A THESIS FOR THE DEGREE OF MASTER SCIENCE

Study on the factor to air tightness of timber frame building

목조주택의 기밀성능에 영향하는 인자에 관한 연구

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Abstract

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Energy consumption statistics from 2005 from the Korea Energy Management Corporation show that building energy usage was about 24.2% of total domestic energy consumption and 64% of total building energy usage was consumed by residential buildings. Thus, about 10% of total domestic energy consumption is due to the heating of residential buildings. Building energy can be calculated by entering the configuration of the building envelope and the rate of infiltration (the volume of the infiltration of outdoor air and the leakage of indoor air) and by doing so, one can determine the annual energy usage for heating and cooling. Therefore, air-tightness is an important factor in building energy conservation. We investigate air infiltration and various factors that decrease it in timber frame buildings and suggest ways to improve air-tightness for several structural types.

Timber frame buildings can be classified into light frame, post and beam and log house. Post and beam includes Han-ok (a Korean traditional building). Six light frame buildings, three post and beam buildings, one Korean traditional Han-ok and and a log house were selected as subjects. Blower door tests were performed following ASTM E779-03. The light frame buildings showed the highest air-tightness, followed by post and beam structures and last, log houses.

After the blower door test, the infiltration of each factor was studied on the experiment as blocking up the elements one by one. All of the experiments were carried out with elements that are near the building envelope. The location of the infiltration was found with a thermal imaging camera recording when the temperature difference was largest (between 2 am and 3 am). Using PVC(Polyvinyl chloride) tape and PE(Poly ethylene) film to cover the area where the infiltration occured, we re-ran the blower door test and examined real infiltration using fogger. Gaps (such as openings and ducts) did not show a significant effect on air-tightness performance. Air infiltration through the building envelope was the most significant.

Among all of the infiltration elements, there were significant gaps at discontinuities in the building envelope. There were many areas that could not be taped, such as between walls, between the wall and the floor. Tape lengths were used for comparison. Light frames, post & beam frames and log houses all had infiltration through gaps between the walls. Since this experiment was a field test which was carried out after the interior finishing, absolute values could not be compared. However, after converting to the same lengths, similar the Canadian EqLA(equivalent leakage area) values were found. There were specific gaps in the envelope according to the structural type of the building, which occurred between the walls for the light-framed house. Accuracy in finishing is required on wall to wall and wall to floor when buildings are constructed. Air-tightness tape and airtight film can improve air-tightness performance. The gaps between frames and walls were expected to lead to easy heat loss in post & beam frame buildings. Based on air-tightness from test results preventing heated air leakage through the gaps, air leakage decreases air-tightness. Significant Infiltration occurred in the log house after three years, which led to material deformation such as shrinkage, expanding and twisting. Therefore, for log houses, these elements should be regularly inspected and maintained to achieve high energy efficiency.

Keywords : Air-tightness, Light frame building, Post and beam building, Log house, Building energy consumption, Low energy building, Building energy performance simulation

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1. Introduction

1.1 Background

Historically, timber frame buildings were built only as country houses or detached houses because of prejudices that they are vulnerable to fire and difficult to maintain. However, the rate of timber frame construction has increased in the public housing market (multi-unit dwellings) as they have become well-known for reducing environmental destruction, helping low-carbon green growth, are healthier for humans and are highly energy efficient. They are the most common architectural form in many developed countries, making up about 95% of all houses in the U.S. and 93% in Canada.

In Korea, the rate of timber frame construction fell to as low as 1% because many people had a negative perception toward timber frame buildings and the construction technology necessary to build timber frame buildings that were strong against temperature and moisture was lacking. However, timber frame buildings are gradually increasing in number. In 2005, the rate of timber frame buildings was only about 5% in the new construction market for detached house, but by last year it had risen to 15%. The timber frame construction market is also prospering as advanced technologies from Canada, Japan and many other countries are introduced in Korea. The rate of the timber frame construction is also increasing in the detached house and luxurious town house markets.

Research on energy use in timber frame buildings is still limited and studies of air-tightness, which affects heating energy, is almost nonexistent. Studies of timber frame buildings need to be carried out and separated from studies of detached houses and high-rise apartments are made of reinforced concrete because timber is an anisotropic and non-homogeneous material.

According to the International Energy Agency (IEA, 2002 statistics), Korea was ranked 10th in world energy usage and 9th in carbon emissions. Because Korea has large energy consumption and carbon dioxide emissions, it will have to reduce industry production or purchase carbon credits from other countries because of the carbon dioxide quotas of the Climate Convention which will go into effect in 2013, which is expected to decrease national competitiveness.

Energy consumption statistics from the Korea Energy Management Corporation in 2005 show that building energy usage was about 24.2% of total domestic energy consumption and 64% of total building energy usage was consumed by residential buildings. Of the total residential energy usage, 60% was for heating, showing that about 10% of total domestic energy consumption is used for heating of residential buildings. The city of Seoul, though the '2030 Green Design Seoul' initiative, is trying to reduce energy usage by 20%, reduce greenhouse gas emissions by 40% and expand new renewable energy usage by 20%. They are also planning to carry out the total amount of energy system and present the total amount of energy usage for 5 years as well as the target amount of reduced usage. The total amount of energy system is a system which grants permission to construct new buildings if they fulfill energy performance simulation criteria. The program used for this simulation is called the BESS (Building Energy Simulation for Seoul.) The building energy is calculated by inputting the configuration of the building envelope and the rate of infiltration, which is the volume of the infiltration of outdoor air and the leakage of indoor air through the building envelop. Doing so, the annual energy usage for heating and cooling can be calculated.

Air infiltration and leakage can lead to a variety of problems, such as heat loss through the building envelope, condensation inside the structure and resident discomfort. The U-value (coefficient of overall heat transmission) is lower for timber-frame buildings than for reinforced concrete buildings, so air-tightness problems have to be solved. The U-value is an importance factor which influences building energy performance and therefore needs to be thoroughly understood.

This study of domestic timber frame buildings is classified into three categories according to structural type: light frame, post & beam and log house.

We use the blower door test method to measure air-tightness performance construct air leakage curves. We compared the air leakage curves with those of existing studies of reinforced concrete buildings and timber frame buildings both in Korea and in foreign countries to help determine methods for improving performance.

1.2 Objectives

The objective of this study was to find the factors which make negative effects on air-tightness of timber frame buildings to improve the thermal property.

To achieve this objective, the air-tightness of existing timber frame buildings were measured by blower door test and the influence of each factor on air-tightness was investigated.

2. Literature review

2.1 Research on air-tightness standard

There are two ways of measuring the air tightness of buildings: the gas tracer method and the blower door test. The gas tracer method measures variations in gas concentration as a function of time after emission. The blower door test calculates air flow using a fan or blower door with a consistent pressure difference between outside and inside. In the early years, both methods were used to measure air tightness, but the blower door test has become the international standard as it is easy to install and execute. Jean-Marie Furbringer (1994) has said that pressure differences are important in measuring the air tightness of buildings and suggested a modification to study infiltration and air leakage. Jeff Ross Stein (2000) performed the blower door test to compare houses with improved airtightness with conventional houses through the Home Energy Rating System (HERS) and emphasized the importance of the HERS. In Korea, Won-Seok Park (2003) introduced the gas tracer method and the blower door test. Through the blower door test, he computed the number of ventilation in the building and urged the establishment of air tightness standards.

2.2 Research on present regional status by actual air-tightness

Since the blower door test has become the international standard for measuring air tightness, research to construct building data base by actual measurement and the present condition survey has become very active. Through the blower door test, the average infiltration rates of cities were measured in various country. Targo Kalamees (2007) compared houses in Estonia, A. Sfakianaki (2008) in Greece, Shuqin Chen (2012) in China and Max Sherman (1998) and Ambrose Dodoo (2011) in the U.S. Seong-Han Goo (2004), Hyun-Gook Shin (2006), Jong-Ho Yoon (2008), Jae-Hoon Cho (2010) in Korea selected tall residential buildings, low detached houses and one-room apartment made of reinforced concrete and carried out the blower door test to measure air-tightness and compare the results with those from overseas.

