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Floor Plan Analysis of Detached Houses for the Low-income Households

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ABSTRACT

Energy poverty has been defined as low-income households who paid energy cost more than 10% of their ordinary income. Therefore, there are various subsidy programs focused on house remodeling for low-income households and one of them is the Home Energy Efficiency Assistance Program which have done by Korea Energy Foundation since 2007. The aim of the program is to improve the thermal performance of dilapidated dwellings and analyzed the detached house for the low-income households to develop the building typology. The database contained approximately 3,061 households which was obtained from the program in 2013 and the results of the study were like this; 1) For the shape of residential houses, the number of rectangular shaped building was higher than non-rectangular shaped ones. 2) For the orientation of buildings, the south layout of the detached housing was dominant to gain heating energy into buildings. 3) For the floor area, the average floor area was 44.2㎡, although its size varied wide variations, which range from 6.3㎡ to 107.1㎡. 4) For the windows and doors, the south-facing window was larger than the other side. Finally it would be possible to determine the characteristics of residential houses for low-income families. A future study could establish typology of low-income housing that it would estimate the performance of each model building before and after the retrofit to improve the energy performance.

KEYWORD

Energy Efficiency,
Heating Energy,
Detached House,
Low-income Households

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1. Introduction

1.1. Background

In recent years, low-income households have carried economic burden due to the widened gap between the rich and the poor and the rise of energy price. According to a 2008-2012 household income and expenditure survey, the ratio of fuel payment to income level is much higher in low-income households than for the middle class. Furthermore, housing type differed by income groups; over 50% of low-income groups lived in detached houses whereas high-income groups lived in apartments. Low-income households not only to live in the dilapidated dwellings, but also generally face financial difficulties. This implies that intensified initiatives are needed for detached houses in order for them to meet minimum energy-performance requirements, both functionally and economically.

The households that spend more than 10% of their ordinary income on energy consumption are called "energy poverty". Targeting the elimination of energy poverty households until 2030, it supported a total of 1.8 trillion won to 3 million households annually over 5 years from 2008 to 2012.[1)] Since 2007, the Korea Energy Foundation has implemented a 'Home Energy Efficiency Assistance Program' to improve energy performance of a house and reduce energy cost for low-income households. As a result of the Home Energy Efficiency Assistance Program in 2013, a total of 2,571 households were beneficiaries. 776 households from the 2,571 houses received wall or roof insulations and saved 22% of energy consumption; 1,006 households reduced 19% of energy consumption by replacement windows; and the households that had both insulations and replacement windows could conserve 25% of heating energy. However, it is necessary to set the baseline of the energy performance of detached houses based on the Home Energy Efficiency Assistance Program for low-income households.

The main purpose of this study is to present the characteristics of detached houses of low-income households, which are varied in size and shape, and examined the plan types of detached houses using the recent dataset stored in 2013.

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1) he Ministry of Trade Industry and Energy, "The 2nd National Energy Basic Plan", T, 2014, pp.129

1.2. Materials and Methods

The study was identified the plan type to apply commonly to the detached houses of low-income groups, especially focusing on plan type, orientation, floor area, wall and window. The reason for considering these factors, 4 items have impact on the energy consumption of a small detached house. And field survey was carried out for 3,061 households by the program, which was extracted in 2013. Consequently, 222 households were investigated in the sample with a 95% confidence interval and standard deviation ±1.96.

2. Previous Research

2.1. Home Energy Efficiency Assistance Program

The Home Energy Efficiency Assistance Program for Low-Income Households is not only aimed at improving the thermal performance of dilapidated dwellings, but also for providing two categories of service; replacing heating devices and retrofitting low efficiency houses. In addition, a purpose of this program is to reduce energy costs of low-income families. Remodeling service includes wall insulation, window replacement, floor improvement and electricity. Figure 1 shows the pictures of the houses before and after the retrofit. Support for heating device includes the provision of boiler, heating mat, gas cooker, electric water heater and so on.[2)]

Before the retrofit

After the retrofit

Fig. 1. Retrofitting low efficiency houses before and after the retrofit cases

Figure 2 shows the annual number of households to receive the support and budget from 2007 to 2013. In 2007, a budget of 1 billion was spent to support 16,501 households. By the type of support, 4,620 households received remodeling service whereas 11,881 households were beneficiaries of heating device. The budget and the number of the eligible sharply increased from 2008, costing 28.5 billion won for 80,130 households. As a result of the project, heating energy efficiency per household increased by 8 to 40% and energy cost reduced by 6.1 billion.

