Extraction and Analysis of Technical Management Factors for Passive Houses in Korea

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Abstract

Construction projects are diverse, ranging from industrial infrastructure to residential facilities, and all of these consume energy during operation and maintenance. From this perspective, passive houses can serve as a green housing model for energy-savings. However, Koreans have not actively adopted passive houses in domestic construction compared to other countries, since the energy cost savings are low compared to construction costs. This study extracts the technical management factors in domestic passive house building through a review of the related literature and a focus group interview (FGI) of relevant experts. Additionally, the relative importance of the 6 high-level management factors and 22 low-level factors was analyzed using the analytic hierarchy process (AHP). The results show that the most important items relate to the performance of the construction materials and the techniques used in construction. The results should help further the development of a passive house model and technical management tailored for the Korean market.

Keywords: passive house; energy cost; focus group interview (FGI); management factor; relative importance analysis

1. Introduction

Construction projects include a broad range of finished structures, from residential properties to industrial installations, each with its own complexity as the project must combine technologies from various fields. Additionally, the modern construction industry requires differentiated strategies and high-level technologies due to increasing demands from consumers and the complexity of high-rise buildings. Accordingly, the construction industry is striving to improve competitiveness by developing new construction technologies and introducing scientific management techniques. At the same time, the industry has shifted its focus from design and construction technologies to the development of technologies for maintenance such as those related to energy. Energy-related technologies not only enable sustainable development but are also competitive in securing economic feasibility. There have been attempts to introduce passive houses, a representative energy-saving technology originating in Germany, into the Korean market. The term passive house refers to buildings that use internal energy sources, such as heat generated from residents and solar radiation. According to the Passivhaus-Institut, a passive house, a construction concept proved through implementation, is a standard that aims to create energy efficient, pleasant, economical, and eco-friendly buildings. It is not a brand name and is open to anyone to use. The Passivhaus-Institut in Germany considers buildings that meet heating or cooling demand of 15 kWh/m² and limit peak heating/cooling load of 10W/m² as passive houses. Additionally, primary energy consumption must not exceed 120 kWh/m². For a building to be considered a passive house, it must be airtight and heat-bridge free, have good thermal insulation, passive house windows, and a heat-recovery ventilator. There are some additional technical specifications: ¹ Wärmedämmung / Thermal insulation: The building exterior must be insulated and the building must have a maximum heat transmission coefficient (U-value) of 0.15 W/m²K even during the coldest periods. ² Passivhausfenster / Passive House windows: The windows in a passive house must be well insulated. The U-value should not go beyond 0.80 W/ (m²K). The G-value needs to be about 50% (G-value refers to the total transmission of available solar heat inside the building). ³ Ventilation heat recovery: A ventilator that efficiently recovers heat can maintain clean indoor air quality and save energy. At least 75% of the heat from the exhaust air must be converted to

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fresh air. However, it is difficult to adopt the Passive House standard suggested by the Passivhaus-Institut in terms of the Korean construction environment and lifestyle, so a Korean-style passive house model is required. This requires various practical research and development (R&D) projects to successfully introduce a Korean-style passive house model. Accordingly, this study aims to extract technical management factors, which are required for a successful implementation of the Korean-style passive house model, through textual studies and expert Focus Group Interview (FGI), and analyzing their relative importance. The analysis results are expected to provide guidelines for technical factors required in the construction of a Korean-style passive house.

2. Methods
This study focuses on passive houses among energy-related technologies, and its technical parts comprise the detailed scope. To achieve this research scope, the research process and methods are as follows.

First, this study identifies the status and problems associated with passive houses through the case analysis of a Korean passive house. Next, it extracts technical management factors through a literature review and expert FGI. Third, the study analyzes relative importance concerning technical management factors using the AHP method. If we take a look at the Korean literature on passive houses, among 44 collected documents, 7 provided general introductions and the standards of a passive house, 5 described construction cases, 3 examined energy consumption, 3 discussed design and construction, and the rest were related to individual technical elements and material performance. On the other hand, this study extracts the technical management factors of a Korean-style passive house through a literature review and expert FGI, and their relative importance were analyzed using the AHP technique. This study is thus differentiated from preceding studies and aims to contribute toward a passive house model that can be applied in Korea with its unique scope and method.

