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**Ph.D. Dissertation of Engineering**

**The Characteristic of Morphological and Demographic  
Changes and  
Its Impact on the Domestic Thermal Environment  
in Low-rise Residential Districts, Seoul**

서울 저층주거지의 도시형태 및 인구학적 특성과  
주거의 열 환경에 미치는 영향

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**Seoul National University  
Interdisciplinary Program in Landscape Architecture**

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**The Characteristic of Morphological and  
Demographic Changes and  
Its Impact on the Domestic Thermal Environment  
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Advised by Prof. Saehoon Kim

Submitting a Ph.D. Dissertation of Engineering

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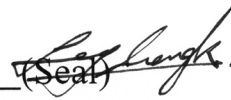


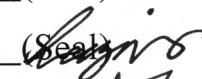

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## **Abstract**

# **The Characteristic of Morphological and Demographic Changes and Its Impact on the Domestic Thermal Environment in Low-rise Residential Districts, Seoul**

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The low-rise residential areas in Seoul have contributed to the relief of the housing shortage during the past 50 years through providing various and affordable housing. However, the relaxation of relevant regulations, rather than the far-sighted planning, has been repeated in order to encourage the private investment on the parcel level redevelopment as a policy for expanding housing supply without public expenditure. As a result, low-rise residential areas in Seoul are facing the aggravation of living environment and sporadic declines. Thus, neither parcel-level redevelopments through uniform relaxation nor large-scale

renewal projects can be a solution for low-rise residential areas anymore. In order to manage the neighborhoods soundly and sustainably, the site-specific planning approach is required to reflect the dynamics of low-rise residential areas. This paper aims to provide the empirical basis for the new policy frame. Particularly, it attempts to understand the problematic situations in low-rise residential areas in the mechanism involving the land use, ownership structure, owner and occupier of an individual land lot as well as the urban morphology, rather than to confine them only in terms of the physical deterioration of dwellings. To do this, three researches are carried out as follow:

The first chapter attempts to reveal the demographical and housing dynamics of low-rise residential districts in Seoul, and then to identify the typology of them. In spite of the stagnation of Seoul's population since the late 1990s, residential areas in Seoul have experienced dramatic demographic and morphological changes. The study explores the diversity of low-residential districts in terms of the trajectories of their population as well as housing stock based on neighborhood-level data. Descriptive statistics and clustering analyses confirm that low-rise residential districts have absorbed the ageing and increasing of households in Seoul through the internal densification, but the contribution to housing provision varies among low-rise neighborhoods, accompanied with various housing types. The uneven transition of low-rise residential districts results in the spatial differentiation of residential areas in Seoul by demographic characteristics and recalls the tailored approach based on the detailed typology of low-rise residential districts, rather than the adjustment of general regulations.

The second chapter aims to expand understanding of the urban morphology's role on residential energy demand beyond the previous approach that focused only on the direct effect of physical urban form. This study suggests the importance of indirect pathways through which three morphological factors—namely urban spatial conditions, land use and architectural attributes—affect the thermal efficiency of residential buildings and then the energy demand. To verify the alternative mechanism of morphology, an empirical building-level dataset of a residential area in Seoul, South Korea was established and analyzed using a structural equation modelling method. The urban morphology models substantially explained the variation in the thermal efficiency of houses, revealing the indirect contribution of the urban design and land use characteristics via other variables as well as the direct contribution of the architectural attributes. For instance, unfavorable urban design conditions of a parcel were associated with substantial underutilization of land property, consequently delaying improvement in residential thermal efficiency. The expectation of redevelopment or the complex ownership of a property also hindered the reinvestment efforts. Policy implications derived from the results were discussed at the end of the paper.

The third chapter aims to identify residence groups that are highly vulnerable to fuel poverty in the urban area of a South Korean city. Thereby, the paper emphasizes that fuel poverty problems occur in different ways according to the social and spatial contexts and thus need a more contextualized policy approach beyond the simplistic criteria of household income and heating cost. To fully capture the meaning of cold homes, an empirical dataset of thermal efficiency of

individual dwellings and actual heating in a residential area in Seoul, South Korea is examined along with the tenure type and the ownership attributes. The analyses reveal that the amount of actual heating energy consumption did not show any clear relation with the thermal efficiency of housing or the tenure type. Additionally, considerably inefficient dwellings like old, detached houses are occupied by elderly owners who often lack both the financial capability and intention to properly maintain their properties. The result indicates that people who are living in cold homes are not always confined to poor residents living in rented homes. The study proposes some new types of potential fuel poverty based on the analyses of thermal efficiency and heating patterns by dwellings.

Keywords: Low-rise residential districts, Demographic change, Housing type, Affordable housing, Residential energy use, Urban morphology, Land use, SEM, Fuel poverty, Thermal efficiency, Actual heating consumption, Tenure type, Ownership, Seoul

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## **Publications**

*Please note that Chapter 1-3 of this dissertation proposal were written as stand-alone papers (see below). Chapter 2 and 3 were published in 2018 and 2019, and chapter 1 will be submitted to an academic journal soon.*

### **Chapter 1.**

You, Y., & Kim, S. Typological characteristics of demographic and housing changes in low-rise residential districts, Seoul

### **Chapter 2.**

You, Y., & Kim, S. (2018). Revealing the mechanism of urban morphology affecting residential energy efficiency in Seoul, Korea. *Sustainable cities and society*, 43, 176-190.

### **Chapter 3.**

You, Y., & Kim, S. (2019). Who lives in and owns cold homes? A case study of fuel poverty in Seoul, South Korea. *Energy Research & Social Science*, 47, 202-214.

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4. Discussion

### **Chapter 2.**

#### **Revealing the mechanism of urban morphology affecting residential energy efficiency in Seoul**

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2. Hypotheses and Research Questions
3. Research Methods
4. Results
5. Discussion and Implications

## **Chapter 3.**

### **Who lives in and owns cold homes?**

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# Introduction

A variety of affordable houses in the low-rise residential districts in Seoul have been supplied amidst the severe housing shortage due to the rapid population increase and urbanization in the past 50 years. However, few assessments of the contribution of low-rise residential district and public support have been made under the apartment-oriented housing and redevelopment policies (The Seoul Institute, 2017). The low-rise residential districts, which accommodate close to half of households living in Seoul, are spontaneously generated residential districts or developed in the early expansion phase of Seoul, which is why their urban infrastructure is relatively poor overall (The Seoul Institute, 2009). In addition, shortsighted policies that induced redevelopment at an individual land lot basis by several rounds of deregulations to cope with housing shortage caused a dense residential environment in relatively small-area land lots (Bang, 2012; The Seoul Institute, 2017). Moreover, the method used in the past of solving the problem of deteriorated residential districts with large-scale redevelopment has become more difficult to adopt in the current dense low-rise residential districts under the recent trend of population declining and stagnation in Seoul (The Seoul Institute, 2014). Furthermore, re-settlement rate of existing residents has been very low, and living basis of them has been dismantled, which is not a sustainable housing welfare policy (AURI, 2011; Shin & Kim, 2016). Thus, there has been growing interest in policies that can attract voluntary re-investment in individual houses and improve the residential environments in low-rise residential districts.



With that background in mind, this study aims to attempt an empirical exploration of low-rise residential districts in Seoul as a basis to derive policy solutions and management direction of low-rise residential districts.

The policies and regulations that have influenced the low-rise residential districts up until now have been applied uniformly without considering the difference in physical and non-physical circumstances between regions and individual land lots. However, the effects have been exhibited at a variety of patterns and levels in actual low-rise residential districts. Thus, this three-part study pays attention to the dynamics of low-rise residential districts, in contrast with existing studies and policies that viewed the low-rise residential districts in Seoul as a single typical characteristic. For this, the first chapter aims to identify the change in low-rise residential districts in Seoul since 2000s at a neighborhood level<sup>1</sup> based on the housing type and residential population structure and then categorize the pattern.

The second and third chapters, targeting Hwagok-dong, which is a typical large-scale low-rise residential district in Seoul, aim to identify the causes of problematic residence within the low-rise residential districts. Here, the problematic residence is defined based on the comfortable thermal environment, which is one of the essential functions of residential space, rather than based on a building construction year simply.

In the second chapter, first, the thermal performance problem in houses will be explained by not only architectural characteristics of houses but also land usage

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<sup>1</sup> Statistically ‘Dong’ which is a basic administrative unit in Korean urban area.

and urban design characteristics. A unique data set including infrared images of 360 residential buildings are collected and analyzed using a structural equation model. The analysis results are verified regarding indirect contributions that were not fully identified in existing studies in terms of the roles of urban spatial characteristics that affect the demand on house-heating energy.

Next, the third chapter will analyze the characteristics of house owners and occupation types of residents who have insufficient heating in a relative sense based on thermal performance and heating energy consumption among the same 360-samples. This attempt aims to reveal the realistic possibility of fuel poverty, which may not be taken into consideration in existing standards that specify the fuel poverty problem.

# **Chapter 1**

## **The typological characteristics of demographic and housing-type changes in low-rise residential districts, Seoul**

### **1. Introduction**

A large number of scholars have studied urban structural transitions in cities in the accelerated urbanization trend throughout the world for the last half century. A variety of deductive approaches and empirical studies have been used to explain how cities have been expanded, which areas remained without changes, and how to raise the intensity of land usage through redevelopment, based on indexes such as population, built environment, and economic activities (Alonso, 1964; Brueckner, 1980; Wheaton, 1982; Bourne, 1996; Champion, 2001; Haase et al., 2010). Here, the selection between urban spatial expansion and densification of existing cities (Broitman & Koomen, 2015) and relevant factors driving the urban phenomena in those two directions, and the reviews on their social and spatial consequences have become major research topics. In this context, this study starts from the question of where the low-rise residential districts in Seoul that belong to existing urban districts have been developed. Thus, this study aims to define

the change in low-rise residential districts in Seoul from studies and theories that focus on structural changes in urban space, in particular existing urban districts.