2.3 Research to improve air-tightness performance

After the research about the actual measurement, the research to improve the air tightness was started to achieve low energy houses.

Jurgen Schnieders (2000) selected passive houses in each area of Europe and undertook the CEPHEUS project, which researched changes that could improve air tightness. In order to satisfy the passive house standard, ventilation should be lower than 0.6ACH and air quality should be tested before and after installing the heat exchanger. Wolfgag Feist (2005), in addition to CEPHEUS project, measured air tightness and carried out simulations in houses with high air-tightness, heat exchangers and super insulation according to the passive house's standard.

Jelle langmans (2010) finds that using vapor barriers will improve air tightness and Thor-Oskar Relander (2010) installed wind barriers on the finishing lines of walls and soft mineral Shreds (PE-foil) on the floors and checked air tightness. Steven Nabinger (2011) used sealing materials to cover electrical line entry/exit points and then rechecked air tightness.

3. Materials and methods

3.1 Air-tightness performance of Korea timber frame building

3.1.1 Materials

Timber frame buildings were classified into light frame, post and beam and log house. Post and beam includes Han-ok (Korean traditional) buildings.

Six light frame buildings, three post and beam buildings, one Korean traditional Han-ok building and one log house were selected as subjects (Figure 3-1).

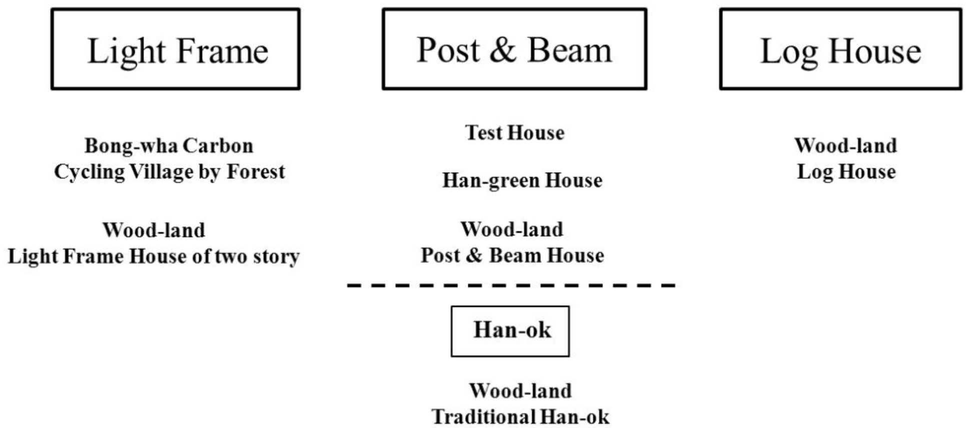

Figure 3-1. Timber frame buildings classified by structure type.

3.1.1.1 Light Frame buildings

Six light frame buildings were chosen (Table 3-1 and Figure 3-2, 3-3):

They were located in Bong-wha and have one of two construction types: low energy or standard.

Table 3-1. Light frame buildings.

	Bong-wha Village			Jang-heung		
	BLA*1	BSA*2	BLB*3	BSB*4	JLA*5	JLB*6
Year	2011			2009		
Location	Seobyeok-ri, Bongwha-gun, Gyeongsangbuk-do			Wood-land, Jangheung-gun, Jeonlanam-do		
Floor area (m^2)	106.8	103.3	103.2	103.2	56.0	64.4
Volume (m^3)	277.8	268.6	268.2	268.2	134.8	194.5
Envelope (m^2)	273.0	264.2	271.6	279.7	153.5	238.0
Types	detached house			detached house		

BLA*1 : Bong-wha Low Energy. A, BSA*2 : Bong-wha Standard. A,
BLB*3 : Bong-wha Low Energy. B, BSB*4 : Bong-wha Standard. B,
JLA*5 : Jang-heung Light Frame. A, JLB*6 : Jang-heung Light Frame. B

Figure 3-2. Bong-wha village, light frame buildings.
(Top left : Low energy A (BLA), Top right : Low energy B (BLB),
Bottom left : Standard A (BSA), Bottom right : Standard B (BSB))

Figure 3-3. Wood-land, Jang-heung, light frame buildings.
(Left : Light frame house A (JLA), Right : Light frame house B (JLB))

3.1.1.2 Post & beam structure

Two post and beam buildings were chosen (Table 3-2 and Figure 3-4):

They were located in Hong-reung, Gwang-reung and Jang-heung. They were also classified as either low energy or standard construction types..

Table 3-2. Post and beam frame buildings.

	Test house	Han-green house	Guest house
	HPB[*1]	GPB[*2]	JPB[*3]
Year	2006	2009	2009
Location	Hong-reung, Dongdaemun-gu, Seoul	Gwang-reung, Pocheon-si, Gyeonggi-do	Wood-land, Jangheung-gun, Jeonlanam-do
Floor area (m^2)	215.0	189.4	63.3
Volume (m^3)	519.9	584.7.8	183.3
Envelope (m^2)	545.0	589.0	273.0
Types	detached house	detached house	detached house

HPB[*1] : Hong-reung Post and beam test house,

GPB[*2] : Gwang-reung Post and beam Han-green house,

JPB[*3] : Jang-heung Post and beam guest house

Figure 3-4. Post and beam buildings.

(Top left : Test house (HPB), Top right : Han-green house (GPB),

Bottom : Guest house (JPB))

▪ **Han-ok building**

One Han-ok building categorized as a post and beam was chosen (Table 3-3 and Figure 3-5):

It was located in Jang-Heung and was a Korean traditional timber frame building .

Table 3-3. Traditional Han-ok building.

	Jang-heung traditional Han-ok building JTH*1
Location	Woodland, Jangheung-gun, Jeonlanam-do
Floor area (m^2)	45.0
Volume (m^3)	128.9
Envelope (m^2)	96.5
Types	detached house

JTH*1 : Jang-heung traditional Han-ok building

Figure 3-5. Jang-heung, traditional Han-ok building.

3.1.1.3 Log House

One log house was chosen (Table 3-4 and Figure 3-6):

It was located in Jang-Heung.

Table 3-4. Log house.

	Log house JLH*1
Year	2009
Location	Woodland, Jangheung-gun, Jeonlanam-do
Floor area (m^2)	43.7
Volume (m^3)	121.0
Envelope (m^2)	146.4
Types	detached house

JLH*1 : Jang-heung log house

Figure 3-6. Jang-heung, log house.

3.1.2 Methods

3.1.2.1 Preparation for blower door test

Before measuring air-tightness, the drainage, vents and electrical sockets were blocked by PVC(Polyvinyl chloride) tape, as shown in Figure 3-7.

Figure 3-7. Blocking for the blower door test.

3.1.2.2 Blower door test

A blower door test was performed following ASTM E779-03, “Standard test method for determining air leakage rate by fan pressurization7”.

To evaluate the air-tightness of each building all windows and the outside door were blocked and the inside doors were opened. The blower door (Minneapolis Blower Door-Model3, The Energy Conservation Co., Figure 3-8) was installed at the main gate as Shown in Figure 3-9 shown as example.