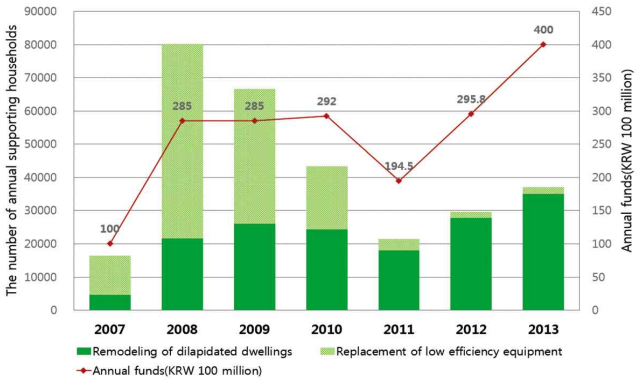


Fig. 2. Number of annual supporting households and annual funds related to the program

In 2011, the budget temporarily shrank to 194.5 billion won, so the number of beneficiaries reduced to 21,418 households, as the remodeling program is more effective in terms of improved energy efficiency than merely providing support for necessities. In 2012, the budget increased again to 29.5 billion won for 27,725 households of low-income brackets. Such rising trend of the budget was also reflected in 2013. A total budget of 40 billion won was assigned and total 38,000 households are estimated to have received support for remodeling (35,000 households) and other necessities (2,000 households).

2.2. Korean Building Typologies

It has been reported that in designing a detached house, the lifestyle, income, consciousness status and social variables associated with regional characteristics of the time are reflected. In the 1970s, the Korean government disseminated reference building of about 50 ㎡-sized house. In the 1980s, it expanded the floor area of a house to 85 ㎡ and distributed 8 kinds of standard drawings according to the characteristics of region. When it came to the 2000s, the government suggested three types of reference houses (82.6 ㎡, 115.7 ㎡, and 148.8 ㎡) as a way to verify and assess the energy performance of a building.

The research of designing the building typology in 1983 includes a total of 17 types of detached house plans: 7 plans for urban and 10 plans for rural detached houses. The design guidelines were established through comprehensive review and analysis of research papers, literatures and construction related raw. Although urban and rural detached house were a little bit different in room layout, they had a similar plan. Figure 3 shows the plan of the smallest (49.5 ㎡) rural house. The plan was quadrangled, based on the traditional construction method. The main space such as bedroom and living room were designed to face to the south, improving indoor environment quality. There were 3 windows on south facade, more than other directions, to connect indoor and outdoor space as well as obtain daylight into

2) The Ministry of Knowledge Economy, "A Study on the Welfare Policy of Major Eastern Asia Countries", 2009, pp.19

buildings. The typology was contained for 3 rooms, 1 living room and 1 bathroom in consideration of required and minimum space for the members of a household.

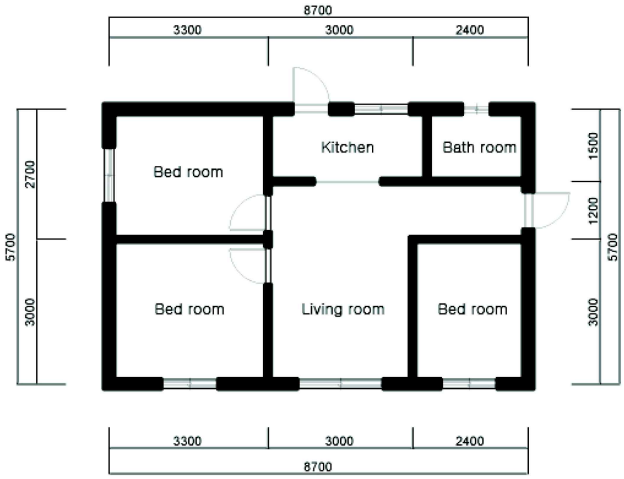


Fig. 3. Floor plan for detached house typology in 1983

The study (2001) on the criteria, institution and promotion of performance certification of energy-saving building analyzed the average sizes of houses that occupants actually resided and wanted to live in and then designed a reference house. Three building typologies were designed: one-stored house of 82.6 ㎡ and 115.7㎡, and double-layered house of 148.8. Figure 4 shows the plan of the smallest house (82.6㎡). The plan was designed to be rectangled including porch and balcony. The orientation of the house was southward, which was the most commonly preferred in South Korea. The windows as facing the south and the north was assumed to be larger than windows on other directions. Floor area was based on Korea Statistical Yearbook (1977). Considering site conditions and the type of family composition, 3 rooms, 1 living room and a bathroom was designed.