### **1.1. Literature Review**

The urban spatial expansion has been dominant in some European cities and major cities in Asia as well as cities in North America, and throughout the mid-to-late 20th century in the midst of rapid urbanization and urban growth. However, densification of existing urban land has also become a major phenomenon as one of the urban changes in response to new demand on urban spaces since the late 20th century (Ogden & Hall, 2000; Couch et al., 2009; Bouzarovski et al., 2010; Lehrer et al., 2010; Hasse et al., 2012). The related studies exhibited that developable lands and low-density urban districts were basic conditions for the densification of existing urban area, but the consequences were uneven and the selective factors such as government plans and policy directions have had major roles in determining the unequal consequences (Broitman & Koomen, 2015).

For the factors that explain the internal densification phenomenon, particularly in terms of housing supply, two opinions from the demand and supply sides are fiercely debated, prompting a number of studies. The demand side explains the urban redevelopment as the back-to-city trend preferred by professional classes who newly emerge according to the economic and industrial structural changes and prefer to live in cities (Ley, 1980; Zukin, 1989; Hamnett, 1991). On the other hand, the supply side explains that the expansion of the rent-gap in the deteriorated regions within the city is the basic condition that introduces the urban redevelopment and industrial main actors in real estate-related industries and

governments—the supply side, rather than the demand side— trigger urban redevelopment (Smith, 1979; Clark, 2005; Shin, 2009).

The discussion about the social effect of more intensive development within cities has also raised various controversial issues. Above all, urban redevelopment has been criticized as negative gentrification, whereby existing residents who belong to low-income vulnerable classes are driven out of their houses and high-income classes occupy the space (Marcuse, 1986; Shin, 2009). However, several studies claimed that the urban redevelopment was not always disadvantageous to the socially vulnerable (Zukin, 2009; McKinnish et al., 2010).

In addition, many recent urban researchers specified that urban densification that accommodates changing urban housing demand, which is different from the class issue, has been classified as re-urbanization. In particular, they viewed the increase in housing demand of a demographic group that is distinctively different from suburban detached house consumers for family purposes, which was dominant in the late 20th century, as the cause of intensification of land usage in existing cities (Ogden & Hall, 2000; Hasse et al., 2010). These consumers were mostly students, non-married households, or young couples without children who could not afford to buy suburban detached houses, which was why they were necessarily not viewed as high-income classes (Hasse et al., 2010). This phenomenon was caused by the demographic change, the so-called second demographic transition (van de Kaa, 1987) due to delay or reduction of marriage and child birth, which led to an increase in one or two-person households.

Among these demographic changes, the shift of living arrangement has

affected the housing market greatly, becoming one of the important factors that explain the change in urban residential areas (Ogden & Hall, 2000; Haase et al., 2010). A household rather than individuals is a unit of housing demand as well as a unit of residential mobility. Also, characteristics of a household indirectly provide complex information such as the social position, living standard, and income level, which determine housing demand (Rossi, 1980).

Furthermore, much attention has been paid to urban spatial change, due to the densification of existing cities, by urban morphology researchers. Moudon (1986) tracked the gradual change in a district of the old city in San Francisco and showed the evolving process into very various patterns according to the location and characteristics of land lots. In contrast, Ryan (2005) disclosed that the large-scale urban redevelopment projects in the old city center of Detroit followed a similar type of suburban land use and urban form regardless of the original morphology.

## **1.2. Background: Low-rise Residential Areas in Seoul**

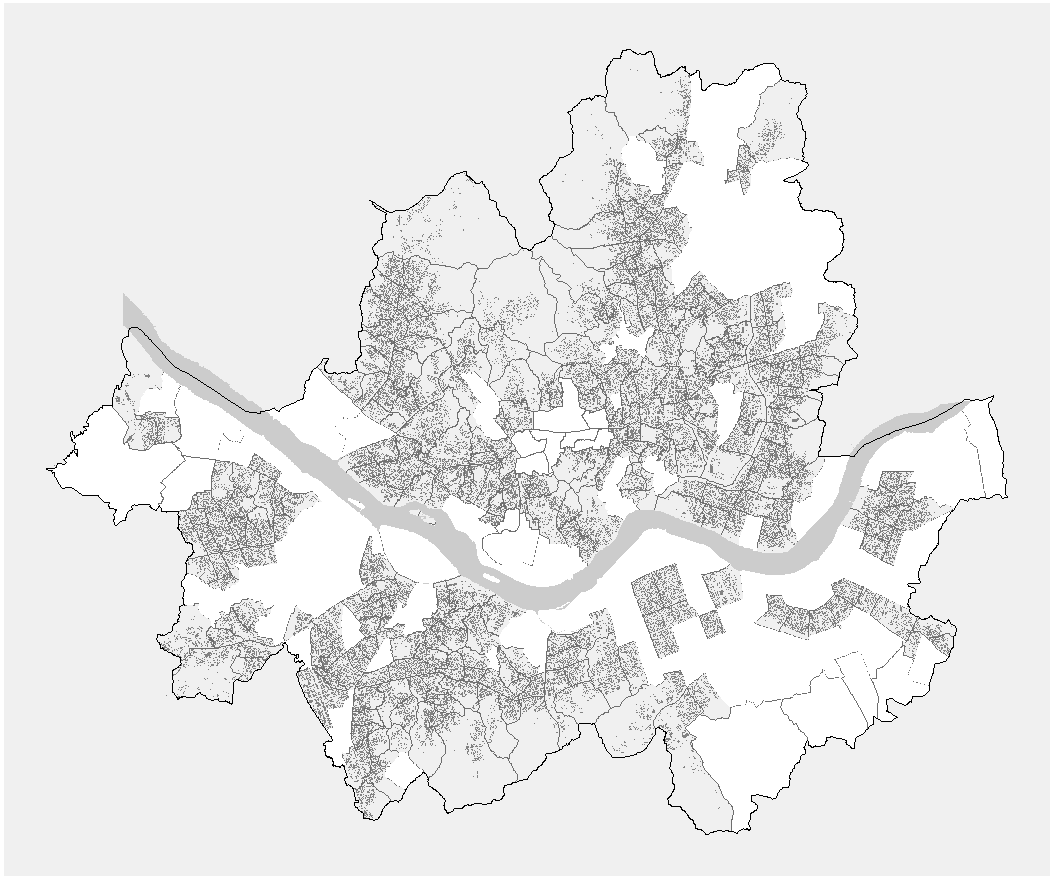
The Seoul metropolitan area followed the trajectory in which urban growth and adaptation including densification of old cities have occurred simultaneously or alternately in the late 20th century in terms of changes in urban structure. Up until the 1960s, the housing development saw critical conditions of unplanned overcrowding and poor residential environment in cities and surrounding suburbs, despite the explosive population increase but the solution of this problem was not the first priority as the post-war recovery in cities and economic development after the Korean War was the most important task. To resolve these conditions,

Gangnam, the southern part of Seoul, started to be developed in earnest from the 1970s, followed by a large-scale development of satellite cities in metropolitan regions from the 1980s, which are now seen in the current Seoul metropolitan region. Simultaneously, the redevelopment of poor residential areas within the old city center and the neighboring areas continued from the late 1970s to early 2000s. Thus, the urban structure change in the Seoul metropolitan region should not be seen as one-sided dominance between expansion and densification.



**Figure 1-1** A low-rise residential district (left) and high-rise apartment complexes (right) in Seoul (Source: Daum Sky View - <http://map.daum.net/>)

The low-rise residential area in Seoul, which is the spatial target of this study, is filled with small individual houses densely, and it refers to residential areas formed spontaneously within the old city boundary and the neighboring areas, and planned districts developed in 1970 to 1980s (Figure 1-2). Thus, the low-rise residential districts in Seoul can be seen as existing urban areas ranging from old cities with hundreds of years of history to the so-called “inner suburb” built at the early stage of Seoul's growth after the Korean War.



**Figure 1-2** Low-rise residential districts in Seoul

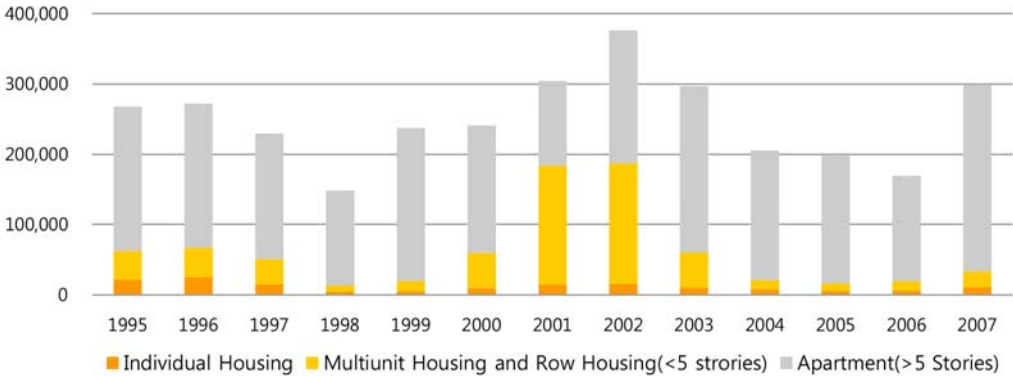
These low-rise residential districts were composed of traditional style houses, ‘Hanok’ and one or two-story low-density detached houses mainly until the 1970s. Since then, the low-rise residential districts in Seoul have experienced several redevelopment booms at the individual parcel level under the severe housing shortage in Seoul, and high-density new housing types have replaced existing detached houses (Figure 1-3). Through this change, the low-rise residential districts considerably contributed to the supply of affordable dwellings in Seoul (Figure 1-4), and dynamic landscape changes occurred at the same time (Bang, 2012). However, the transition made the residential density higher than the



infrastructure can cope with and worsened the residential environment, such as lighting (The Seoul Institute, 2017).



**Figure 1-3** Typical housing types of Seoul LRDs in each redevelopment boom period



**Figure 1-4** New housing supply in Seoul and the metropolitan

The low-rise residential districts still accommodate a considerable population in Seoul, but high-rise apartments, which have become the dominant residential type in Seoul, have eroded the proportion of low-rise residential areas. In addition, remaining low-rise residential districts are considered poor residential areas in a relative sense (The Seoul Institute, 2011). In fact, construction qualities of small-sized houses built in low-rise residential districts were not sufficiently high (The Seoul Institute, 2017). Thus, if the building age is more than 30 years, it is

considered as a dilapidated dwelling, the ratio of which is currently very high, at 31.6%. Moreover, the infrastructure, such as roads, parking spaces, and parks, do not satisfy the current urban planning standards and building regulations. These factors have delayed spontaneous re-investment in some low-rise residential districts due to the expectation of large-scale full-demolition redevelopment, which was somewhat unrealistic. As a result, their residential environments became worse and their attraction as residential areas was lost.