The blower door machine blew air from the outside to inside to get a pressure difference of 70Pa between the inside and outside. One hundred air flow rates were recorded and the average was calculated. Then, the direction of the blowing was switched from inside to outside and the average depressurized air change rate was calculated. The pressure difference was changed to 65Pa and the same procedures were repeated up to 25Pa at 5Pa interval. With these 5 average values for each pressure level, a regression coefficient was calculated using an air leakage regression model with the method of least squares. The air leakage rate was calculated using equation 3-1.

$$Q = C(\Delta P)^n \qquad \text{(Equation 3-1)}$$

where,

Q : Air leakage rate, m^3/h

C : Leakage coefficient

ΔP : Pressure gap between indoor/outdoor, Pa

n : Pressure exponent

At the 50Pa pressure difference, the air leakage is called as CFM50 (cubic feet per minute). When the measured air leakage needed to be compared with another building with a different floor area, generally ACH50 (air change per hour) could generally be used. The ACH50 was calculated by equation 3-2.

$$\mathrm{ACH50} = \frac{\mathrm{CFM50} \times 60}{\mathrm{V}} \qquad \text{(Equation 3-2)}$$

where,

V : Building volume, ft^3

ACH50 : Air change/hour

CFM50 : Cubic feet per minute

To help understand the air leak, the Canadian EqLA (equivalent leakage area) was also calculated. The Canadian EqLA is the area of a sharp edged orifice that would leak the same amount of air as the building does at a pressure of 10Pa.(Canadian National Research Council) The Canadian EqLA was calculated using equation 3-3.

$$\mathrm{A_L} = \mathrm{Q}\sqrt{\rho/\Delta \mathrm{P}}\,/\mathrm{C_D} \qquad \text{(Equation 3-3)}$$

where,

A_L : Effective leakage area, m^2

Q : Air leakage in ΔP, m^3/s

ρ : Air density, kg/m^3

ΔP : Pressure gap between indoor/outdoor, Pa

C_D : Coefficient of discharge

Figure 3-8. Blower door test equipment.

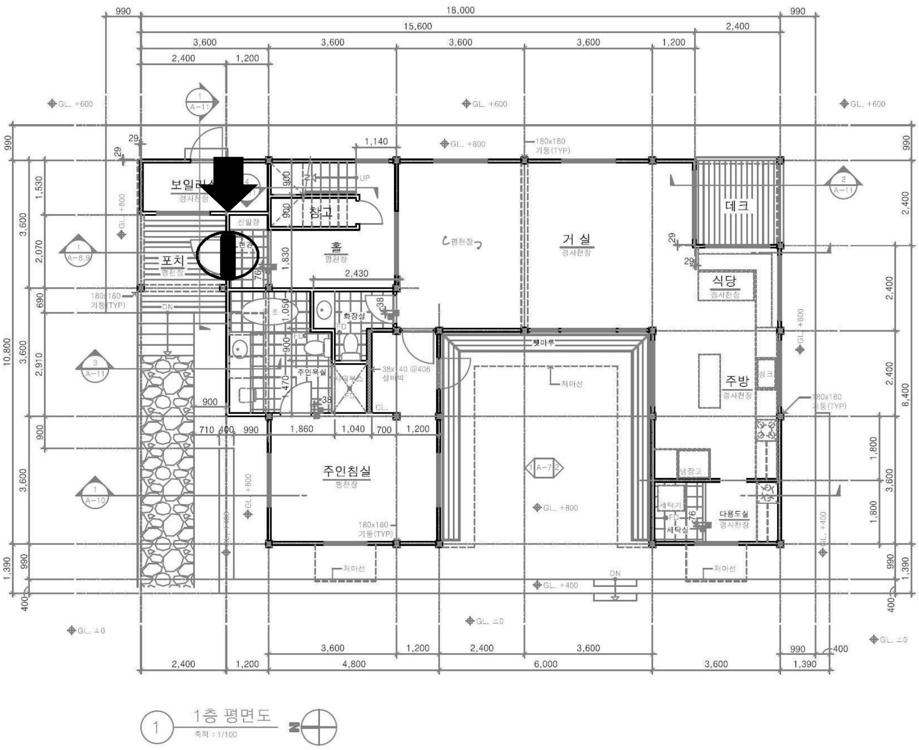

Figure 3-9. Floor plan and location of the blower door (arrow).

3.2 Air infiltration through gaps in the building envelope

3.2.1 Materials

We used three timber frame buildings for this study: a Jang-heung light frame (JLA, Figure 3-3) building, a Jang-heung post & beam (JPB, Figure 3-3) building and a Jang-heung log house (JLH, Figure 3-6) in Wood-land. These were selected because the same constructor built all 3 building with the same interior design in the same year. Additionally, these three buildings showed worse air-tightness than other timber frame buildings and hence had the largest potential improvement gains.

Figure 3-10. The thermal infrared camera.

3.2.2 Methods

To find gaps where air leakage occurred, infrared thermal images (IR Flexcam, Infrared solution Co., Figure3-10) were taken from 2 to 3 A.M. from circuit breaker and air duct openings. To study the causes of decreasing air-tightness, buildings with the worst performance were tested in detail.

Gaps were tightly covered to determine the factors causing air infiltration (various openings, gaps between the walls and the walls and the frame, circuit breakers, air ducts and the illuminator) by their effecting rate, each tape were untapped one by one. A fogger (Z-800 watts fogger, Antari Co, Figure 3-11) was used to confirm air infiltration by the naked-eye.

All expected air leaking gaps were covered by polyethylene (PE) film and PVC tape.

Measuring the expected infiltration rate using a blow door can be done by computing the ACH50 value difference before covering the gaps and after removing the tape to CFM50. Then, the Canadian EqLA can be obtained.

Figure 3-11. The fogger.

3.3 Air infiltration through discontinuities in the building envelope

3.3.1 Materials

We used three timber frame buildings for this study: a Jang-heung light frame (JLF, Table 1) building and a Jang-heung log house (JLH, Table 1) in Wood-land.

Additionally, because it performs very well, a post and beam Han-green house in Gwang-reung (GPB, Figure 3-4) was also chosen to better understand how to improve performance.

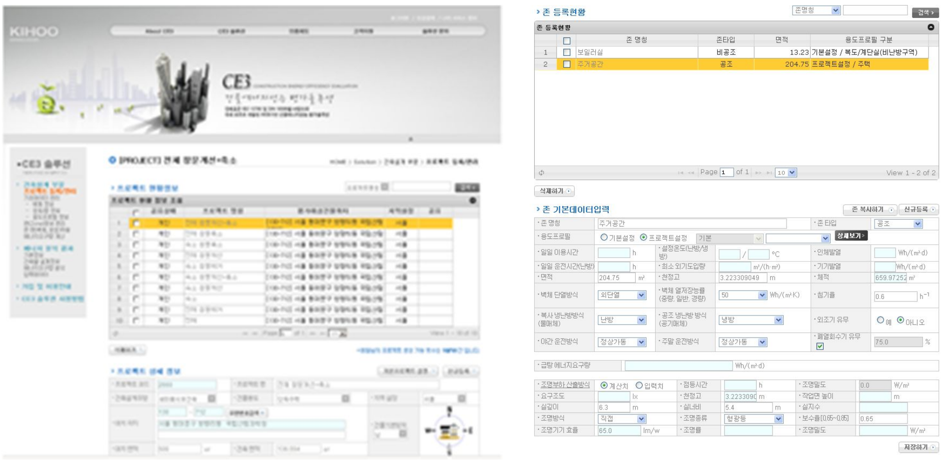

Figure 3-12. CE3 simulation.

3.3.2 Methods

Each structural type has specific gaps in the building envelope: light frame buildings have gaps between walls, post and beam buildings have gaps between the frame and the walls and log houses have gaps between the laminated logs making up the walls.

Specific gaps which were especially susceptible were covered by PE(Poly ethylene) film and PVC tape and the blower door test was performed. The ACH50, CFM50 and the Canadian EqLA were compared with reference air-tightness values.

At this time, the building which showed the best infiltration performance through gaps on envelope was simulated by CE3. CE3, Construction Energy Efficiency Evaluation is a commercial web-based solution program based on international standards ISO 13790 and German evaluation standards DIN V 18599 (Figure3-12). Saving of fossil fuel from covering the gaps between frame and wall was calculated.