2.3. Other Established Building Typologies

Thirteen European countries participated in 'Typology Approach for Building Stock Energy Assessment (TABULA)' project to establish residential building typology. The project aimed to create a harmonised structure for European building typology in order to estimate the energy demand of the residential building stocks at national level. These building typologies were available on the TABULA web site. The web site also gave access to a web tool that was able to calculate the performance of each model building before and after planned initiatives to improve the energy efficiency have been carried out. Particularly, two types of building typology models were established within

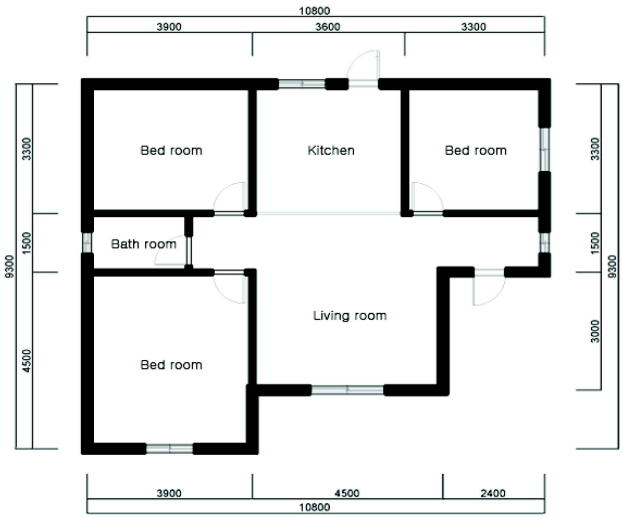


Fig. 4. Floor plan for detached house typology in 2001

the project for the Danish residential building stock. For both types, the buildings were divided into three main building types (single family houses, terraced houses and blocks of flats) and grouped in nine construction periods by building tradition (Figure 5). The first typology model type was based on real existing buildings and is suitable for showing typical energy saving initiatives. The second typology consists of average design building models which was used to establish a space heating balance model.

Fig. 5. Real example buildings of Denmark

3. Floor Plan Analysis of Detached Houses of Low- Income Households

3.1. Statistical Data to Support the Analysis

This study was based on 2,571 detached houses from the total 3,061 households that are beneficiaries of retrofit service provided through the Home Energy Efficiency Assistance Program in 2013. The chosen samples are located in twelve main cities including Gangneung, Seoul, Gwangju and Daegu. The construction periods are varied from 1930 to 2013. Field survey was conducted to make a checklist in an attempt to analyze the current status of the houses before the retrofit. In addition, it was used as input data for the assessment of building energy performance. As shown in Figure 6, basic information of a building was filled into the checklist and floor plan and images (before and after the retrofit) were inserted. A building was segmented data input (wall, roof and floor) and material, thickness and type of insulation of each part were entered in the checklist. Furthermore, the size of window, glass type and heat transmission coefficient were filled out in the list. Within the checklists, 4 items (plan type, orientation, floor space, walls and windows) were analysed.

To reduce time and labor required to analyze 2,571 detached houses, the study sampled out households of proper representation. A two-phase stratified sampling method was proposed to be describe the set of households (Figure 7). Stratified sampling is to divide the population into strata with homogeneous characteristic and extract samples from each stratum. Because this sampling method has lower dispersion of estimated values than random sampling, it is possible to acquire estimates of high reliability. In the first phase, the number of houses was divided by region. Subsequently, Neyman allocation was used to calculate optimum floor-area sample sizes. The reason for selecting Neyman allocation method was that the floor area of the sample houses had high deviation from 6.3 ㎡ to 107.1 ㎡. The equation of Neyman Allocation Method is shown below.