As described above, both densification and decline have occurred simultaneously in the low-rise residential districts, and both problems need to be solved to manage the low-rise residential districts in a sound manner. Various policy studies have been conducted to solve the problems (AURI, 2011; AURI, 2012; The Seoul Institute, 2018), and legislative attempts to promote voluntary re-investment have also been added. However, the policy frame that has been applied to the low-rise residential districts over the past several decades was a universal regulation-oriented approach that was applied to all places equally, rather than a planning approach considering the differences in urban context between low-rise residential districts. Only recently have studies have started on classification of the characteristics of low-rise residential districts and detailed policy direction based on the classification. However, the classification criteria focused on physical variables such as housing deterioration level and road adjacent conditions (The Seoul Institute, 2017), and the resident's characteristics were not taken into consideration. Few studies (Seong & Lee, 2016) have been conducted on the trend of changes over a certain period of time; most studies evaluated the low-rise residential districts based on the numerical data at a

specific time.

### **1.3. Research Purpose**

The purpose of this study is to verify the characteristics, levels, and dynamics relating to the recent trend of the low-rise residential districts in Seoul as the densification of existing urban districts in the discussion of changes in urban structure. In particular, it aims to propose a policy foundation to manage the low-rise residential district and furthermore existing urban districts by specifying which diversity is revealed by the densification phenomenon of low-rise residential districts and classifying the diversity.

To do this, this study investigates a change in the low-rise residential districts based on the dwelling population and housing stock. As discussed in the above, the combination of both changes will explain which changes are induced in low-rise residential districts by the demographic change that shapes the housing demand. In addition, it will describe how changes in housing stock in the low-rise residential districts due to the supply side factors benefit which residents.

Generally, population increase and investment in built environment go hand in hand. In contrast, population decrease and aging buildings due to delay of re-investment also move in the same direction. For residential areas, this may be substituted with a problem of housing stock such as supply rate of new houses or deterioration level of houses along with the increase or decrease in resident population. Thus, the spectrum of low-rise residential district classification could be developed based on the level of variation from the linear relationship between population and housing stock, which was the first criterion.

Whether there was a qualitative difference in housing stock and population structure behind the similar change in the number of houses and population will be also evaluated as a basis of the dynamics of low-rise residential districts. In recent years, Korean society has experienced a rapid increase in the number of one- or two-person households and aging people. The second criterion of the classification of low-rise residential districts could be the deviation of the pattern that this trend was reflected in the low-rise residential districts.

In addition, large metropolitan regions including Seoul faced rapid changes in housing type due to common-housing dominant supply. Housing type is one of the important factors that form urban morphology in the residential areas, which can be an index that displays which spatial changes occurred in the residential areas through the densification process. In this regard, the urban morphological change in the low-rise residential districts was also investigated as a characteristic that displays the diversity of the low-rise residential districts.

This study also evaluated what contributions and problems were made for the housing provision in Seoul by each low-rise residential districts typology based on the population-housing characteristics. Finally, crisis faced by each of the types in the low-rise residential districts was discussed. By doing this, this study aims to propose a basis of differentiated policy according to the pattern of each different low-rise residential district and, consequently, how the management and planning approach to low-rise residential districts should be sub-divided in detail.

## **2. Research Methods and Data**

### **2.1. Research Methods**

Two-phase analysis was conducted to verify and classify changes of the demography and the housing stock in low-rise residential districts in Seoul. First, the characteristics of the change in demography-housing in the low-rise residential districts were differentiated from those of the total of Seoul and other types of residential districts in Seoul. To do this, population increase or decrease level of aging, changes in the number of households and household size, and distribution ratio by housing type and housing stock were compared using descriptive statistics; the significances of differences in major variables were verified using ANOVA.

Next, it derived the change pattern of the low-rise residential districts in Seoul in terms of the demography-housing perspective, and discussed the meaning thereof. A cluster analysis was conducted to distinguish the low-rise residential districts that showed statistical homogeneity in three categories: population-age, population-household, and the number of houses-housing types, and characteristics and spatial distributions of the clusters by each category were analyzed. Finally, a cluster analysis on all variables in the three categories was conducted to derive major types in the low-rise residential districts, and characteristics of each type and differentiation between types were verified.

The spatial distribution of each type was verified for the analysis, along with the spatial factors in each of the classification phases. The proximity to downtown, access to public transportation, whether a district was designated for a

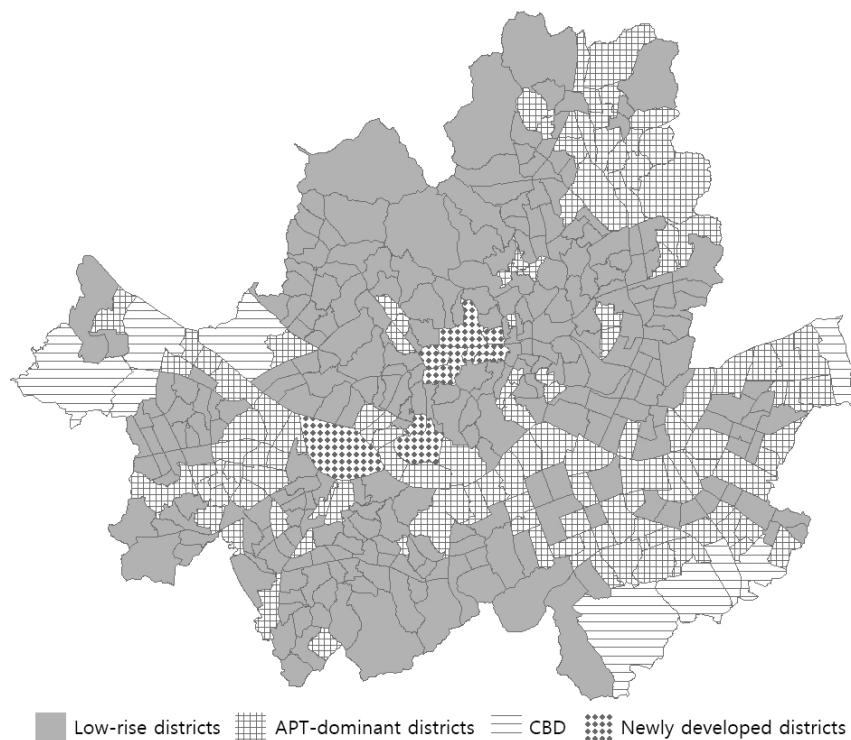
renewal project, distribution of major urban functions, and qualitative aspects in each district in Seoul were reviewed in an integrated manner.

### **Definition of the low-rise residential district**

A low-rise residential district refers to a residential area where detached single houses or multi-family houses in individual lots and multi-unit housing, small-scale common housing, are densely located, in contrast with apartment complexes. It is referred to by many different terms by researchers, such as detached house districts (Bang, 2012; Seong & Lee, 2016); general residential districts (Lim et al., 2014); multi-row block districts (The Seoul Institute, 2006); or small-lot residential districts (AURI, 2009). Nonetheless, it generally refers to a residential district where around 20 small-sized lots surrounded by around 6 m-wide roads are clustered regularly or irregularly and where various types of houses of less than five stories are mixed (The Seoul Institute, 2017). In actual urban spaces, small-sized apartment complexes are mixed together, and occupation rate of apartments out of all houses is continuously displayed within the low-rise residential districts. Thus, the spatial range that can be specified as the low-rise residential district may vary depending on which criteria are used.

In this study, low-rise residential districts referred to the districts of which apartment ratio was less than 60% in the housing stock at dong level. The districts categorized as apartment-dominant residential areas in 『Urban Form Study of Seoul』 (The Seoul Institute, 2009) were excluded. In addition, districts where the land use of more than 60% of the dong area is central business or general commercial were also excluded. Some underdeveloped areas still remaining in

Seoul and districts where new urban development was underway were also excluded from the low-rise residential district of the study target, as their characteristics were greatly different from those of general low-rise residential districts. Figure 1-5 shows the distribution of the low-rise residential district and by other types.



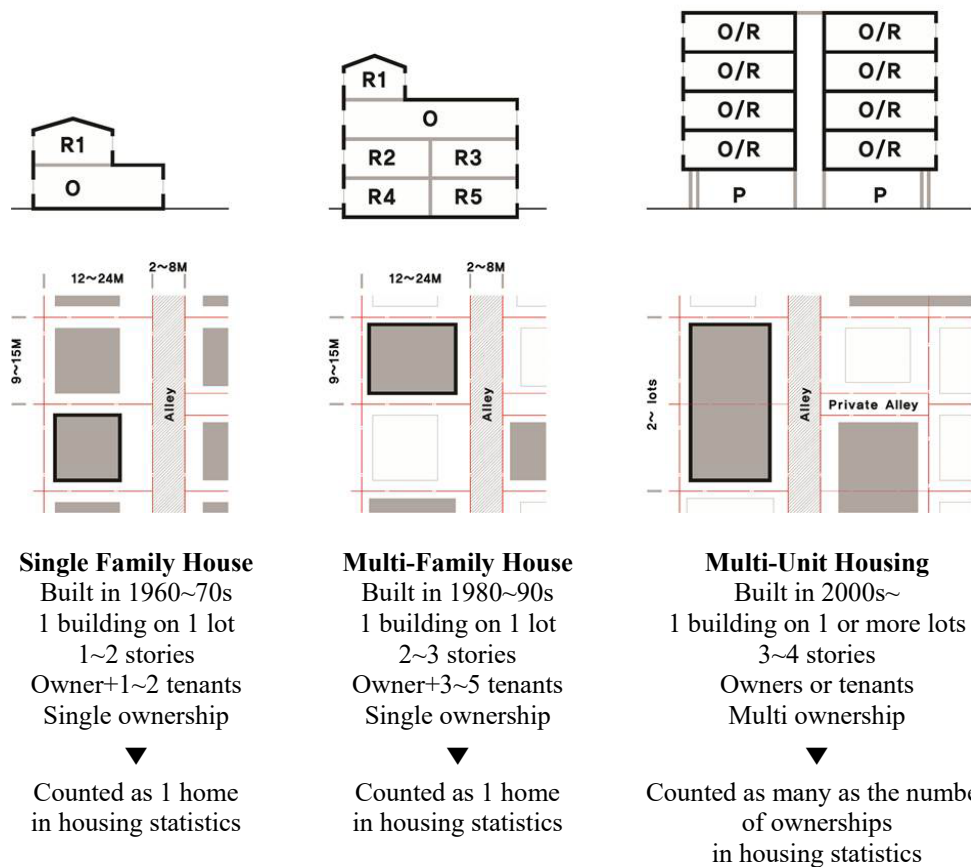
**Figure 1-5** Distribution of 419 districts by types of morphology and land use

