |
|-----------------------------|---------------------|----------------------|---------------------|----------------------|
| U value, W/m <sup>2</sup> K | 0.079               | 0.316                | 0.120               | 0.279                |

#### 3.2. Energy performance and economic feasibility

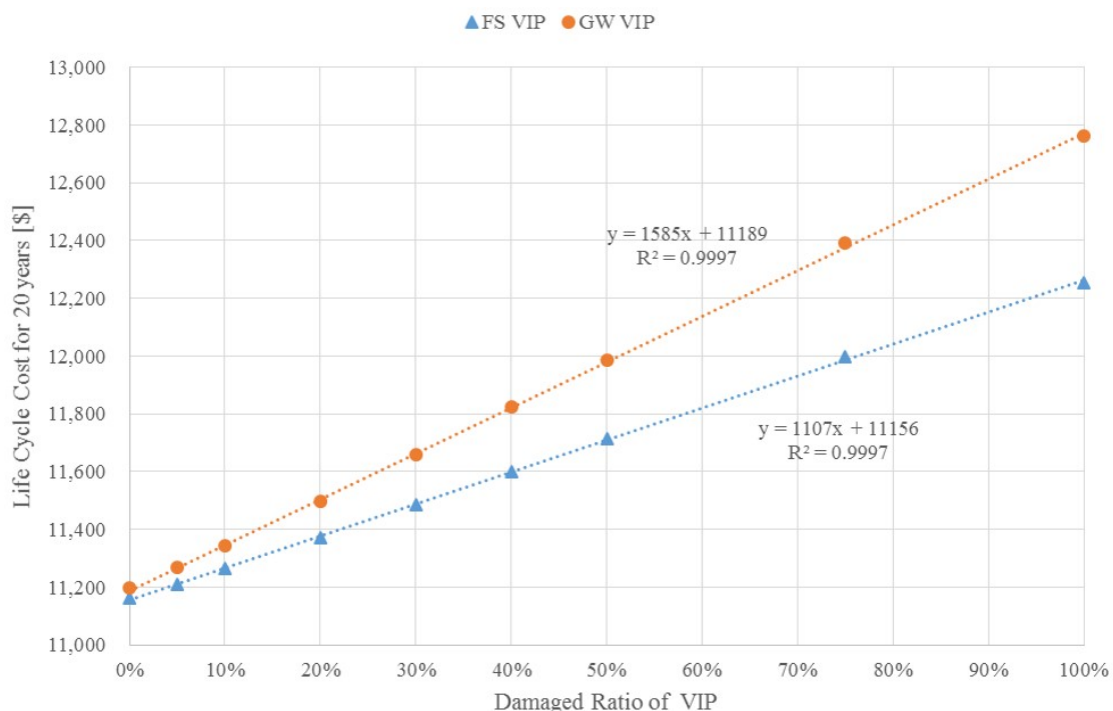
Table 6 shows the annual heating load variation according to the types and the ratio of damaged VIPs for the typical apartment housing. Because the thermal conductivity of GW VIP is better than the conductivity of FS VIP, the heating load can be reduced by installation of GW VIP compared to FS VIP when the ratio of damaged VIPs is lower than 50%. However when the VIP is damaged, FS VIP has better performance than GW VIP, as the ratio of damaged VIPs is increased more than 50%, FS VIP is superior to GW VIP as shown in table 6.