2.1 Case Analysis
A passive house is a structure that meets conditions for insulation, windows, airtightness, and thermal bridges. Korea has accomplished much research and technical development in terms of the technical realization of each condition. In Korea, the first passive house, "a building that uses a built-in energy source," was constructed in 2009. A detached house in "S" village in Gangwon Province, a detached house in "D" village in Gyeonggi Province, and a neighborhood living facility in "B" village in Gyeonggi Province are the representative passive houses. Efforts to build energy-efficient and low-energy buildings were then made nationwide. According to the Passive House Institute of Korea website, among 49 low-energy/passive structures, except for 3 national park offices, a Korea Expressway Corporation office, a community service center, and a purpose built dormitory, most are detached houses. It is labelled a 3-liter house when energy demand for heating is 30 kWh/m² and a 1.5-liter house when energy demand is 15 kWh/m². A 1.5-liter house's energy demand for heating is the same as for passive houses, and there are eight of these. Among them are a senior citizens center which belongs to a multi-family residential complex in "W" village in Incheon, a detached house in "B" village in Seoul, and an educational research center in "C" district in Gyeonggi Province which have been officially certified as passive houses from the Passivhaus-Institut.²

2.2 Literature Review Analysis
Most research related to passive houses is conducted by societies related to construction planning, building equipment, and solar energy, and most focus on the technical aspects. This section presents the analysis of the literature related to passive houses to define the houses that belong to Level 1 technological CSFs. The analysis was conducted in two rounds. The first round centered around the literature on the core technologies for passive house design and construction. The second round focused on the literature on POE, pilot studies, and other research on the implementation performance of passive houses.

2.3 Expert FGI
This chapter reports the results of the Focus Group Interview (FGI) of experts to extract the technical management factors of passive houses. A total of eight experts participated in the FGI and among them, 2 were architects, 1 has a Ph.D. in construction management, 1 was a professional engineer building mechanical facilities, 2 were qualified professional engineers in the facilities field, and 2 were engineers from relevant fields. The expert FGI was carried out in the form of a workshop from June 17-18, 2014. The experts provided their opinions as to the core technical management factors required in the passive house construction process.
2.4 AHP Analysis
This research provides an analysis of the relative importance of the passive house technical management factors extracted using the analytic hierarchy process (AHP) technique. Expert Choice 11 was used in this study for the AHP survey to put the extracted factors into an AHP hierarchy structure (Fig.1).

The AHP survey was conducted on 15 experts who have technical knowledge of passive houses. Table 1. reports the details from the AHP survey.

Table 1. Overview of AHP Survey

| Division          | Contents                                      |
|-------------------|-----------------------------------------------|
| Survey Period     | 20 October 2014 - 27 October 2014             |
| Respondents       | - Registered Architects 3                      |
|                   | - Professional Engineer (Building Construction) 2 |
|                   | - Professional Engineer (Mechanical) 3          |
|                   | - Energy Researcher 5                          |
|                   | - Related areas Professor 2                    |
| Survey Contents   | Analysis of the relative importance for technical management factors (Priority calculation) |

3. Results
3.1 Case Analysis
According to this record, Korea also has construction technologies that meet the Passivhaus-Institut’s construction standard. However, the standard cannot be adopted as is in Korea. For example, a 1.04-liter detached house in "D" village in Gangwon Province tried to obtain Passive House certification (Fig.2.). However, because the Korean standard for heat exchangers differed from that of Germany, it could not obtain certification from the Passivhaus-Institut.

Fig.2. "D" Village 1.04-liter Detached House

Therefore, it is important to consider the difference between Korean and European construction criteria, and the following application problems:
1) The energy demand for the heating of passive houses is based on standard climate conditions in central Europe, such as Germany. Therefore, a new standard based on each region in Korea should be established.