### Temporal range

The population in Seoul continuously increased since the late 20th century, from 2.45 million in 1960 to 10.6 million in 1990. However, starting from the mid-1990s, the population has started to decline to have around 9.7 million as of 2017, and the number is fluctuating within a narrow range now. In terms of the

population structure, four-person households decreased but one or two-person households increased rapidly. Thus, the number of households continued to increase despite of the population stagnation. The period was the time that a new urban plan and regulation were applied, which brought a significant change in the low-rise residential districts in Seoul. The new urban plan was the first attempt that designated potential redevelopment districts through universal plans in the <Seoul Housing Redevelopment Master Plan> established in 1998. From this time, the low-rise residential districts were considered as the next redevelopment target through this master plan, when the large-scale redevelopment of illegal poor housing areas was complete in fact, which started from the 1970s (Shin & Kim, 2016). Since then, a considerable area of low-rise residential districts has been redeveloped into large-scale apartment complexes. Furthermore, larger areas are still considered to be redeveloped or regarded as a potential redevelopment target (The Seoul Institute, 2017). The new regulation relaxed the Housing and Building Acts, which enabled four-story or higher housing construction in a small lot, which was previously limited to building only up to two or three-story buildings. By this measure, the construction of multi-unit housings with four to five-story boomed through combining two to three lots of detached houses, and the multi-unit housing became a typical housing type of the low-rise residential district in place of detached houses (Figure 1-6). Thus, this study paid attention to the pattern of change and differentiation in low-rise residential districts after the 2000s, when such changes of population and housing stock started to occur in Seoul.





**Figure 1-6** The shape, size, tenure type and ownership by housing type

## 2.2. Data collection

The population and housing data used in this study were obtained from statistical data of the Population & Housing Census in 2000, 2005, 2010, and 2015. The minimum statistical unit of the data was a basic census output, whose spatial range was too small. Thus, it created a problem of excessively large variation of statistical values. The boundary of the basic census output was also changed often due to the factors such as redevelopment, which made it difficult to compare the statistical data by time period. This study utilized the administrative

dong unit data, which could guarantee the continuity of the space unit in a relative sense and show the change in the low-rise residential district sharing the same residential community. Considering the division and integration of some administrative dongs since 2000, the data were developed by arranging the current 424 administrative dongs into 419 districts. To analyze the dong area and spatial geography, re-adjustment was conducted to have 419 districts by utilizing the boundary of administrative districts (eup, myeon, and dong) GIS from Statistics Korea. Among them, seven districts (Garak 1-dong, Godeok 1-dong, Godeok 2-dong, Gyonam-dong, Namgajwa 1-dong, Daeheung-dong, and Bugahyeon-dong) whose housing and population data in 2015 were meaningless compared to those in 2000 due to the large scale redevelopment underway at the time of the 2015 Population Census, and two districts (Gahoe-dong and Samcheong-dong) that were “Historic Preservation District” where traditional houses were densely populated, were excluded. The descriptive statistical results are presented in Table 1-1.

**Table 1-1** Descriptive statistics of 410 low-rise residential districts: changes in population, household and housing stock between 2000~2015

Variables	Min. ~ Max.	Mean (S.E.)
<i>Pop. Growth Rate</i>	-0.3887~5.5048	0.0715 (0.4977)
<i>Elderly (over 65)</i>	-0.0079~8.9157	1.3692 (0.7508)
<i>Mid-age: Parent (35~50)</i>	-0.5374~6.1461	0.1140 (0.6031)
<i>Child (0~15)</i>	-0.7935~8.2149	-0.2738 (0.6948)
<i>Young adults(20~34)</i>	-0.5952~4.069	-0.1141 (0.4235)
<i>Household growth rate</i>	-0.3309~6.0905	0.2926 (0.5328)
<i>Single-person household growth rate</i>	-0.3325~9.8933	1.3877 (1.0909)
<i>Housing growth rate</i>	-0.3272~19.2630	0.6182 (1.2303)
<i>Change in ratio of detached.</i>	-0.9936~0.0000	-0.2173 (0.1805)
<i>Change in ratio of APT.</i>	-0.1493~0.9934	0.1335 (0.1929)
<i>Change in ratio of multi-unit.</i>	-0.3594~0.6814	0.1445 (0.1446)

The housing statistical data were developed by housing type, but detached and multi-family houses (Figure 1-6) were not distinguished in the data prior to 2005. Thus, detached and multi-family houses were combined into detached houses in the analysis. In addition, the rental unit within a detached house or a multi-family house is not counted as a dwelling unit in the housing stock statistics of the Housing Census though the space is independently occupied by a tenant household. Thus, the increase in the number of dwellings could be exaggerated if detached and multi-family houses were demolished and redeveloped into common housings such as multi-unit housings (Figure 1-6). The statistical problem was taken into consideration when interpreting the analysis results.

Finally, spatial data such as the Seoul geographic information system (GIS) including buildings, land lots, and subway routes, and current status of Renewal Project in Seoul as of 2015 were used to analyze the change type of population and housing in the low-rise residential districts.

### **3. Results**

#### **3.1. Characteristics of Changes in Demography and Housing of Low-rise Residential Districts**

The most prominent trend in the statistical data in Seoul since 2000 was that the low-rise residential districts have experienced relatively a large change from population and housing stock viewpoints. Although the resident population in the low-rise residential districts showed no significant change, the numbers of houses and households considerably increased, and the composition of housing type changed significantly. The above finding was commonly verified in both comparison results (Table 1-2) with the total of all districts in Seoul and with the total of districts by type of residential areas and also in comparison results with the average of all districts of Seoul and each residential type (Table 1-3). This showed that the changes in population and housing demand in Seoul was largely absorbed by the low-rise residential districts. The apartment-oriented residential districts in the same period also showed a similar change with that of the low-rise residential districts. However, there was a significant difference between the two residential types in terms of level of change, and the statistical significance was also clearly revealed through the ANOVA (Table 1-3).

Another feature of the low-rise residential district in terms of the population-housing change is that the width of the change was relatively very great. Compared to the change in population-housing in 117 apartment-oriented residential districts, that of 274 low-rise residential districts was seen at much more various levels (Table 1-3). This was confirmed not only in the distribution

range but also in the standard deviation in the statistics. In particular, the distribution range and standard deviation in household and housing stock-related variables were much larger in the low-rise residential districts. Thus, the low-rise residential districts showed a clearly distinguished pattern of population-housing change compared to that of other types of residential districts, but the results verified that the population-housing change was revealed at very various levels among the low-rise residential districts.

**Table 1-2** Changes in the totals of population and housing stock in Seoul, low-rise residential districts, APT-dominant districts, CBDs and newly developed districts

Variables	Year	Seoul the total of 419Ds	Low-rise the total of 280Ds	APT the total of 120Ds	CBD the total of 10Ds	New Dev. the total of 9Ds
<i>Population</i>	2000	9,853,972	6,589,028	3,065,194	79,653	120,097
	2005	9,762,546	6,556,840	3,016,793	69,319	119,579
	2010	9,631,482	6,279,846	3,095,719	78,698	177,219
	2015	9,904,312	6,536,105	3,009,910	90,542	267,755
<i>Pop. growth rate</i>	2000-2015	0.51%	-0.80%	-1.80%	13.67%	122.95%
<i>Ratio of elderly pop.</i>	2000	5.43%	5.53%	5.10%	8.97%	5.82%
	2015	12.33%	12.84%	11.30%	15.33%	10.53%
<i>Eld. growth rate</i>	2000-2015	128.20%	130.17%	117.33%	94.36%	303.31%
<i>Mid. growth rate</i>	2000-2015	2.32%	2.54%	1.73%	16.89%	128.71%
<i>Child growth rate</i>	2000-2015	-35.65%	-36.83%	-36.27%	-17.87%	102.39%
<i>Young growth rate</i>	2000-2015	-18.18%	-18.25%	-18.60%	6.00%	86.25%
<i>N. of household</i>	2000	3,085,714	2,095,791	926,815	27,396	35,712
	2015	3,784,490	2,583,037	1,070,809	36,046	94,598
<i>H.hold growth rate</i>	2000-2015	22.65%	23.25%	15.54%	31.57%	164.89%
<i>Average of household size</i>	2000	3.19	3.14	3.31	2.91	3.36
	2015	2.62	2.53	2.81	2.51	2.83
<i>Ratio of single-p household</i>	2000	16.28%	18.19%	11.79%	24.59%	14.01%
	2015	29.48%	33.19%	20.97%	36.77%	21.73%
<i>Sing. growth rate</i>	2000-2015	122.17%	124.91%	105.55%	96.72%	310.88%
<i>N. of housing units</i>	2000	1,916,537	1,101,085	786,707	19,487	24,480
	2005	2,321,949	1,415,684	855,316	19,046	28,898
	2010	2,525,210	1,516,717	932,035	25,299	51,159
	2015	2,793,244	1,729,502	955,411	27,293	81,038