4. Results and Discussion

4.1 Air-tightness performance of timber frame building

4.1.1 Air-tightness results

Eleven timber buildings were tested by the depressurization (DEP) and pressurization method (PRE) using the blower door. They showed large differences according to structural type. As Table 4-1 shows, light frame buildings showed the best air-tightness and showed only 1/3 of the heat loss of post and beam structures

The air leakage curves of the buildings were calculated using equation 3-1. Appendix shows the air flow rate under an air pressure difference of 0-50Pa and compares it with air-tightness according to building type.

Table 4-1. Air-tightness results.

	N*	DEP(h^{-1})			PRE(h^{-1})		
		Max	Min	Mean	Max	Min	Mean
Light frame	6	23.41	3.10	8.47	23.58	3.66	8.92
Post and beam frame	3	59.16	5.74	24.97	61.25	6.07	26.13
(Han-ok)	1			74.12			89.47
Log house	1			66.29			68.39

N* : Number of buildings

Among the light frame buildings in Bong-hwa village, two were built using a special wall designed for low energy consumption. In the wall of low the energy building, PE film was inserted between the gypsum board and the frame (Figure 4-1, Source : Kim et al, 2012). These types of buildings showed 122% and 154% better air-tightness (DEP) than similar sized houses built using standard walls. Based on this comparison between low energy and standard light frame buildings, we confirmed that PE films contribute to air-tightness, as shown in Table 4-2.

Wood-land in Jang-heung showed worse air-tightness than the one in Bong-hwa village. JLA and JLB in Jang-heung (Figure 3-3) were built in 2009. However, these two buildings showed different air-tightnesses, even though they were built at the same time and had the same wall detail. The volume of JLB was 126.39% more than that of JLA, but the air-tightness was 2.12 higher than JLB. JLA was placed on columns without a wall system on the first floor, so the effective building envelope area exposed to the outdoors increased from 173.57m^2 to 237.97m^2, as shown in Figure 4-2. Based on this comparison, the area of the building envelope exposed to the outside had a significant effect on air-tightness. As the low energy light frame buildings (BLA and BLB) showed, PE film can increase air-tightness. If a large exposed floor is required in the building design, a special floor design such as a PE film should be considered.

Four post and beam buildings were tested. The test house (HPB, Figure 3-4) was built in 2006 and showed air-tightness almost twice as good as the Han-green house (GPB, Figure 3-4 and Table 4-2), built in 2009, which was constructed using double glazed windows, while some windows in HPB and the post and beam guest house in Jang-heung (JPB, Figure 3-4) were single glazed. It also had larger area using glass fiber insulation. The Han-green house was built using a semi-passive construction method. JPB built in Jang-heung, Wood-land showed a lower air-tightness of 43.51 (DEP,h^{-1}) and 47.35 (PRE,h^{-1}), as shown in Table 5-2.

The air-tightness of the traditional Korean Han-ok building (JTH, Figure 3-5) was also evaluated by the blower door test. It can be categorized as a post and beam structure. It showed very low air-tightness, 74.12 (DEP,h^{-1}) and 89.47 (PRE,h^{-1}), as seen in Table 5-2. JTH had a floor heating system, meaning the low air-tightness may be good for ventilation but also making JTH cold and uncomfortable to live in during winter. So, as JTH gets more attention in housing market, its air-tightness needs to be improved. The log house in Jang-heung (JLH, Figure 3-6) had very low air-tightness of 75.61 (DEP,h^{-1}) and 81.75 (PRE,h^{-1}), as shown in Table 5-2. The wall of JLH is made by stacking logs and gaps formed when the wood shrinks and the anisotropic nature of wood are the main reason for the poor air-tightness.

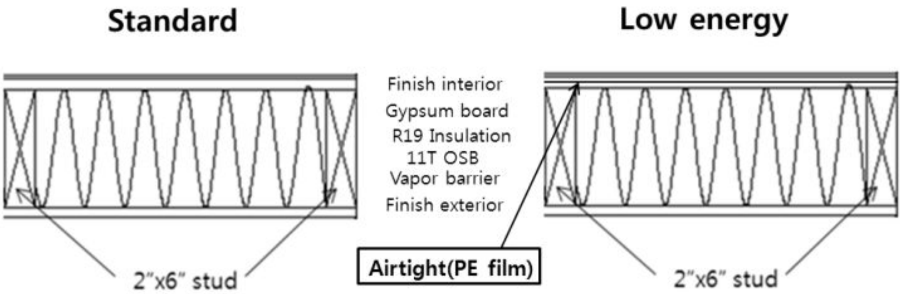

Figure 4-1. Composition of standard and low energy walls.

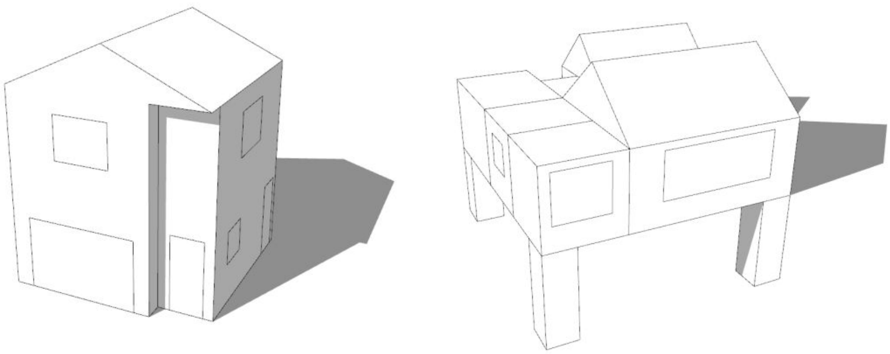

Figure 4-2. Schematic drawings for light frame A(Left) and light frame B(Right).

Table 4-2. Air-tightness results of Bong-wha village light frame buildings.

Type	Location	Name	Air change at 50Pa		
			DEP	PRE	Mean
Light frame	Bong-wha villige	BLA	3.10	3.66	3.38
		BSA	4.76	5.21	4.99
		BLB	3.41	3.82	3.62
		BSB	4.16	4.50	4.33
	Jang-heung	JLA	10.72	11.43	11.08
		JLB	23.41	23.58	23.50
Post and beam	Hong-reung	HPB	10.01	11.08	10.55
	Gwang-reung	GPB	5.74	6.07	5.91
	Jang-heung	JPB	43.51	47.35	45.43
Han-ok	Jang-heung	JTH	74.12	89.47	81.80
Log house	Jang-heung	JLH	75.61	81.75	78.68

4.1.2 Comparison of air-tightness with overseas test result

Light-framed houses such as the Wood-land and Han-green houses showed better air-tightness than detached housed in the Chung-chung region, as shown in Table 4-3.

For the post and beam structures, GPB showed a similar performance to Finland housing from 1981 to 1998 and Norwegian housing in the 1980s. Moreover, it showed slightly better performance than English housing (Table 4-3). JTH, which is a post and beam structure and the log house were similar to the worst American housing. With these results, we can confirm the possibility that timber can successfully be used to build low energy housing.

Table 4-3. Air-tightness of the domestic and overseas single-family homes.

Country	Year	Number of building	Air-change rate (ACH50, h^{-1})		
			Mean	Min	Max
USA	-	12,902	29.7	0.5	84
Canada	1985-1995	222	3.1	0.4	11
UK	-	471	13.1	2.0	30.0
Belgium	1995-1998	51	7.8	1.8	25.0
Sweden	-	44	1.0	-	-
Finland	1981-1998	171	5.9	1.6	1.8
Finland	2002-2004	100	3.9	0.5	8.9
Norway	1980	61	4.7	2.0	8.0
Korea (Chung-cheong*)	2008	22	16.4	4.7	31.6

*Reinforced concrete. **Source : Yoon et al, 2008**

4.2 Air infiltration through gaps in the building envelope

Thermal imaging analysis found the following infiltration gaps:

Openings

Circuit breaker and duct

Air conditioner

Envelope

After the blower door test, the infiltration of each factor was studied in a second experiment that closed the elements one by one to evaluate the effect of each one. All of the experiments were carried out with elements near the building envelope.