2) Because most Koreans prefer floor heating, the amount of heat required to make residents feel comfortable may differ from that of people living in air-heated houses.

3) From the economic angle, construction costs in Korea are still higher for energy-efficient buildings than in Germany.

4) It will take more time to offset the increased construction costs with fuel savings through low energy consumption than in Europe because electricity in Korea is relatively cheaper than in European countries.

5) There is a need to develop technologies and construction materials to apply passive house principles to large-scale buildings, such as business facilities and multi-family residential buildings.

6) The passive house requires a lot of initial investment costs. Accordingly, it will be difficult to build proper passive structures if the existing practice of minimizing construction costs continues.

7) Selecting a constructor based on the lowest bid price limits housing performance related to construction costs.

3.2 Literature Review Results
1) 1st analysis result
From analyzing the keywords of 20 documents, the technical contents included low energy use, air tightness, and energy saving to support the purpose of a passive house (Fig.2.).

Table 2. First Literature Review on Passive Houses

| Division | Reference Information | Keyword | Technical factors          |
|----------|-----------------------|---------|----------------------------|
| 1        | Cha, J. H., Journal of KIEAE Vol. 5 No. 1, 2013 | Building energy, Heating energy | Heating system, Heat bridge |
| 2        | Cho, S. Y. et al., Journal of AIIK, Vol. 30 No. 5, 2014 | Heat bridge | Heat bridge, Heat insulation structure |
| 3        | Kim, J. S. et al., KIEAE Journal 2010 Conference Proceeding, 2010 | Air tightness, Low-energy | Air tightness, Energy Recovery ratio |
| 4        | Lee, J. et al., Journal of SAREK 2013 Conference Proceeding, 2013 | Low-energy House | Air tightness, Heat insulation |
| 5        | Lee, D. E. et al., The Architectural Institute of Korea, Excellent thesis exhibition, 2009 | Energy saving, Renewable Energy | Skin heat insulation |
| 6        | Kim, J. H. et al., KIEAE Journal 2011 Conference Proceeding, 2011 | Highly sealing proficiency | Highly Sealing proficiency |
| 7        | Cho, K. M. et al., Journal of KIEAE Journal, Vol. 11 No.4, 2011 | Air tightness, Low-energy | Air tightness, Windows system |
| 8        | Jeong, S. M. et al., KIEAE Journal 2018 Conference Proceeding, 2018 | Energy efficiency | Energy Efficiency ratio, Building location |
| 9        | Jeong, S. M. et al., KIEAE Journal 2011 Conference Proceeding, 2011 | Energy efficiency, Construction | Building location, Energy Recovery ratio |
| 10       | Jeong, S. M. et al., KIEAE Journal 2013 Conference Proceeding, 2013 | Energy efficiency, Component technologies | Building location |
| 11       | Kim, B. N et al., The Korean Solar Energy Society 2010 Conference Proceeding, 2010 | Component technologies, Optimal configuration | Air tightness, Heat insulation, Energy Recovery ratio |
| 12       | Park, S. W et al., KIEAE Journal 2005 Conference Proceeding, 2005 | Fuel cell | Fuel cell |
| 13       | Lee, M. J. et al., Journal of AIIK, Vol. 28 No. 3, 2014 | Energy-saving design standards | Highly sealing proficiency, Energy Recovery ratio |
| 14       | Kim, S. I et al., The Korean Solar Energy Society 2014 Conference Proceeding, 2014 | Heating and cooling loads | Heating and cooling loads |
| 15       | Jang, B. K. et al., Journal of AIIK 2010 Conference Proceedings, 2010 | Green building, Building optimization | Air tightness, Structure of a window, Noise |
| 16       | Shin, S. E. et al., The Korean Housing Association, 2011 Conference Proceeding, 2011 | Passive design principles, Passive strategies, Energy efficiency | Air tightness, Noise |
| 17       | Shin, S. et al., Journal of AIIK Vol. 29 No. 5, 2013 | Divination based on topography, Passive elements | Heat exchange type |
| 18       | Park, S. I. et al., Journal of the Regional Association of Architectural Institute of Korea, Vol. 15 No. 2, 2013 | Skin configuration, Skin heat insulation | Skin composition |
| 19       | Kim, M. K. et al., Journal of AIIK Vol. 25 No. 8, 2009 | Climate control, Energy Plus | Heat transmission coefficient |
| 20       | K. H. et al., Journal of the Regional Association of Architectural Institute of Korea, 2012 Conference Proceeding | Winter regions, Multi-layered housing, Passive design | Heating and cooling loads, Building skin |
2) 2nd analysis result