<i>Hous.growth rate</i>	2000-2015	45.74%	57.07%	21.44%	40.06%	231.04%
	2000	28.65%	43.86%	8.23%	46.67%	30.00%
<i>Ratio of detached.</i>	2015	12.71%	17.98%	3.79%	14.99%	4.66%
	$\Delta$	-15.94%	-25.88%	-4.44%	-31.68%	-25.34%
	2000	50.87%	25.36%	85.59%	51.05%	47.58%
<i>Ratio of APT.</i>	2015	58.60%	41.38%	87.06%	78.04%	84.13%
	$\Delta$	7.73%	16.02%	1.47%	26.99%	36.55%
	2000	9.25%	14.47%	2.05%	0.92%	6.79%
<i>Ratio of multi-unit.</i>	2015	23.43%	33.37%	7.16%	4.16%	9.38%
	$\Delta$	14.18%	18.90%	5.11%	3.24%	2.59%

**Table 1-3** Descriptive statistics of low-rise residential districts and APT-dominant districts and ANOVA results between two groups

Variables	Low-rise 274 Ds	APT-dominant 117 Ds	ANOVA
	Mean (S.E.)	Mean (S.E.)	Two-tailed P value
	Min. ~ Max.	Min. ~ Max.	
<i>Population growth rate</i>	0.0210(0.2486) -0.3887~1.9698	0.0200(0.2513) -0.3088~1.0613	0.891
<i>Elderly (over 65)</i>	1.3601(0.5125) 0.0841~3.3626	1.2512(0.5625) 0.3165~3.3106	0.230
<i>Mid-age: Parent (35~50)</i>	0.0723(0.3282) -0.3584~2.8874	0.0237(0.3488) -0.5374~1.6955	0.433
<i>Child (0~15)</i>	-0.3742(0.3442) -0.7108~2.7127	-0.2596(0.3014) -0.7517~0.8806	0.097 *
<i>Young adults (20~34)</i>	-0.1533(0.2568) -0.5952~1.0411	-0.1798(0.2424) -0.5834~0.6522	0.466
<i>Household growth rate</i>	0.2656(0.3015) -0.3309~2.2621	0.1887(0.2601) -0.2698~1.4199	0.065 *
<i>Single-person household growth rate</i>	1.3953(0.9559) -0.2295~8.6915	1.1941(0.8952) -0.3325~5.6087	0.408
<i>Housing growth rate</i>	0.6259(0.5472) -0.2038~4.9926	0.2669(0.2955) -0.1785~1.7346	0.000 ***
<i>Change in detached houses ratio</i>	-0.2682(0.1467) -0.9847~-0.0145	-0.0543(0.0496) -0.2054~0.000	0.000 ***
<i>Change in multi-unit housing ratio</i>	0.1925(0.1475) -0.3594~0.6814	0.0490(0.0643) -0.0327~0.2948	0.000 ***
<i>Change in APT ratio</i>	0.1544(0.1814) -0.1488~0.9922	0.0292(0.0720) -0.1493~0.2971	0.000 ***

**Table 1-4** Correlations between demographic and housing stock variables and *p*-value

	<i>Pop</i>	<i>Eld.</i>	<i>Mid</i>	<i>Child</i>	<i>Youth</i>	<i>H.hold</i>	<i>Sg.H</i>	<i>Housing</i>	<i>R_det</i>	<i>R_mul</i>	<i>R-APT</i>
<i>Pop</i>	1.000										
<i>Elderly</i>	0.587 (0.000)	1.000									
<i>Mid</i>	0.934 (0.000)	0.501 (0.000)	1.000								
<i>Child</i>	0.884 (0.000)	0.422 (0.000)	0.893 (0.000)	1.000							
<i>Young</i>	0.793 (0.000)	0.321 (0.000)	0.675 (0.000)	0.560 (0.000)	1.000						
<i>H.hold</i>	0.863 (0.000)	0.490 (0.000)	0.805 (0.000)	0.713 (0.000)	0.844 (0.000)	1.000					
<i>Sg. H</i>	0.251 (0.000)	0.227 (0.000)	0.191 (0.002)	0.052 (0.393)	0.484 (0.000)	0.627 (0.000)	1.000				
<i>Housing</i>	0.780 (0.000)	0.496 (0.000)	0.818 (0.000)	0.747 (0.000)	0.543 (0.000)	0.692 (0.000)	0.092 (0.129)	1.000			
<i>R_det</i>	-0.424 (0.000)	-0.026 (0.674)	-0.517 (0.000)	-0.406 (0.000)	-0.330 (0.000)	-0.339 (0.000)	0.060 (0.000)	-0.634 (0.320)	1.000		
<i>R_mul</i>	-0.138 (0.022)	0.016 (0.790)	-0.163 (0.007)	-0.249 (0.000)	0.002 (0.970)	-0.046 (0.453)	0.060 (0.325)	0.013 (0.831)	-0.056 (0.354)	1.000	
<i>R-APT</i>	0.520 (0.000)	0.141 (0.019)	0.562 (0.000)	0.615 (0.000)	0.302 (0.000)	0.374 (0.000)	-0.090 (0.136)	0.475 (0.000)	-0.545 (0.000)	-0.569 (0.000)	1.000

In addition, the correlations of changes in population, households, and housing in the 247 low-rise residential districts exhibited that the demographic change and spatial change were not revealed in a single dominant direction (Table 1-4). The increases in aging population and one-person households, which could be the most noticeable demographic change in the entire of Seoul, were very weakly correlated with both of changes in other demographic characteristics and housing stock. This trend implied that the increases in aging population and one-person households occurred in residential districts of various characteristics in terms of the population-house stock viewpoint. However, the number of children, which apparently declined overall, was strongly correlated with the changes in overall population and the number of households, along with the middle-aged people who were their parent generation, and showed a positive correlation with the apartment ratio. Thus, the residence of “family” in the traditional meaning was

only limited somewhat to a residential district of specific characteristic.

### **3.2. Typologies of Change in Age-structure, Household-size and Housing Stock of Low-rise Residential Districts**

The hierarchical cluster analysis results of standardized values of each index in the three categories—age structure, household structure, and house type— with regard to the population-house indexes in the low-rise residential districts in Seoul are presented in Appendix 1-A to C. The ideal number of clusters was determined based on the Pseudo-F value. However, when the number of districts that belonged to each cluster was too small, it was considered as an outlier thereby determining the number of the clusters that could verify the main significant clusters. The characteristics of the major clusters of the low-rise residential districts in the three categories are presented in Tables 1–5, 7, and 9.

#### **1) Age-structure**

There were five major types of the low-rise residential districts in Seoul in terms of the change in population and age structure, and the characteristics of each type, including the five clusters whose number of districts was relatively small, are presented in Table 1-5. A4, which accounted for the highest proportion, was the district in which aging progressed the fastest in relative and absolute senses. This was because the population of children and young adults and middle-aged people was considerable decreased, whereas the population of old people grew rapidly while the entire population was stagnant or slightly declining.

However, the relationship between the population of young adults and



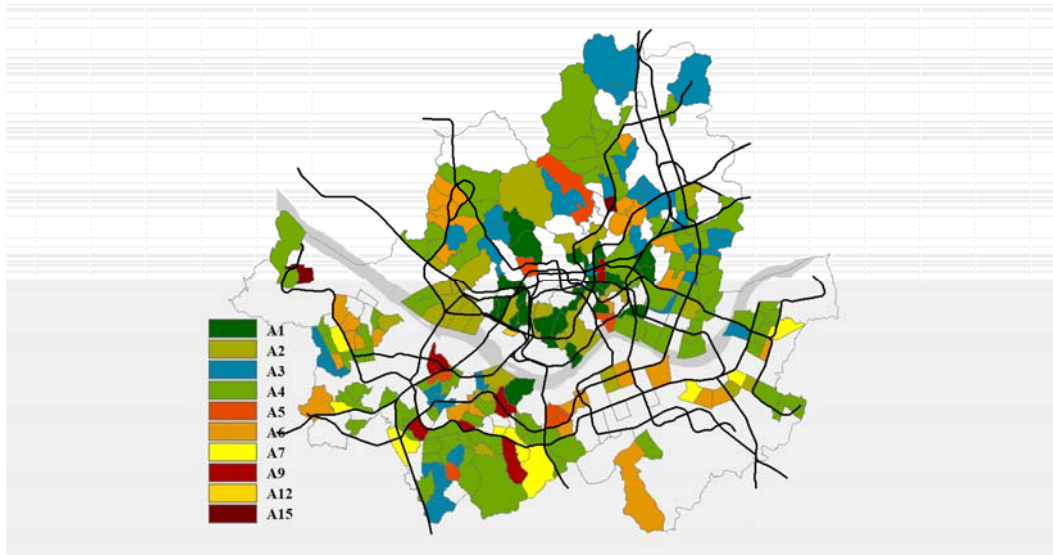
population of old people were not always mutually exclusive. That is, the aging progress in A2 was relatively low although the population was stagnant, like in A4, whereas A7 revealed a clear trend of increasing population only in the elderly and the youth in their 20s and 30s. The relative aging progress was also different between A1 and A3, where population declining was distinctive as the increase rate of population of old people showed a significant difference between A1 and A3.