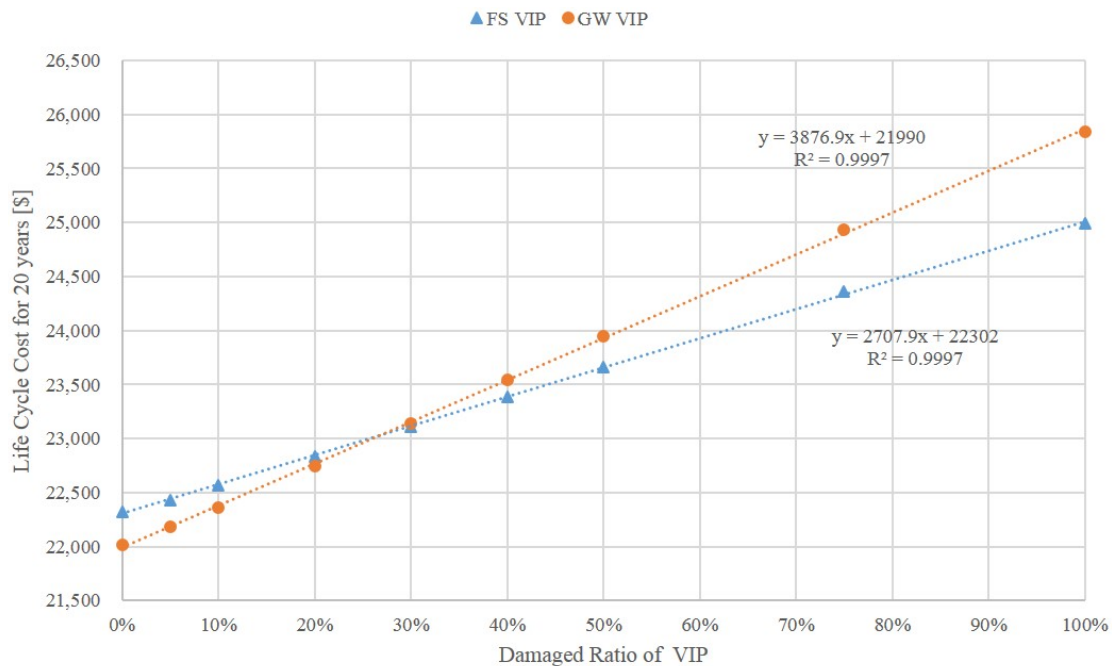
**Table 6.** Heating load variation according to the types and damaged ratio of VIP.

| Damaged ratio of VIPs, % | GW VIPs Heating load, kWh | Ratio of Increased heating load, % | FS VIPs Heating load, kWh | Ratio of Increased heating load, % |
|--------------------------|---------------------------|------------------------------------|---------------------------|------------------------------------|
| 0                        | 6,514                     | Base case                          | 6,720                     | Base case                          |
| 5                        | 6,575                     | 0.9                                | 6,761                     | 0.6                                |
| 10                       | 6,640                     | 1.9                                | 6,807                     | 1.3                                |
| 20                       | 6,775                     | 3.9                                | 6,902                     | 2.6                                |
| 30                       | 6,915                     | 5.8                                | 7,000                     | 4.0                                |
| 40                       | 7,061                     | 7.7                                | 7,100                     | 5.4                                |
| 50                       | 7,202                     | 9.6                                | 7,199                     | 6.7                                |
| 75                       | 7,556                     | 13.8                               | 7,448                     | 9.8                                |
| 100                      | 7,877                     | 17.3                               | 7,671                     | 12.4                               |