The analysis of the keywords of 24 documents, show that most were about technologies related to low energy, airtightness, and energy savings to support the purpose of a passive house (Table 3.).

Table 3. Second Literature Review on Passive Houses

| Division | Reference Information | Reference Information | Technical factors |
|----------|-----------------------|-----------------------|-------------------|
| 1        | Kim, Y. R. et al., Journal of AKB, 2013 Conference Proceeding. | Building construction materials | Heat insulating material |
| 2        | Kwon, K. W. et al., Journal of SAREK, 2013 Conference Proceeding. | Air tightness | Heat insulating material |
| 3        | Hwang, H. J. et al., Journal of SAREK 2013 Conference Proceeding, 2010. | Monitoring system, Low-energy | Air tightness, Heat insulation |
| 4        | Cho, J. K. et al., Journal of SAREK, 2009 Conference Proceeding, 2009. | Low-energy system, Pilot project | Air tightness, Heat insulation |
| 5        | Lee, Y. J. et al., Journal of AKB, 2013 Conference Proceeding, 2013. | Passive strategy, HBM, Energy simulation | Air tightness test, Recovery ratio |
| 6        | Cho, J. K. et al., Journal of SAREK, 2007 Conference Proceeding, 2007. | Eco-friendly, Energy | Energy Recovery ratio |
| 7        | Rie, F. H. et al., Journal of SAREK, 2009 Conference Proceeding, 2009. | Monitoring system, Low-energy, Profficiency Assessment | Heating and cooling loads, Air tightness, Heat insulation |
| 8        | Han, J. W. et al., KIEAE Journal 2007 Conference Proceeding, 2007. | Low-energy apartment, Building construction materials | Heat insulating material |
| 9        | Krak, M. S. et al., Journal of KICEM 2009 Conference Proceeding, 2009. | Eco-biite house, High proficiency windows, Ground thermal system | Windows, Windows system, Windows proficiency |
| 10       | Kim, J. S. et al., KIEAE Journal 2010 Conference Proceeding, 2010. | Low-energy, Eco-friendly | Energy Recovery ratio |
| 11       | Kim, M. S. et al., KIEAE Journal 2013 Conference Proceeding, 2013. | Low-energy experimental housing | Energy Recovery ratio, Air tightness test |
| 12       | Cho, J. K. et al., Journal of SAREK, 2010 Conference Proceeding, 2010. | Low-energy experimental housing | Energy Recovery ratio, Air tightness test |
| 13       | Cho, H. N. et al., KIEAE Journal 2013 Conference Proceeding, 2013. | Experts incentive, Integration design | Energy Recovery ratio, Air tightness test |
| 14       | Hwang, B. H. et al., KIEAE Journal 2009 Conference Proceeding, 2009. | Low-energy, Green house | Air tightness, Heat insulation |
| 15       | Bae, S. H. et al., Journal of SAREK, 2013 Conference Proceeding, 2013. | Green house plus | Energy Recovery ratio |

3) Analysis of 1st and 2nd results

After analyzing the 1st and 2nd results (Fig.3.), there are 13 and 11 technical factors for airtightness and energy recovery ratio, respectively. According to item similarity, there are 10 groups: 20 items were grouped together for airtightness, and 13 each for insulation and energy recovery ratio. As a result, most of the technical factors target common areas (Table 4.). The exterior was the most common area, followed by windows. As for application purpose, insulation performance was the most common keyword, followed by airtightness and comfort.