**Table 1-5** Major clusters of population growth rates and age structure

Cluster	<i>Population</i> All age mean min.~max.	<i>Elderly</i> over 65 mean min.~max.	<i>Parents</i> 35~49 mean min.~max.	<i>Child</i> ~15 mean min.~max.	<i>Young</i> 25~34 mean min.~max.
<i>A1</i>	-0.1488	0.6318	-0.0752	-0.4976	-0.3010
<i>25 Ds</i>	-0.2776~-0.0207	0.6318~0.9603	-0.1775~0.0280	-0.675~-0.2910	-0.4595~-0.0817
<i>A2</i>	0.0187	0.9532	0.1239	-0.3781	-0.0864
<i>29 Ds</i>	-0.1238~0.2108	0.6110~1.2653	-0.0737~0.3066	-0.5267~-0.1895	-0.3500~0.1367
<i>A3</i>	-0.2056	1.1747	-0.2227	-0.5876	-0.4296
<i>36Ds</i>	-0.3511~-0.1026	0.6742~1.7640	-0.3509~-0.0755	-0.7108~-0.4454	-0.5952~-0.2965
<i>A4</i>	-0.0668	1.4267	-0.0507	-0.4929	-0.2574
<i>97Ds</i>	-0.1743~0.0750	0.8755~2.1265	-0.2260~0.1972	-0.6778~-0.2401	-0.4338~-0.0182
<i>A5</i>	0.2679	1.3834	0.4790	0.0503	-0.0715
<i>8Ds</i>	0.1700~0.3767	0.8419~1.8587	0.3112~0.5808	-0.0585~0.1979	-0.1942~0.0181
<i>A6</i>	0.1292	1.6393	0.2147	-0.2076	-0.0971
<i>31Ds</i>	0.0088~0.3046	1.1734~2.2755	0.0464~0.4247	-0.4200~0.0307	-0.2857~0.1171
<i>A7</i>	0.0666	1.6474	0.0703	-0.4549	0.1249
<i>10Ds</i>	0.0200~0.1292	1.473~1.9390	-0.0582~0.2301	-0.6441~-0.3655	0.0418~0.3041
<i>A9</i>	0.2865	1.1953	0.3470	-0.3447	0.5509
<i>7Ds</i>	0.1769~0.4271	1.0115~1.357	0.2585~0.4548	-0.6261~-0.0549	0.3660~0.7647
<i>A12</i>	0.1164	0.7999	-0.0679	-0.5549	0.2564
<i>5Ds</i>	0.0498~0.1675	0.5161~1.1766	-0.1206~-0.0362	-0.7083~-0.4337	0.1427~0.3595
<i>A15</i>	0.3333	2.2826	0.3751	-0.1440	0.1283
<i>6Ds</i>	0.2877~0.4259	1.9720~2.4814	0.1742~0.4647	-0.3156~0.0970	0.0228~0.2797
<i>Total</i>	0.0210	1.3601	0.0723	-0.3742	-0.1533
	-0.3887~1.9698	0.0841~3.3626	-0.3584~2.8874	-0.7108~2.7127	-0.5952~1.0411

For the types (A5, A6, A9, A12, and A15) where the population was increased,

the number of low-rise residential districts that belonged to the cluster was small, and population increase rates were relatively higher in all ages than the means or the decrease rate was slower except for A6. However, some clusters showed a distinctive difference: that the increase in population of old people was relatively more noticeable (A6), the population increase in the youth in their 20s and 30s was higher (A9 and A12), or the population increase in children and their parents was relatively higher (A5).



**Figure 1-7** The distribution of age-structure change clusters

The major clusters in the change in age structure showed somewhat irregular spatial distribution, as shown in Figure 1-7 whereas population decrease and relative aging were more dominant overall in districts in the north of the Han River, as revealed in A1, A3, and A4 (Table 1-6). In A3, where considerable population decrease and aging were underway, a considerable number of districts where public transportation accessibility to the outskirts of the city via subways was inconvenient were included. In contrast, A7, A9, A12, and A15, where the

youth in their 20s and 30s were introduced relatively more than in other districts belonged to districts that were far from the downtown or public transportation, such as railway station sphere, was closer.

**Table 1-6** Districts belonging to major clusters of the age-structure change

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
A1 25 Ds	부암동 송인1동 이화동 창신2동 청운효자동 장충동 신당5동 중림동 신당동 동화동 보광동 용산2가동 이태원2동 청파동 효창동 금호2.3가동 성수1가2동 왕십리도선동 답십리1동 전농1동 보문동 충현동 아현동 염리동 흑석동
	평창동 혜화동 다산동 남영동 이태원1동 한남동 후암동 왕십리2동 행당1동 능동 목 1동 동선동 삼선동 북가좌1동 연희동 공덕동 서강동 서교동 성산1동 신수동 연남동 합정동 목2동 노량진1동 상도2동 서림동 논현1동 방이1동 송파1동
A3 36Ds	창신1동 송정동 중곡3동 청량리동 망우3동 면목3.8동 면목5동 중화2동 석관동 장위 1동 장위2동 장위3동 정릉3동 번2동 송천동 도봉1동 방학2동 창3동 상계3.4동 응암 2,3,4동 홍은1동 홍제1동 홍제3동 신월3동 신월6동 신월7동 독산2동 시흥3동 시흥4동 시흥5동 신길3동 신길5동 신길6 동 노량진2동 난곡동 풍납1동
	마장동 성수1가1동 성수2가1동 용답동 구의1동 구의2동 군자동 자양1동 자양2동 자 양4동 중곡1동 중곡2동 중곡4동 용신동 이문1동 장안2동 제기동 휘경1동 망우본동 면목2동 면목4동 면목7동 면목본동 목2동 상봉2동 중화1동 미아동 번1동 삼양동 송 중동 수유1동 수유2동 수유3동 우이동 인수동 쌍문1동 쌍문2동 쌍문3동 상계2동 상 계5동 갈현1동 녹번동 불광동 수색동 신사2동 증산동 남가좌2동 홍은2동 망원1동 망원2동
A4 97Ds	목3동 신월1동 신월2동 신월5동 신정4동 방화2동 화곡4동 가리봉동 개봉1동 개봉3 동 고척2동 구로2동 구로4동 독산3동 독산4동 시흥1동 대림1동 도림동 신길1동 신 길4동 사당1동 사당3동 사당4동 사당5동 상도4동 대학동 미성동 보라매동 삼성동 서원동 신사동 신원동 조원동 청룡동 방배2동 방배3동 개포4동 거여1동 마천1동 마 천2동 오금동 성내1동 성내2동 암사1동 천호1동 천호2동 천호3동
	금호1가동 장안1동 휘경2동 월곡1동 월곡2동 종암동 창2동 갈현2동 구산동 대조동 신사1동 역촌동 응암1동 북가좌2동 목4동 신월4동 우장산동 화곡2동 화곡8동 화곡본동 수궁동 상도3동 신대방2동 반포 4동 방배1동 양재2동 논현2동 삼성1동 삼전동 석촌동 성내3동
A6 31Ds	

## 2) Household-size

The change in the number of households and one-person households had seven major clusters, as presented in Table 7. The population in H5 type, which was the

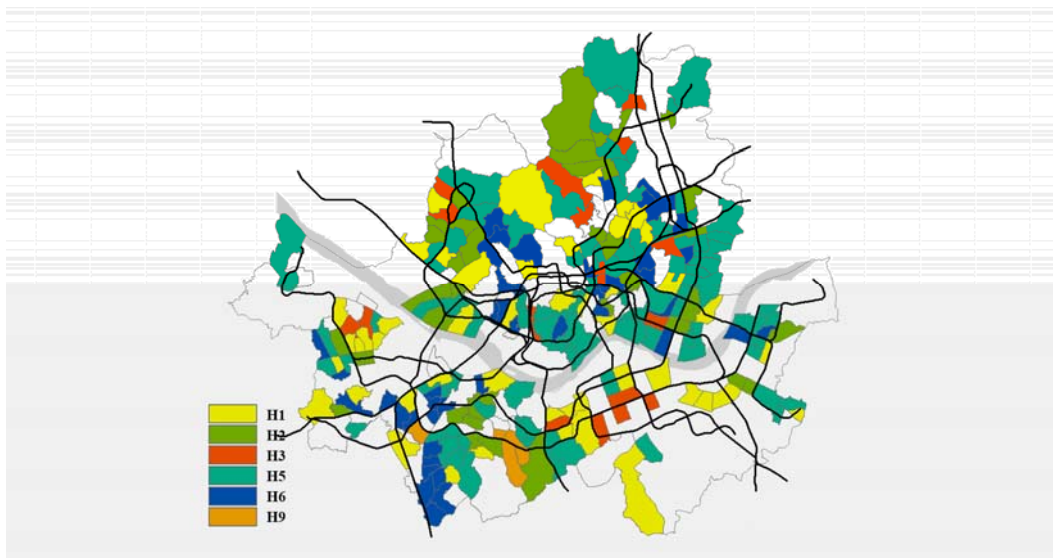
majority, was slightly declined or stagnant, as shown in A1, while the numbers of households and one-person households were increased, although the numbers were lower than the means of the low-rise residential districts. However, the number of households and household size showed more dynamic differentiation in the remaining types. The population increase in H2 consisting of 41 districts was insignificant, but the increase in the number of households—in particular, one-person households—was very significant. H1 and H9 showed a similar population increase, of around 10%, but there was a significant difference in the numbers of households and one-person households between them. This result indicated that the population influx in H1 was more dominant in three- to four-person households, whereas that in H9 was in one-person households.

**Table 1-7** Major clusters of pop., household & single-person h.hold growth rates

<i>Cluster</i>	<i>Population mean min.~max.</i>	<i>Household mean min.~max.</i>	<i>Single-person H.hold mean min.~max.</i>
<i>H1: 48 Ds</i>	0.1039 -0.0636~0.3767	0.3190 0.1600~0.4981	1.0848 0.1847~1.6062
<i>H2:41 Ds</i>	0.0181 -0.1555~0.1793	0.3565 0.1513~0.5613	2.1673 1.6361~2.9814
<i>H3:17 Ds</i>	0.2730 0.2035~0.3670	0.5793 0.4720~0.6751	1.6763 1.2395~2.1447
<i>H5:95 Ds</i>	-0.0979 -0.2268~0.0584	0.1269 -0.0473~0.2550	1.1704 0.0771~1.8128
<i>H6:44Ds</i>	-0.1806 -0.3511~-0.0312	-0.0497 -0.2519~0.0491	0.5452 -0.0463~1.0729
<i>H9:5Ds</i>	0.1107 0.0200~0.2772	0.6298 0.5571~0.7757	3.5849 3.3248~4.1454
<i>Total</i>	0.0210 -0.3887~1.9698	0.2656 -0.3309~2.2621	1.3953 -0.2295~8.6915

Despite the numbers of households and one-person households having clearly increased in Seoul and low-rise residential districts, a considerable number of

low-rise residential districts (H6) had a significant population decrease and reduction in households as well as relatively lower increase in one-person households. For these districts, the reduction in the number of households was rather limited compared to the population decline, which implied that one-person households were replacing the three- and four-person households. In contrast, a number of clusters (H10 to H16 and H19 to H20), to which a small number of districts belonged, including H3 and H9, exhibited that the clear population increase led to the increase in the number of households regardless of the household size.