Table 4-4 shows the air-tightness effect rate results of each gap.

Table 4-4. Air-tightness results of decreasing factors.

	Light frame	Post and beam	Log house
	ACH50(h^{-1})/ Difference	ACH50(h^{-1})/ Difference	ACH50(h^{-1})/ Difference
Openings	10.06/-1.37	44.82/-2.53	76.40/-5.35
Circuit breaker and duct	11.22/-0.21	47.3/-0.05	81.70/-0.05
Heater and air conditioner	11.35/-0.08	46.89/-0.46	81.70/-0.05
Envelope	9.80/-2.35	44.31/-3.04	76.39/-5.36

4.2.1. Openings

Heat loss through the openings was confirmed using a thermal image camera, as shown in Figure 4-3. Regardless of the envelope type, similarly sized windows had similar the Canadian EqLA values. This means that the size of the window frame and the performance of the window itself affected the air tightness, not the walls.

4.2.2. Circuit breaker and duct

Heat loss through openings was detected by a thermal image camera, as shown in Figure 4-4. The circuit breaker and duct were very different in each house. Although the Canadian EqLA values did not match, this element cannot be considered an important one because affected area was very small.

4.2.3. Heater and air conditioner

Since all three houses used floor heating systems, the air conditioners were not compared to the heaters. The whole areas were covered with PE film and the Canadian EqLA values were calculated regardless of the structure and the size of air conditioner (Figure 4-5). Similar to the circuit breaker and duct, the affected areas were small in all three structures.

4.2.4. Envelope

Infiltration through the envelope was evaluated because infiltration through the gaps had no significant effect on air-tightness, as shown in the previous results.

When potential elements which can cause infiltration are post-blocked, the infiltration through the building envelope can be calculated, as shown in Figure 4-6. The value from the blower door test was converted to the Canadian EqLA. The light frame structure had the smallest infiltration, 3.83m^2. The infiltration of the post and beam structure was 19.67cm^2 and that of the log house was 33.76cm^2 . The value was the same as it was before covering the expected infiltration elements.

From this analysis, it was concluded that the lowest air infiltration occurred through envelope.

Figure 4-3. Blocking and thermal image of the openings.

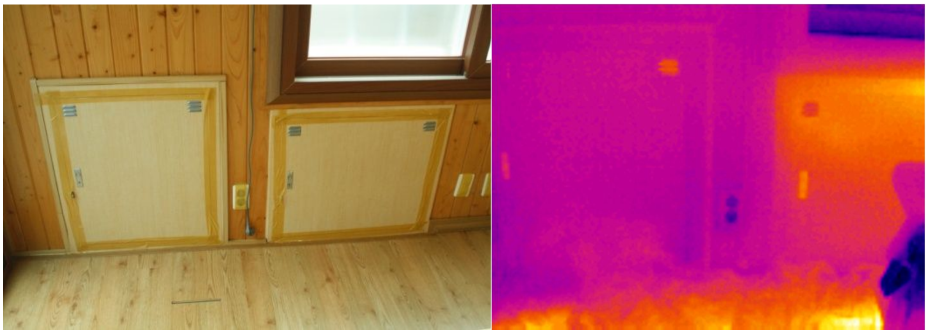

Figure 4-4. Blocking and thermal images of the circuit breaker and duct.

Figure 4-5. Blocking and thermal images of the heater and air conditioner.

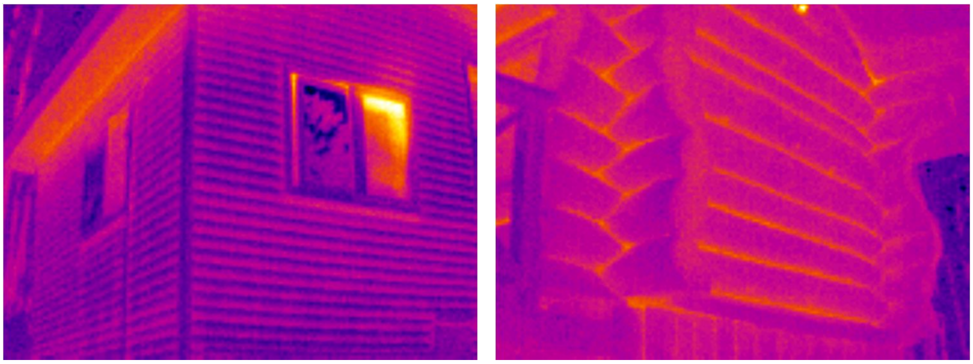

Figure 4-6. Infiltration through the building envelope.

(Left : Light frame house A (JLA), Right :Log house (JLH))

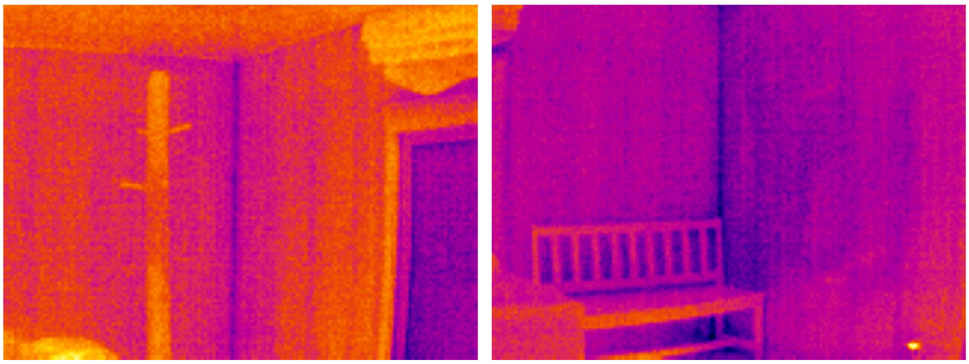

Figure 4-7. Thermal images of the Jang-heung light fram A house envelope.

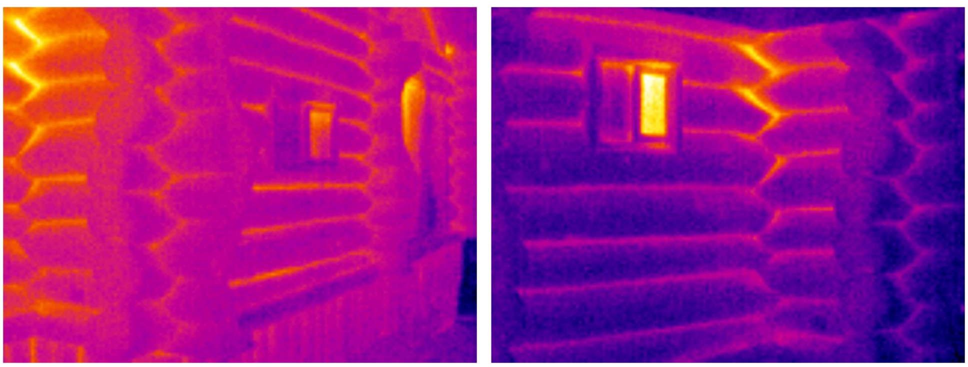

Figure 4-11. Thermal image of the Jang-heung log house envelope.

4.3 Air infiltration through discontinuities in the building envelope

Among all of the infiltration elements, the gaps between the walls showed the most variation. There were many areas that could not be taped, such as between the walls, between the walls and the floor, the sink and built-in wardrobes. The lengths of the tapes were used for comparison. All three structures had infiltration through the gaps between the walls. Since this experiment was a field test which was carried out after the interior finishing, the absolute values could not be compared. However, after converting to the same length, the Canadian EqLA values were also similar.

Infiltration occurred even more in the log houses compared to the other structures because of the gaps between the logs.

4.3.1 Light frame between wall and wall in envelope

In this section, we discuss the test of the light frame structure A (JLH.A, Figure3-3) in the Jang-heung Wood-land was (Table 3-2).