Table 4. Summary Results of the Passive House Literature Review

| Division | Technical factors | Section | Expectation outcome |
|----------|-------------------|---------|---------------------|
| 1        | Heat transmission coefficient | Windows | Comfortableness |
| 2        | Heat bridge | Joints | Insulation performance |
| 3        | Air tightness | Skins | Airtightness performance |
| 4        | Highly sealing proficiency | Skins | Airtightness performance |
| 5        | Highly heat insulation | Skins | Insulation performance |
| 6        | Air tightness test | Skins | Airtightness performance |
| 7        | Fuel cell | Energy | Energy efficiency |
| 8        | Cooling and heating loads | Heating and cooling load | Comfortableness |
| 9        | Skin composition | Skins | Insulation performance, Airtightness performance |
| 10       | Skin heat insulation | Skins | Insulation performance |
| 11       | heat insulation | Skins | Insulation performance |
| 12       | High-performance windows | Windows | Insulation performance |
| 13       | Building skin | Skins | Insulation performance |
| 14       | Structure of a window | Windows | Insulation performance |
| 15       | Heat exchanging type ventilation system | Windows | Comfortableness |
| 16       | Sealing proficiency | Skins | Airtightness performance |
| 17       | Ventilation system | Ventilation | Comfortableness |
| 18       | Windows | Windows | Insulation performance |
| 19       | Heat insulation structure | Skins | Insulation performance |
| 20       | Noise | Configured space | Minimize noise |
| 21       | Energy Recovery ratio | Energy | Energy efficiency |
| 22       | Heat insulating material | Insulation Materials | Insulation performance |
| 23       | Windows system | Windows | Insulation performance |
| 24       | Building location | Location | Optimization of residential location |
| 25       | Windows proficiency | Windows | Insulation performance |
| 26       | Ventilation | Ventilation | Comfortableness |
| 27       | Heating system | Heating and cooling | Comfortableness |

Fig.3. Frequency Analysis Results for the 1st and 2nd Management Factors from the Literature Analysis

3.3 Expert Interview Results

During the FGI, all the experts suggested insulation systems, airtightness, and mechanical window equipment, similar to the results of the literature review. They also suggested 10 technical factors
including additional devices, wall construction, and the use of eco-friendly finishing materials (Table 5.). The results from the FGI after classifying the technical factors by section and object were similar to the literature review, and emphasize the exterior, windows, heating/cooling system, and ventilation. The application purposes were classified as insulation, airtightness, comfort, and energy efficiency.

Table 5. FGI Results for Passive Houses

| Division | Technical factors | Section | Expectation outcome |
|----------|-------------------|---------|-------------------|
| 1        | External Insulation Systems | Skins | Insulation performance (Super insulation) |
| 2        | High performance windows | Windows | Airtightness performance |
| 3        | Additional devices (solar connecting type blind) | Internal | Insulation performance, Airtightness performance |
| 4        | Mechanical equipment system (Energy Recovery Ventilator) | Internal | Comfortableness |
| 5        | Duct construction | Air conditioning system and Ventilation | Airtightness construction |
| 6        | Wall construction (insulation material) | Wall | Super insulation |
| 7        | Securing space | Floor, wall | Insulation performance, Airtightness performance |
| 8        | Renewable energy technologies (Geothermal system) | Whole | Energy Efficiency |
| 9        | Application of eco-friendly finishing materials | Finishing section | Eco-friendly |
| 10       | Filter Change etc. | Whole | Maintainability |

3.4 AHP Results

Fig.4. reports the results of entering the AHP survey results in Expert Choice 11. Figs.5. – 11. show the priority analysis results of the Level 2 and management factors. Each graph below presents a ranking according to the weighted value for each item.

1) Level 2 AHP analysis results

From analyzing the importance of six management factors (including insulation performance, airtightness performance, comfort, noise, and residential elements), insulation performance (0.265) and airtightness performance (0.265) were the highest, followed by energy efficiency and residential elements (Fig.5).