**Figure 1-8** The distribution of household size change clusters

The districts where population and the number of households were decreased, or showed limited increase, were revealed (H5 and H6) in the spatial distribution of changes in the number of households and household size by cluster were mostly located in the outskirts of the city but they were also revealed in districts adjacent to old towns simultaneously (Figure 1-8). H2 and H9, where the increase

in one-person households was noticeable, included relatively low land price districts and districts around universities (Table 1-8).

**Table 1-8** Districts belonging to major clusters of the household change

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
<i>H1</i> 48 Ds	사직동 평창동 혜화동 필동 다산동 금호4가동 왕십리2동 구의2동 장안1동 회기동 월곡1동 월곡2동 종암동 삼양동 구산동 수색동 북가좌2동 연희동 공덕동 서강동
	목2동 목4동 신월4동 우장산동 화곡2동 화곡4동 화곡8동 고척2 구로5동 수궁동 가산동 영등포본동 노량진1동 난향동 서림동 반포4동 방배1동 방배본동 서초3동 양재2동 논현2동 삼성1동 마천1동 삼전동 석촌동 송파1동 잠실본동 성내3동
<i>H2</i> 41 Ds	금호1가동 마장동 능동 중곡2동 화양동 목1동 상봉2동 동선동 안암동 미아동 수유1동 수유2동 우이동 인수동 쌍문2동 쌍문3동 상계2동 대조동 신사1동 신사2동 응암1동 남가좌2동 홍은2동 망원2동 성산1동 연남동 합정동
	신정4동 화곡1동 오류1동 사당1동 상도2동 상도3동 신대방2동 남현동 보라매동 서원동 청룡동 방이1동 방이2동 길동
<i>H3</i> 17 Ds	송인2동 황학동 남영동 성수2가3동 휘경2동 정릉2동 정릉4동 방학1동 창2동 갈현2동 역촌동
	등촌2동 화곡본동 방배4동 서초1동 대치4동 역삼1동
<i>H5</i> 95 Ds	부암동 송인1동 이화동 장충동 중림동 신당동 보광동 용산2가동 이태원1동 청파동 한남동 후암동 성수1가1동 성수1가2동 성수2가1동 용답동 행당1동 구의1동 군자동 자양1동 자양2동 중곡1동 중곡3동 중곡4동 용신동 이문1동 장안2동 제기동 청량리동 휘경1동 망우3동 망우본동 면목2동 면목3.8동 면목4동 면목7동 면목본동 목2동 중화1동 보문동 삼선동 장위1동 정릉3동 번1동 번2동 송중동 수유3동 도봉1동 방학2동 쌍문1동 창3동 상계3.4동 상계5동 갈현1동 녹번동 불광동 응암2,3,4동 증산동 북가좌1동 망원1동 서교동 신수동
	목3동 신월1동 신월2동 신월5동 신월7동 방화2동 개봉3동 도림동 신길1동 신길4동 사당3동 사당4동 사당5동 상도4동 흑석동 난곡동 미성동 삼성동 신사동 신원동 조원동 방배2동 방배3동 개포4동 논현1동 거여1동 마천2동 오금동 성내1동 성내2동 암사1동 천호1동 천호2동
<i>H6</i> 44Ds	창신1동 창신2동 청운효자동 신당5동 동화동 이태원2동 효창동 금호2.3가동 송정동 왕십리도선동 자양4동 답십리1동 전농1동 면목5동 중화2동 석관동 장위2동 장위3동 송천동 충현동 홍은1동 홍제1동 홍제3동 아현동 염리동
	신월3동 신월6동 개봉1동 구로2동 구로4동 독산2동 독산3동 독산4동 시흥1동 시흥3동 시흥4동 시흥5동 대림1동 신길3동 신길5동 신길6동 노량진2동 풍납1동 천호3동
<i>H9</i> 5Ds	- 구로3동 낙성대동 인현동 중암동 행운동

### 3) Housing stock

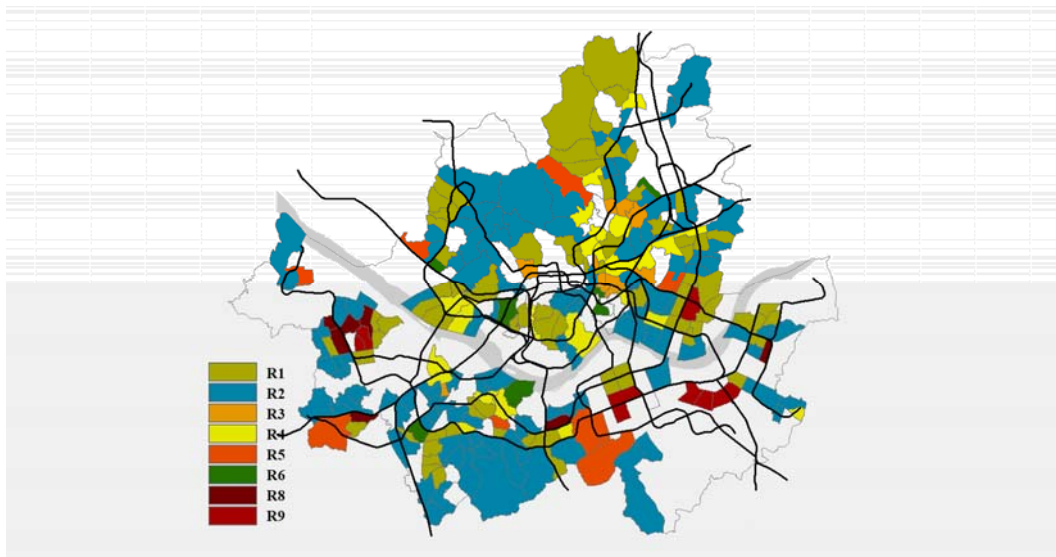
For the housing stock increase in the low-rise residential districts and change in

occupation rate by house type, the districts were divided into eight major clusters. While the low-rise residential districts showed an increase in housing stock overall, they also had differentiation in the contribution by house type cluster-by-cluster (Table 1-9). The housing stock increase in the majority cluster R2 did not exceed the mean, and the contribution of the multi-unit housing was higher than that of the apartments. In contrast, R8, which showed a housing stock increase similar to that of R2, revealed that the number of the multi-unit housing was rather declined slightly, but the house supply was focused on apartments. R1, which was the second majority district and had a considerable housing stock increase, showed noticeable construction of multiple-unit housings rather than apartments. For other major clusters that showed a significant increase in housing stock in spite of the small number of districts that belonged to the clusters, apartment-oriented house supply (R3, R5, and R6), multi-unit housing-oriented house supply (R9), and increase in both types (R4 and R8) were revealed.

**Table 1-9** Major clusters of housing stock growth rate and changes in the occupation ratio by housing type

<i>Cluster</i>	<i>Housing growth r. mean min.~max.</i>	<i>Change in r. of det. mean min.~max.</i>	<i>Change in r. of APT mean min.~max.</i>	<i>Change in r. of multi. mean min.~max.</i>	<i>R. of det. in 2000 mean min.~max.</i>	<i>R. of APT in 2000 mean min.~max.</i>
<i>R1:</i>	0.5648	-0.2893	0.0519	0.3300	0.4882	0.1428
<i>74 Ds</i>	0.2286~0.9711	-0.4347~-0.1684	-0.1275~-0.2047	0.2240~0.5015	0.1977~0.8030	0~0.4866
<i>R2:</i>	0.3298	-0.1619	0.0925	0.1532	0.3377	0.3162
<i>118 Ds</i>	-0.2038~0.8120	-0.3518~-0.0145	-0.1017~0.4476	-0.0126~0.3261	0.0027~0.7188	0~0.5998
<i>R3:</i>	0.8484	-0.5339	0.4886	0.0504	0.6769	0.1664
<i>11 Ds</i>	0.3382~1.3250	-0.6126~-0.4530	0.4053~0.5682	-0.0081~0.1187	0.4902~0.9214	0~0.3438
<i>R4:</i>	0.8026	-0.4015	0.2986	0.1593	0.5353	0.1686
<i>24 Ds</i>	0.2399~1.2793	-0.5177~-0.2813	0.1547~0.3868	0.0789~0.3309	0.2465~0.7593	0~0.4343
<i>R5:</i>	1.1340	-0.1963	0.3621	0.0813	0.2138	0.2962
<i>9 Ds</i>	0.7149~1.5564	-0.2533~-0.1510	0.2262~0.6165	-0.0306~0.1375	0.1013~0.3352	0.0052~0.5392

<i>R6:</i>	0.3388	-0.3116	0.3801	-0.0295	0.4169	0.2709
<i>8 Ds</i>	0.1688~0.5599	-0.4295~-0.2146	0.2846~0.5568	-0.1189~0.0921	0.1128~0.7188	0~0.4610
<i>R8:</i>	1.5316	-0.3492	0.1542	0.1990	0.3512	0.2557
<i>7 Ds</i>	1.2000~1.9775	-0.5180~-0.2114	0.0647~0.2444	0.0951~0.2745	0.2426~0.4123	0.0050~0.5130
<i>R9:</i>	1.3930	-0.4375	0.0098	0.5301	0.5076	0.0909
<i>9 Ds</i>	0.8313~1.9251	-0.5742~-0.3287	-0.1488~0.1719	0.4486~0.6814	0.2943~0.9794	0~0.2812
<i>Total</i>	0.6259	-0.2682	0.1544	0.1925	0.4227	0.2305
	-0.2038~4.9926	-0.9847~-0.0145	-0.1488~0.9922	-0.3594~0.6814	0.0027~0.9794	0~0.5998