In the blower door test, a fogger was used to uncover infiltration occurring through gaps (Figure 4-7). The gaps were then taped to study how much air flow was occurring.

The taping was 14.4m covering the six corner edges, 2.4m for each.

The blower door test was conducted before and after taping to compare ACH50, CFM50 and the Canadian EqLA.

The JLH`s commissure between the walls was 14.4m long (2.4m per each, 6 commissures) and the ACH50 was 11.43 (h^{-1}). After taping, this value was 11.31 (h^{-1}), a decrease of 0.12 (h^{-1}).

As seen in Table 4-5, the Canadian EqLA decreased from 677.30cm^2 to 672.79cm^2. These values can be translated to surface areas, becoming 4.41cm^2 and 4.38cm^2, respectively. CFM50 decreased 10.87 ft^3/min. The correction factor (n) was 20 and the infiltration decrease was calculated to be 0.54ft^3/min. The decrease of air-tightness performance (using CFM50 per 1m) was 0.04ft^3/min.

Infiltration is often found in the corners between the walls in buildings with especially high air-tightness. The quality of framing at the corners and insulation are important for air-tightness.

Table 4-5. Comparison of air-tightness results in the light frame house.

	Air change at 50Pa	EqLA at 10Pa	
		Lenth (cm^2)	Rate (cm^2/m^2)
Pre-block	11.43	677.30	4.41
Post-block	11.31	672.79	4.38

4.3.2 Post and beam frame between gaps between the frame and the walls in the envelope

We conducted a test on the post and beam structure in Jang-heung, Wood-land. However the subject building showed very low air-tightness even after covering the gaps between the posts and the walls. It showed an improvement from 45.3 (h^{-1}) to 43.5 (h^{-1}), but the performance was still low. Thus, more detailed and specific gap effects were evaluated by conducting an experiment on a more air-tightened building, a Han-green house (GPB, Figure 3-4).

Thermal images of the Han-green house were taken in winter with heating by a portable infrared camera (IR Flexcam, Infrared solutions Co. Ltd.) to discover where heat loss was occurring (Figure 4-8, 4-9). Based on the thermal image analysis, the gaps between the frame and the in-fill walls were a potential source of heated-air leak.

To investigate the influence of the gaps between the frame and the walls on air-tightness and energy efficiency, all possible air-leaking areas between the frame and the walls were blocked by taping, as shown in Figure 4-10. The blower door test and CE3 simulations were conducted in the same way and all input variables except the air-change rate (ACH50) were the same as in the simulation without taping. For the air-change rate (ACH50), the mean value of four tests with taping was used. Lastly, heating energy demands and annual energy demands were compared with the simulation without taping.

Table 4-6 shows the air-change rate (ACH50) evaluated by the blower door test. Four pressurization / depressurization methods were used and the mean value of the four tests results was calculated. The mean air-change rate (ACH50) of the Han-green house was 5.91 h^{-1}.

Table 4-3 shows that the Han-green house had a lower air-change rate (ACH50) than USA, UK, Belgium and is similar to Finland in the 80-90s. Also, it shows much better performance than Chung-cheong, Korea, which might be representative of reinforced concrete (RC) buildings because most residential buildings in Korea are made of reinforced concrete. This lower air-change rate

(ACH50) means that the Han-green house has relatively better air-tightness than structures in other countries except cold region countries such as Finland, Norway and Canada. It is noticeable that the air-tightness of the Han-green house showed much better performance than the results from structures in the Chung-cheong region in Korea.

All possible air-leakage areas between the frame and the in-fill walls were blocked by PVC tape (K&T Co Ltd.). We then compared results from before and after to determine how much air leaked through the gap.

The mean air-change rate (ACH50) without taping was 5.91 h^{-1}; the taping decreased this to 5.25 h^{-1}. Blocking the possible air-leaking areas improved the air-tightness by 11.2%. This means that air can leak between the glulam frame and the in-fill wall and thus should be carefully considered when designing these types of buildings.

Air-tightness of the Han-green house was measured by a blower door test. It was concluded that the Han-green house has relatively high air-tightness compared with structures in other countries, even though heated air can leak through the gaps between the frames and the in-fill walls.

The gaps between the frames and the in-fill walls were expected to lead to large amounts of heat loss. Based on comparisons of air-tightness from tests preventing heated air leakage through the gaps, we found that air leakage decreases air-tight performance by 11.2%. Therefore, to improve the energy efficiency of post and beam buildings with exposed wood frames (for aesthetic reasons), the design between the frame and the in-fill walls should be considered carefully.

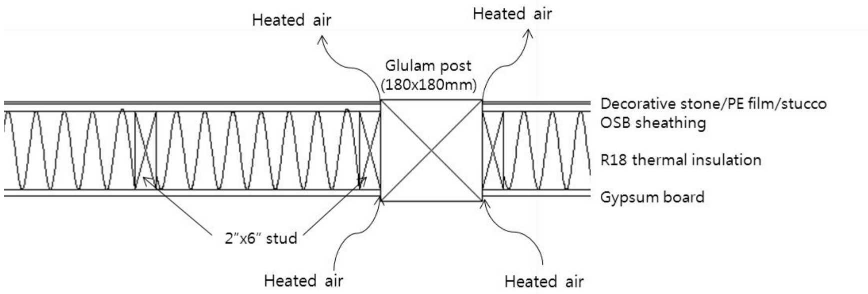

Figure 4-8. Expected air-leakage.

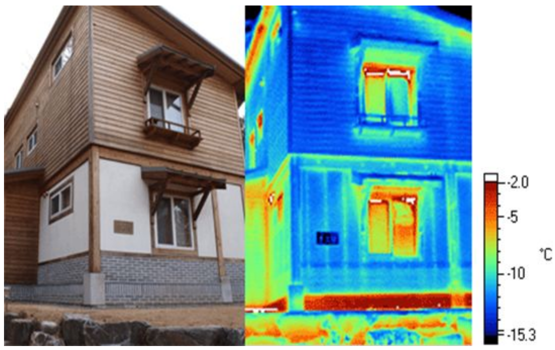

Figure 4-9. Thermal image analysis showing heat loss.

Figure 4-10. Taping the gaps between the frame and the walls.

Table 4-6. Air change according to the presence of taping (units : ACH50, h^{-1}).

	Pressurization	Depressurization	Mean
Without taping[1]	6.07	5.74	5.91
With taping	5.36	5.13	5.25
Difference	-0.71 (-11.7%)	-0.61 (-10.6%)	-0.66 (-11.2%)

[1] Taping was applied to prevent heated air from leaking through the gaps between the frame and the walls

Table 4-7. Heating energy demand per a year for Han-green.

	Without taping	With taping	Difference
Heating energy demand per unit area(kWh/m^2·a)	134.50	130.70	-3.80 (-2.8%)
Fossil fuel demand per unit area (Liter/m^{2}year)	13.50	13.10	0.38 (-2.8%)
Fossil fuel demand of whole Han-green house (Liter/year)	2547.40	2475.50	71.90 (-2.8 %)

4.3.3 Log house between logs in envelope

A log house (JLH, Figure 3-6) in Jang-heung Wood-land was also tested. A fogger was used to discover where infiltration was occurring in the gap during the blower door test as shown in Figure 4-11(page 31). The gaps were taped to see how much air flow occurred (Figure 4-12). Table 4-8 shows the estimated taping length by dividing the commissure part between the log and the logs of the front, back and side. A blower door test was conducted to compare ACH50, CFM50 and the Canadian EqLA before and after taping.

The commissure of log house between logs was 196.41m long and ACH50 was 81.75(h^{-1}). After taping, ACH50 was 77.38(h^{-1}), which was a decrease of 4.37(h^{-1}).

Table 4-9 shows that the Canadian EqLA value decreased from 5546.2 cm^2 to 5012.9 cm^2, which corresponds to a surface area decrease of 37.89cm^2 to 34.24cm^2. CFM50 decreased to 383.47ft^3/min. After setting the correction factor(n) to 20, CFM50 decreased to 19.17ft^3/min, corresponding to a decrease in air-tightness of 1.95ft^3/min.