$$n_h = n \times (N_h \times S_h) / \sum N_i \cdot S_i \quad (1)$$

where,

n_h : The number of sample households on hth stratum

N_h : The number of total households on hth stratum

S_h : Standard deviation of hth stratum

N_i : The number of total households on each stratum

S_i : Standard deviation of each stratum

n : The number of total households of low-income in detached houses

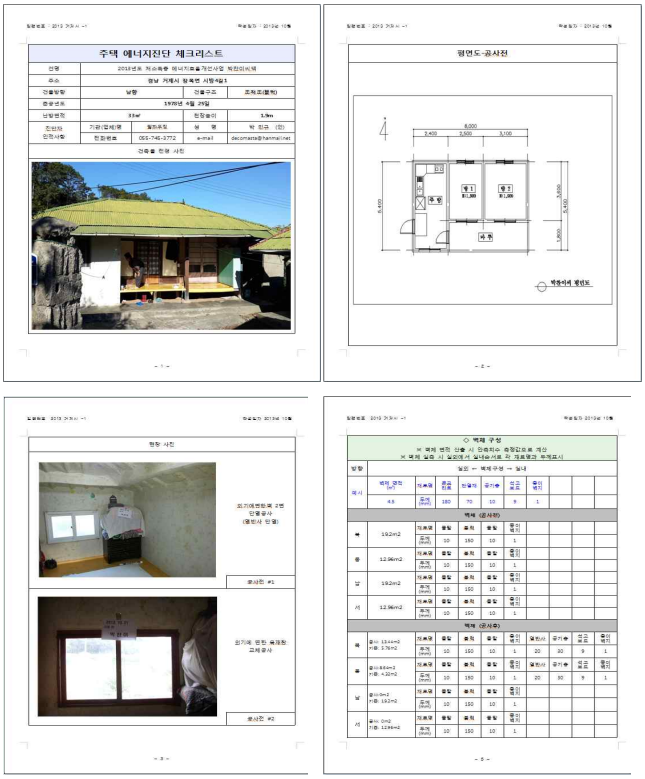


Fig. 6. Example of the checklist

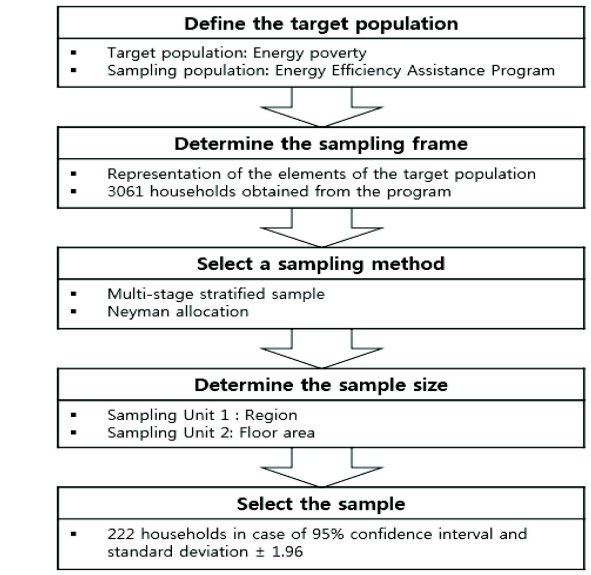


Fig. 7. Sampling design process

As shown in Table 1, the estimation of sample size shows that optimum sample size is from min. 179 to max. 1671 at confidence level of 95% and error range from 1% to 3%. When level of confidence elevates to 99%, optimum sample size is from min. 309 to max. 2781. In this study, 222 households were selected with a 95% confidence level and 2.7% marginal error. The population by area region, mean, standard deviation and size of the samples are described in Table 2.

Table 1. Sample size determination table

95% confidence interval			99% confidence interval		
Margin of error			Margin of error		
1%	2%	3%	1%	2%	3%
1617	404	179	2781	695	309

Table 2. Population and sample distribution of detached house for low-income households

Region	Gangneung		Gwangju		Daegu	
Type	Population	sample	Population	sample	Population	sample
Avg. area[㎡]	44.9	44.5	49.1	53.8	39.1	37.8
Standard deviation	±17.9	±18.1	±19.3	±23.9	±24.0	±18.8
No. of. houses	233	19	421	21	252	20
Region	Daejeon		Mokpo		Busan	
Type	Population	sample	Population	sample	Population	sample
Avg. area[㎡]	48.3	48.3	41.7	40.0	35.0	28.9
Standard deviation	±20.0	±19.8	±17.4	±16.8	±16.0	±10.4
No. of. houses	214	21	60	15	117	11
Region	Seoul		Incheon		Jeonju	
Type	Population	sample	Population	sample	Population	sample
Avg. area[㎡]	40.3	40.6	42.3	42.6	46.9	47.7
Standard deviation	±21.7	±22.1	±22.3	±18.6	±20.5	±24.0
No. of. houses	436	19	80	21	262	21
Region	Cheongju		Pohang		Jinju	
Type	Population	sample	Population	sample	Population	sample
Avg. area[㎡]	46.6	47.1	40.8	42.0	48.0	48.4
Standard deviation	±18.3	±18.1	±19.3	±22.0	±17.5	±17.1
No. of. houses	111	19	132	17	253	18