2) AHP analysis of insulation performance

In terms of insulation performance, insulation materials (0.434) were most important, followed by specialty glass (triple glass etc.), as reported in Fig.6.

3) AHP analysis of airtightness performance

The analysis of airtightness performance, shows that insulation materials (0.434) were the most important, followed by specialty glass (triple glass etc.), as shown in Fig.7.

4) AHP analysis of comfort

In terms of comfort, heating and cooling (0.300) were the most important, followed by ventilation systems (0.216), as reported in Fig.8.

5) AHP analysis of noise

Fig.9. reports the results of the analysis for noise, wherein residential space (0.667) and installation space (0.333) were the most important.

6) AHP analysis of energy efficiency

Fig.10. reports the analytical results from the analysis related to energy efficiency, showing that power consumption (0.540) and heating and cooling energy (0.297) were the most important.

7) AHP analysis of residential elements

In terms of residential elements, windows (0.750) and shading devices (0.250) were the most important, as reported in Fig.11.
4. Discussion

The literature review of 44 documents and the expert FGI provided the technical management factors for the successful realization of a Korean-style passive house. These were reclassified based on object (Level 1) and target (Level 2), resulting in classifications into targets based on the six objects (Table 6.). Next, this study conducted an AHP analysis to determine the relative importance of the technical management factors extracted from the literature review and FGI. From among the six high-level (Level 2) management factors, insulation and airtightness performance, which are unique technical attributes of passive houses, were the most important. In terms of the low-level (Level 3) management factors, insulation materials, wall construction, windows, heating/cooling systems, residential specifications, and power consumption ranked high. Their relative importance is (in descending order) insulation materials, windows, power consumption, wall construction, and floor connections. The core management factors are construction materials performance and the technological aspects of certain elements.

5. Conclusion

The green construction concept was recently introduced in the construction industry, resulting in the development of various methods to save energy during development, operation, and management. Among these, the passive house is the most-well known method, though it was not actively adopted in Korea due to the energy specifications for heating and the low energy savings relative to construction costs.

Table 6. Classification of Passive House Technical Management Factors

| Division | Level 1 (Object) | Level 2 (Target) |
|----------|-----------------|------------------|
| 1        | Insulation performance | Skins, Connections part, Window or Door, Insulation materials, Specialty Glass (Triple Glass etc.) |
| 2        | Airtightness performance | Skins, Wall, Floor connections part, Application materials, Entrance door |
| 3        | Comfortableness | Ventilation system, Heating and cooling, Structure, Element core of Heat recovery ventilator, Pre-heated system, Glass |
| 4        | Noise | Installation space, Residential space |
| 5        | Energy effectiveness | Heat recovery ratio, Power Consumption, Heating and cooling energy |
| 6        | Residential location | Windows, Shading Device |
This study therefore extracted the technical management factors from a literature review and expert FGI to further the development of a passive house model applicable in Korea. The extraction includes six management factors including insulation performance, airtightness performance, and comfort, with an additional 22 detailed management factors. These were further analyzed to determine their relative importance using an AHP analysis. AHP analysis results:

1) Insulation performance and airtightness performance were the most important, with values of 0.265, the highest priority among the 6 technical factors (Level 2).
2) The analysis of the technical factors (Level 3) shows that insulation material, wall construction, and window performance factors were highly important.
3) The most important technical factors were those related to securing the degree of accuracy in construction for certain elements.

This study's results are expected to contribute to systematic technical management in the passive house construction process. Future studies could develop a management method for the items that ranked high in relative importance.

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Notes
1) http://www.passiv.de/de/02_informationen/01_wasistpassivhaus/01_wasistpassivhaus.htm
2) http://www.phiko.kr/bbs/board.php?bo_table=z3_02&page=2&page=1
3) Expert Choice 11 is a decision-making software package, also used for the AHP analysis.
4) http://www.phiko.kr/bbs/board.php?bo_table=z3_02&wr_id=37

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