The lengthwise commissure between the logs was calculated. Infiltration was expected and a blower door test with an IR camera and fogger was conducted to identify heat loss and infiltration before and after taping.

Using equations 1, 2 and 3 to calculate CFM50, we found it to be 1.95ft^3/min. Significant infiltration had occurred in the building three years after completion, leading to material deformations such as shrinkage, expanding and twisting. Therefore, when constructing log houses, these elements should be regularly inspected and maintained for high energy efficiency.

Figure 4-12. Taping between the log lamination layer and the fogger.

Table 4-8. Length of log lamination layer.

	Front wall	Side wall	Back wall	Total wall
Commissure length between logs and log (m)	47.91	88.10	60.40	196.41

Table 4-9. Comparison of air-tightness results in the log house.

	Airflow at 50Pa	EqLA at 10Pa	
		Length (cm^2)	Rate (cm^2/m^2)
Pre-block	81.75	5546.20	37.89
Post-block	77.38	5012.90	34.24

5. Conclusions

This study found that air infiltration through the building envelope was the most significant source of air leakage, regardless of structural type.

Light frame buildings showed the highest air-tightness on the blower door test, followed by post and beam structures and log houses.

We found that the building envelope was the most effective factor in decreasing air-tightness. Other factors (e.g., openings and ducts) did not show significant effects on air-tightness performance (all less than 10%).

Therefore, the building envelope was investigated in detail. Discontinuous parts within the envelope were blocked by PVC tape and based on these tests, the following area were found to be most responsible for air leakage:

- between the walls (for light-framed houses)

- between the frame and the walls (for post and beam frame houses)

- between the logs (for log houses)

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초 록

에너지관리공단의 에너지소비 통계 자료를 보면 국내 총 에너지 소비량 중 주거용 건물의 난방에너지 소비가 10% 이상을 차지한다. 이러한 주거용 건물의 에너지 효율 향상에 중요한 부분을 차지하는 두 가지 요인은 건물의 외피가 가지고 있는 열관류율과 기밀성능이다. 본 연구는 이 기밀성능에 초점을 맞추어 진행되었다.

건물에 누기와 침기가 발생하면 건물 외피를 통한 열손실, 구조체 내부의 결로 발생, 거주자의 열적 쾌적도 저하 등의 다양한 문제가 발생한다. 특히 목조건물은 건식공법으로 시공되기 때문에 기밀성 확보는 반드시 필요하다. 이러한 기밀성능 향상을 위한 출발점은 기존 국내 목조건물의 상황에 대해서 정확히 파악하는 것이다. 국내의 목조건물을 구조별로 크게 경량 목구조, 기둥-보 목구조, 통나무 주택과 같이 세 가지로 분류한 뒤 Blower Door Test(압력차법)을 이용하여 실측을 통해 대상 건물들의 기밀성능을 측정하고 비교, 분석하였다. 이 실험에서 비교적 최근에 지어진 건물들 그리고 경량 목구조, 기둥-보 목구조, 통나무집 순으로 기밀성능의 결과가 높게 나타났다. 봉화 탄소 순환 마을에 지어진 경량 목조 건물은 다른 건물들에 비해 우수한 기밀성능을 나타내었는데 그 중에서도 석고보드 마감 전에 PE film으로 기밀막을 설치한 건물이 약 30%정도 우수한 기밀성능을 나타냈다. 이것은 외피면 자체로 빠져나가는 침기가 상당히 많은 부분을 차지 한다는 것을 의미한다. 기둥-보 목조주택은 뚜렷한 경향이 나타나지 않았는데 이는 노출되는 목재의 사이즈와 채움 벽의 구성이 저마다 달랐기 때문이다. 전통

한옥은 통풍이 잘되고 바닥 난방을 하는 만큼 가장 낮은 기밀성능을 나타내었다. 통나무 주택도 목재의 재료적 특성으로 인해 시간이 지남에 따라 발생하는 수축, 이완, 쪼개짐 등의 영향으로 적층된 통나무 사이에 틈이 발생했고 이 때문에 기밀성능이 저하되어 한옥에 이어 두 번째로 실측주택 중 낮은 기밀성능을 나타내었다.

이 실험 결과를 바탕으로 실제 침기가 발생 하는 부분을 보다 정확히 탐지하기 위해 각 구조별 대상 주택을 재 선정해 열화상 카메라를 이용하여 열손실 부분을 탐지 하였다. 건물외피는 크게 벽체 부분과 비벽체(개구부, 에어컨, 덕트 및 두꺼비집) 부분으로 나눌 수 있었다.

비벽체 부분의 기밀성능 저하를 알아보기 위해서 PVC tape와 PE film으로 밀봉한 뒤 Blower Door Test를 재 실시해서 각 인자들의 기밀성능 저하를 알아본 결과 비벽체 부분은 10% 미만의 영향력으로 벽체에 비해 미미 했다.

벽체 부분의 기밀성능 저하를 알아보기 위해서 각 구조별 목조건물 벽체의 특징을 나타내는 부위에 PVC tape를 이용해 밀봉하여 기밀성능을 재측정 하였다. 경량 목구조의 벽체와 벽체가 만나는 부분, 기둥-보 주택의 구조체와 벽체가 만나는 부분, 통나무 주택의 통나무가 적층되는 부분에서 실제로 침기가 발생하는 것을 확인하였다. 앞으로 저에너지 주택으로 가기 위해서 반드시 이 부분의 보완에 관한 연구가 필요할 것이다.

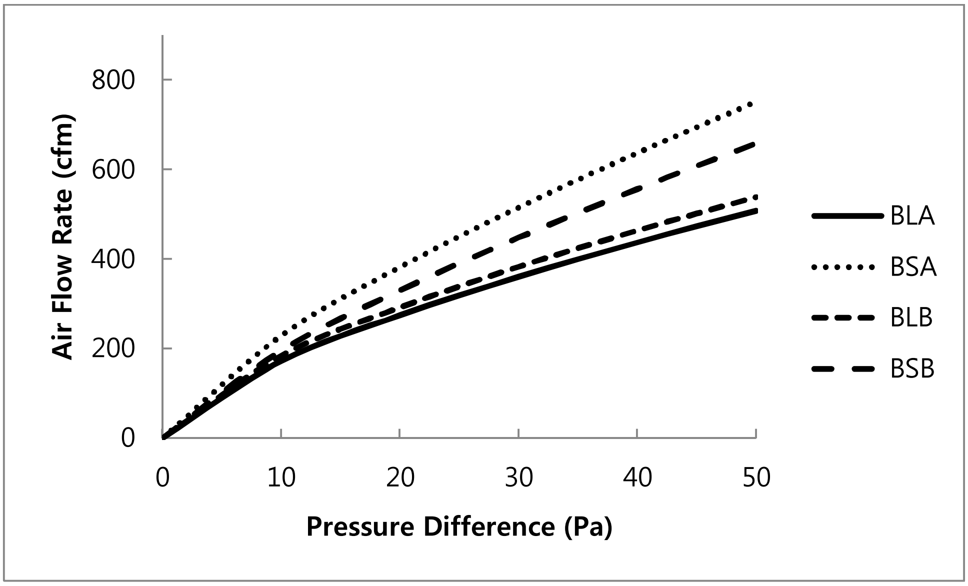
이상과 같이 본 연구는 목조건물을 구조별로 분리하고 실측하여 현재 국내 목조건물의 기밀성능을 파악하고 분석하였다. 또 구조별로 벽체, 비벽체로 나누어 기밀성능 저하 인자를 탐지 하고 각각의 영향률을 파악하였다. 이는 앞으로 목조건물이 저에너지 주택이나 제로 에너지 하우스로 가기 위한 가능성을 확인하였다.