3.2. Results and Discussion

1) Plan Type

According to the study on the criteria, institution and promotion of performance certification of energy-saving building, 5 floor types were set for this study: rectangular, modified rectangular, L-shaped, C-shaped and mixed.[3)]

Table 3 shows the number of households and proportion by plan type. 140 households of the total 222 households have rectangular plan and are followed by modified rectangular plan (24.8%), L-shaped plan (9.0%), C-shaped plan (1.8%) and mixed shaped plan (1.4%). The rectangular and modified rectangular plan takes 87.9% of the total. Therefore, it indicated that the most of the houses for low-income families are the rectangular plan type.

Table 3. floor type analysis of detached house for low-income households

	Rectangle	Modified rectangle	L-shape	C-shape	Mixed
					
No. of. houses	140	55	20	4	3
Percentage [%]	63.1	24.8	9.0	1.8	1.4

2) Orientation

Most of the houses were designed to face the south to obtain daylight into buildings. Table 4 shows the number of households and proportion by facing from living room. 151 houses (68.0%) of the total face southward. When those facing southward, the southwest and southeast are all combined, it takes 74.3% (165 houses). Therefore, it confirmed that most of the houses of low-income households face the south.

Table 4. Orientation analysis of detached house for low-income households

	East	West	South	South-east	South-west	North	North-east
No.of. houses	23	13	151	8	6	20	1
Percentage [%]	10.4	5.9	68.0	3.6	2.7	9.0	0.5

3) Floor Area

The floor area of the sampled houses varied widely from 6.3 ㎡ to 107.1 ㎡ (Figure 8). Forty-four households (19.8%) had the floor area of 30 ㎡ ~ 40 ㎡, which takes the highest proportion. It is followed by 42 households (18.9%) of 40 ㎡ ~ 50 ㎡ and 38 households (17.1%) of less 10 ㎡. The number of households with greater than 100 ㎡ was just 4, which is extremely low. Average floor area turned out to be of 44.2 ㎡ (standard deviation 20.2). The floor area of other building typologies developed in 1983 is 49.5 ㎡ and that in 2001 is 82.6 ㎡ (see in 2.2). Comparing with these, the floor area of detached houses for low-income groups is smaller than those of the others.

4) Window and Wall

Table 5 shows the width and height of wall and window by location. The length of the wall of detached house for low-income households is 6,040 mm to both the east and west and 7,220 mm to both the south and north, respectively. Also, floor height is 2,800 mm.

3) The Ministry of Commerce, Industry and Energy, "A Study on the Criteria, Institution and Promotion of Performance Certification of Energy-Saving Building", 2012, pp.36