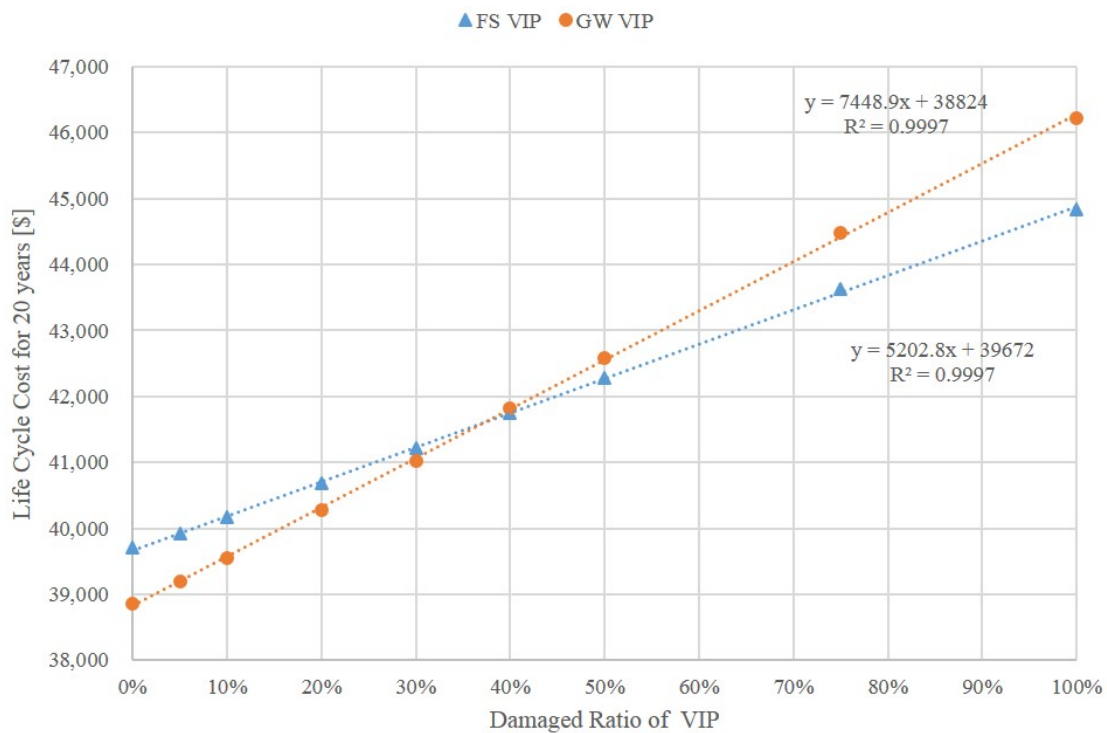
To evaluate the life cycle cost of typical apartment housing which VIPs are installed, the initial cost was calculated including the material cost and construction cost. The initial cost for installation of GW VIPs and FS VIPs were 3,719 \$ and 3,449 \$ respectively. Figures 3-5 shows the life cycle cost according to ratio of damaged VIPs by 3 cases of useful life respectively. In this analysis, the useful life is assumed as 10, 20 and 30 years and the cost of destruction was not considered as the cost is the same for both types of VIPs.

In case the useful life is 10 years, the life cycle cost of FS VIP is lower than the cost of GW VIP regardless the ratio of damaged VIPs as shown in figure 3 because the initial cost of GW VIP is higher. If the useful life is 20 years, GW VIP is economic when the ratio damaged VIPs is lower than 26% however when the ratio of damaged VIPs is higher than 26%, FS VIP is economic because operation cost of GW VIP increase as the ratio of damaged VIPs increased. In case the useful life is 30 years, the life cycle cost is the same for both VIPs when the ratio of damaged VIPs is 38% as shown in figure 5. For economic feasibility, the VIPs should be selected in consideration of the predicted ratio of damaged VIP in the construction field and the useful life of the VIPs.

**Figure 3.** Life cycle cost according to damaged ratio of VIPs (useful life: 10 years).



**Figure 4.** Life cycle cost according to damaged ratio of VIPs (useful life: 20 years).



**Figure 5.** Life cycle cost according to damaged ratio of VIPs (useful life: 30 years).

#### 4. Conclusions

Vacuum insulation panel (VIP) is one of most efficient insulations, however, the thermal performance of VIP is significantly influenced by the vacuum condition. This study evaluated the influence of thermal conductivity variation by destruction of vacuum condition to energy performance and economic feasibility in Korea.

- The thermal conductivity of GW VIP is better than the conductivity of FS VIP in the other

hand when the vacuum condition is destroyed, FS VIP has better thermal performance than GW VIP.

- For Korean typical apartment housing, the heating load can be reduced by installation of GW VIP compared to FS VIP when the ratio of damaged panels is lower than 50%.
- Economic feasibility differs according to the ratio of damaged panels and useful life. GW VIP is economic when useful life is longer and the ratio of damaged panels is lower; on the other hand, FS VIP is economic when useful life is shorter and the ratio of damaged panels is higher.

In the future work, the prediction of damaged ratio and the useful life will be studied to select proper VIP in the construction field.

### Acknowledgments

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### Appendix: List of symbols

$i$  : Discount rate, %  $i_n$  : Nominal interest rate, %

$f$  : Inflation rate, %  $P_v$  : Present value, \$

$N_v$  : Net value, \$  $n$  : Elapsed years

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