Keywords : 기밀성능, 경량 목조주택, 기둥-보 목조주택, 통나무 집,
저에너지 주택, 건물 에너지 성능시뮬레이션

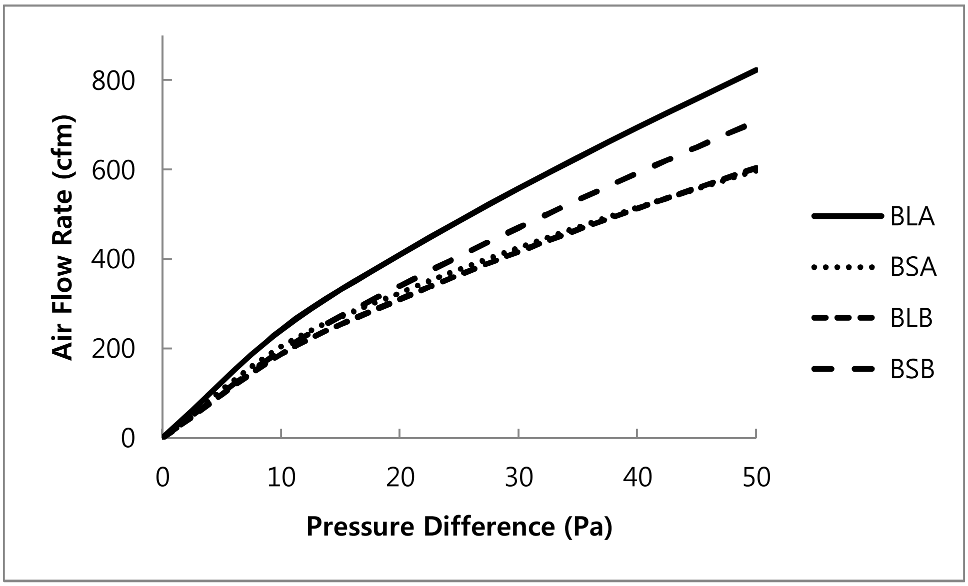
Student number: 2010-23419

APPENDIX. Air-leakage curve of subject buildings.

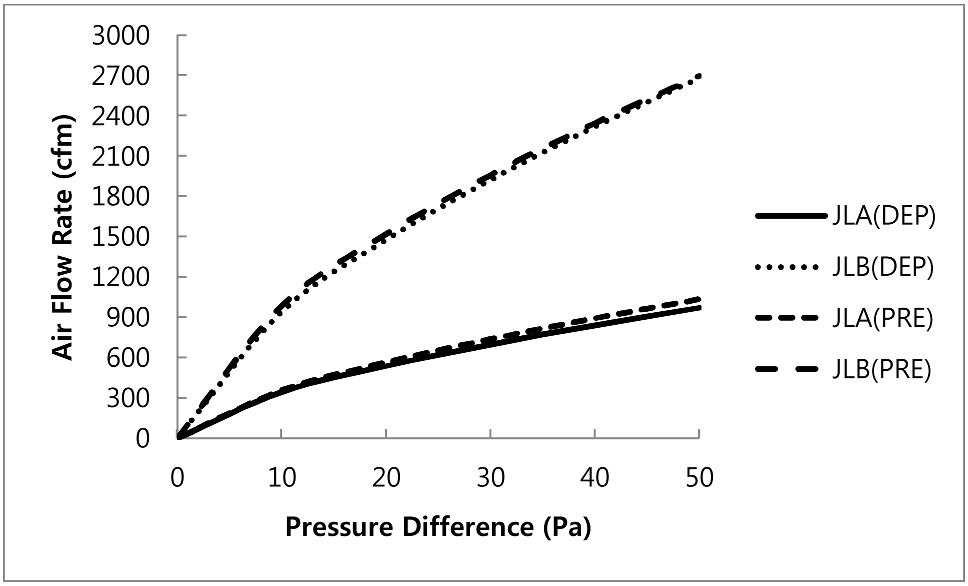
A-1. Air-leakage curve of Bong-wha village light frame buildings by DEP



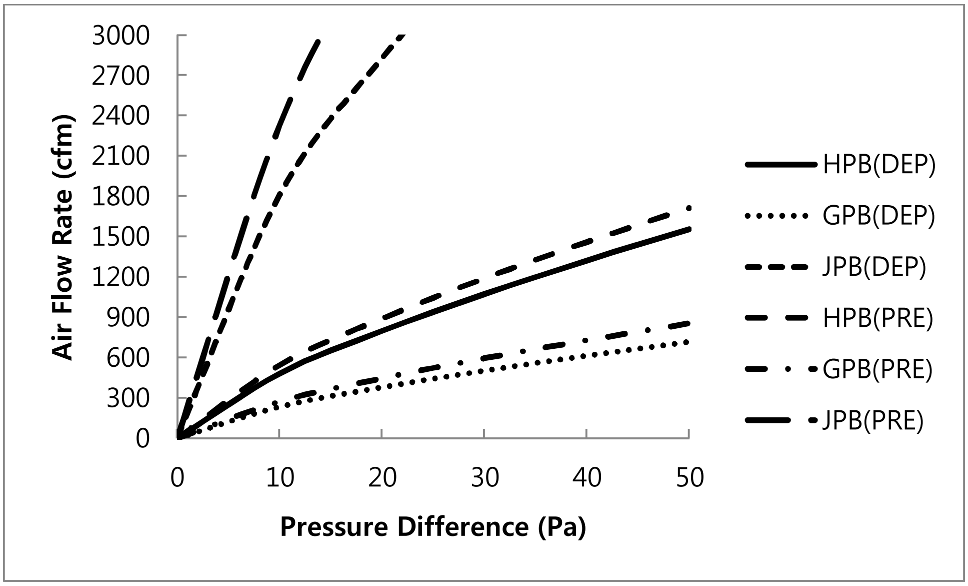
A-2. Air-leakage curve of Bong-wha village light frame buildings by PRE



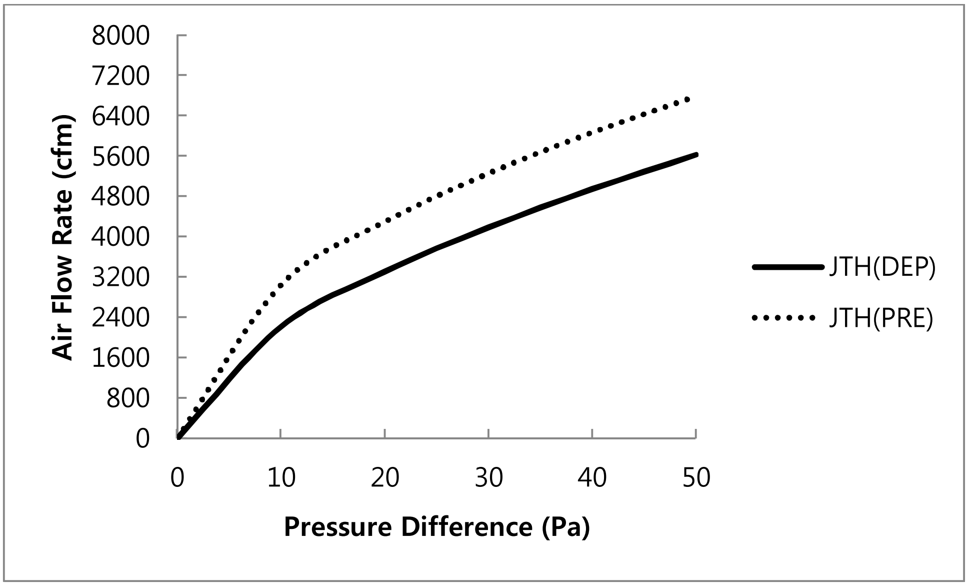
A-3. Air-leakage curve of light frame A and light frame B in Jang-heung.



A-4. Air-leakage curve of post & beam buildings.



A-5. Air-leakage curve of traditional Han-ok building



A-6. Air-leakage curve of log house