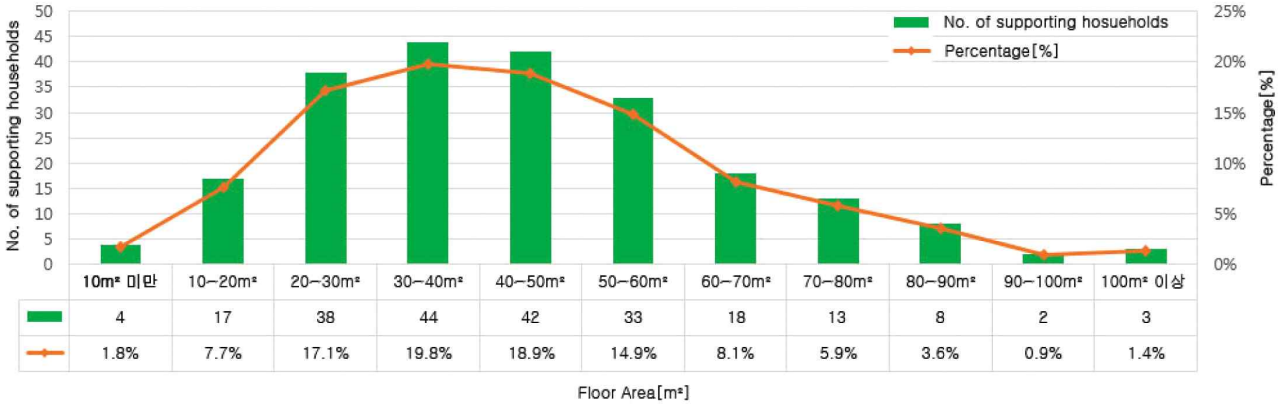


Fig. 8. Floor area analysis of detached house for low-income households

As regards window, the south-facing window (1,640 mm (w) × 1,380 mm (h)) is larger than any other windows, and followed by the east-facing window (1,350 mm (w) × 1,090 mm (h)) and the west-facing window (1,280 mm (w) × 1,060 mm (h)) and that as facing the north (1,220 mm (w) × 970mm (h)) in order of window size. As regards door, the south-facing door (950mm (w) × 1,880 mm (h)) is the widest of all facing other directions and followed by that facing the east (850mm (w) × 1,880 mm (h)), that facing the west (830mm (w) × 1,810 mm (w)) and that as facing the north (850mm (w) × 1,750 mm (h)) in order of door size. In the total number of windows by facing, 222 houses had 301 windows as facing the south and it is equal to 1.4 window on average per house. 258 windows faced the north (1.2 per house) and 179 windows (0.8 per house) and 169 windows (0.8 per house) faced the east and east, respectively, which are reactively smaller numbers than the windows facing all directions. In the total number of door by facing, 125 doors faced the south, which is equal to 0.6per house, the greatest. It is followed by 48 doors (0.2 per house) facing the east, 44 doors (0.2 per house) facing the west and 31 doors (0.1 per house) facing the north. Doors as facing all directions but the south were placed evenly.

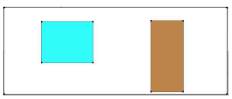
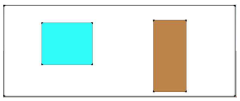
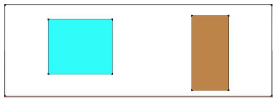
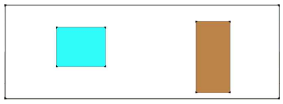
4. Conclusions

The main objective of this study is to present the plan type of detached houses of low-income households to develop building typology. The parameters of the building were established mainly by using a recent dataset from 2013. The result of this study is shown below.

1) It confirmed that 140 houses (63.1%) of the total 222 has the rectangle floor shape. Therefore, rectangular plan is the most common floor type for the detached houses for low-income households.

2) It confirmed that 151 houses (68.0%) of the total 222 are placed to face the south from living room. Since the figure reaches up to 74.3% (165 houses) when the houses facing the south, southwest and southeast are all combined. Therefore, most of the

Table 5. Analysis of windows and doors of detached house for low-income households

	East	West	South	North
Image				
Wall	6,040mm(w) × 2,800mm(h)	6,040mm(w) × 2,800mm(h)	7,220mm(w) × 2,800mm(h)	7,220mm(w) × 2,800mm(h)
window size	1,350mm(w) × 1,090mm(h)	1,280mm(w) × 1,060mm(h)	1,640mm(w) × 1,380mm(h)	1,220mm(w) × 970mm(h)
Total. no. of windows	179	169	301	258
Avg. no. of windows	0.8	0.8	1.4	1.2
door size	850mm(w) × 1,880mm(h)	830mm(w) × 1,810mm(h)	950mm(w) × 1,880mm(h)	850mm(w) × 1,750mm(h)
Total. no. of doors	48	44	125	31
Avg. no. of doors	0.2	0.2	0.6	0.1

houses of low-income households are southward.

3) It confirmed that 44 houses (19.8%) of the total 222 have floor space of 30㎡~40㎡ or smaller. The average floor area is 44.2㎡, which is smaller than that of Korean building typologies.

4) It confirmed that the length of detached house of low-income household is 6,040 mm to both the east and west and 7,220 mm to both the south and north, respectively. As regards window and door by facing, window as facing the south (1,640 mm (w) × 1,380 mm (h)) and door as facing the south (950mm (w) × 1,880 mm (h)) are the largest of all windows and doors as facing other directions, respectively. In the total number of windows and door by facing, the total 222 houses had 301 windows facing the south (1.4 windows per household) and 125 doors face the south, which are the highest of all others.

Moreover, the outcome of this study provides the basis for further investigations aimed at developing a reference house for low-income households and calculating the energy performance compared with existing houses.

Acknowledgement

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