**Figure 1-9** The distribution of housing stock and residential type change clusters



**Table 1-10** Districts belonging to major clusters in the housing stock change

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
<i>R1: 74 Ds</i>	<p>송인2동 이화동 창신2동 청운효자동 혜화동 용산2가동 이태원2동 청파동 효창동 후암동 사근동 구의1동 구의2동 군자동 자양1동 중곡1동 중곡3동 중곡4동 화양동 이문1동 망우3동 면목2동 면목5동 면목본동 목2동 안암동 장위1동 번1동 송천동 수유1동 수유3동 우이동 인수동 도봉1동 방학2동 쌍문1동 창3동 갈현2동 구산동 대조동 신사1동 역촌동 북가좌2동 신촌동 망원1동 성산1동 연남동 합정동</p> <p>목2동 목3동 목4동 신월1동 신정4동 가리봉동 개봉3동 독산2동 독산3동 독산4동 시흥4동 사당1동 사당4동 상도3동 상도4동 신사동 조원동 중앙동 방배2동 논현1동 논현2동 방이2동 성내2동 암사1동 천호1동 천호2동</p>
<i>R2: 118 Ds</i>	<p>부암동 창신1동 평창동 필동 장충동 신당동 다산동 보광동 이태원1동 마장동 성수1가1동 성수1가2동 성수2가1동 송정동 용답동 자양2동 자양4동 장안2동 제기동 청량리동 회기동 휘경1동 망우본동 면목3.8동 면목4동 면목7동 목1동 중화1동 중화2동 석관동 성북동 장위2동 정릉3동 미아동 번2동 송중동 수유2동 쌍문2동 쌍문3동 창2동 상계2동 상계3.4동 상계5동 갈현1동 녹번동 불광동 신사2동 응암1동 증산동 남가좌2동 연희동 충현동 홍은1동 홍은2동 홍제1동 홍제3동 망원2동 신수동 염리동</p> <p>신월2동 신월3동 신월4동 신월5동 신월6동 신월7동 등촌1동 방화2동 우장산동 화곡6동 개봉1동 고척2동 구로2동 구로5동 수궁동 오류1동 가산동 시흥1동 시흥3동 시흥5동 대림1동 대림2동 도림동 신길1동 신길3동 신길5동 신길6동 노량진1동 노량진2동 사당3동 사당5동 신대방2동 낙성대동 난곡동 남현동 대학동 미성동 보라매동 삼성동 서림동 서원동 신원동 인현동 청룡동 행운동 반포4동 방배3동 방배본동 양재2동 개포4동 삼성1동 거여1동 마천2동 방이1동 오금동 풍납1동 길동 성내1동 천호3동</p>
<i>R3: 11 Ds</i>	<p>사직동 송인1동 신당5동 황학동 왕십리도선동 왕십리2동 답십리1동 길음2동 월곡1동 월곡2동</p> <p>신길4동</p>
<i>R4: 24 Ds</i>	<p>남영동 한남동 성수2가3동 행당1동 용신동 전농1동 휘경2동 상봉2동 동선동 보문동 삼선동 정릉2동 종암동 삼양동 방학1동 서강동 서교동</p> <p>영등포동 영등포본동 상도1동 상도2동 신림동 방배1동 마천1동</p>
<i>R5: 9 Ds</i>	<p>장안1동 정릉4동 수색동 방화1동 오류2동</p> <p>성현동 서초1동 서초3동 양재1동</p>
<i>R6: 8 Ds</i>	<p>동화동 금호2.3가동 장위3동 북가좌1동 공덕동 아현동</p> <p>구로3동 흑석동</p>
<i>R8: 7 Ds</i>	<p>-</p> <p>등촌2동 화곡1동 화곡3동 화곡본동 개봉2동 방배4동 성내3동</p>
<i>R9: 9 Ds</i>	<p>능동 중곡2동</p> <p>화곡2동 화곡4동 역삼1동 삼전동 석촌동 송파1동 잠실본동</p>

The spatial distribution of changes in housing stock by cluster is shown in Figure 1-9. R1 and R9, where the increase in multi-unit housing was significant,

belonged to the low-rise residential districts with relatively good urban structure created through the land compartmentalization and rearrangement projects in the 1970s to 1980s. In contrast, R3, R5, and R6, where the increase in apartments was dominant, had many redevelopment projects inside the districts. They were surrounding districts around downtown, where land location was good, or relatively underdeveloped outskirt districts of the city.

### **3.3. Typologies of Low-rise Residential Districts**

The cluster analysis was conducted based on all variables in the three categories: changes in population and age structure, household size, and housing stock. The results showed that the low-rise residential districts in Seoul were divided into LR1, which was the majority, and other seven types, whose number of districts was small but distinctively differentiated. As presented in Table 1-11, the population-house variable values in LR1 were distributed in a relatively wide range such that the mean of each variable was somewhat weak in terms of representativeness. Thus, the distribution of the actual variable values required analysis at the same time. In contrast, other small-number group types had a relatively narrow range of variable values and a significant difference compared to the values in LR1<sup>2</sup>. Thus, the cluster analysis results of the low-rise residential districts required analysis based on distinctive characteristics that the other types had compared to LR1, rather than comparing them equally.

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<sup>2</sup> These statistical results were because the difference between LR1 and other clusters was much larger than the statistical difference between sub-clusters produced after LR1 was subdivided. Thus, the small-number groups other than LR1 were analyzed as kinds of exceptional cases, and the cluster analysis results of the low-rise residential districts that belonged to LR1 are presented in Appendix 1-E.

**Table 1-11** Major clusters of demographic and housing stock change

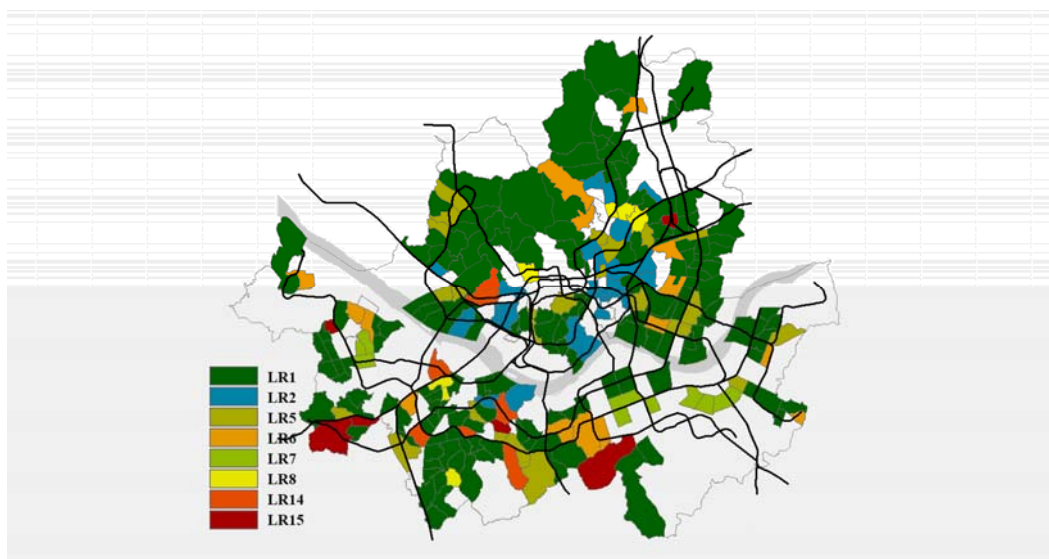
<i>Clust.</i>	<i>Population growth r. mean min.~max.</i>	<i>Elderly over 65 mean min.~max.</i>	<i>Mid-age 35~49 mean min.~max.</i>	<i>Child ~15 mean min.~max.</i>	<i>Young 25~34 mean min.~max.</i>	<i>Household growth r. mean min.~max.</i>	<i>S-person H.hold mean min.~max.</i>
<i>LR1:</i>	-0.0785	1.2847	-0.0541	-0.4771	-0.2682	0.1356	1.1798
<i>162Ds</i>	-0.3887~-0.2423	0.0841~2.4443	-0.3584~-0.5542	-0.7096~-0.1979	-0.5274~-0.0884	-0.3309~-0.4720	-0.2295~-2.9814
<i>LR2:</i>	-0.1064	0.7992	-0.0195	-0.4267	-0.2918	0.0870	0.7936
<i>26Ds</i>	-0.3511~-0.0922	0.2427~1.3394	-0.3414~-0.2540	-0.6725~-0.1749	-0.5952~-0.0297	-0.2434~-0.3872	-0.0463~-1.7295
<i>LR5:</i>	0.1025	1.3433	0.1042	-0.4387	0.0967	0.4798	2.3612
<i>26Ds</i>	-0.0153~-0.2628	0.5161~1.9126	-0.1206~-0.3390	-0.7083~-0.1462	-0.1550~-0.3660	0.1600~-0.8162	1.3742~4.5840
<i>LR6:</i>	0.2728	2.0155	0.3278	-0.1176	0.1854	0.5334	1.4798
<i>16Ds</i>	0.0088~-0.5275	1.3435~2.8018	0.0436~0.5636	-0.3156~-0.2269	-0.3170~-0.2797	0.2736~-0.7916	0.8445~2.1447
<i>LR7:</i>	0.0992	1.5870	0.2943	-0.3463	-0.0197	0.3990	1.3189
<i>9Ds</i>	0.0097~-0.3670	1.1599~1.8506	0.0040~0.9789	-0.4291~-0.1122	-0.1498~-0.2817	0.2598~-0.6751	1.0850~1.6862
<i>LR8:</i>	0.2385	1.5128	0.3586	-0.0570	-0.0662	0.2593	0.5275
<i>7Ds</i>	0.0436~-0.5373	0.8419~2.2423	0.0415~-0.6441	-0.5050~-0.1689	-0.2714~-0.2239	0.0489~-0.3898	0.1847~-1.1275
<i>LR14:</i>	0.2903	1.1272	0.3093	-0.3379	0.5999	0.8935	3.6636
<i>6Ds</i>	0.1769~-0.4271	0.5484~1.3570	0.1368~0.4548	-0.6261~-0.0549	0.4601~-0.7647	0.6662~1.1814	2.5911~4.3298
<i>LR15:</i>	0.6834	3.0429	0.7702	0.3702	0.2563	0.9673	2.0381
<i>6Ds</i>	0.5598~-0.7846	2.7304~3.3626	0.3914~0.9924	-0.1229~-0.8499	0.1320~-0.4459	0.8308~1.0940	1.5979~3.1958
<i>Total</i>	0.0210	1.3601	0.0723	-0.3742	-0.1533	0.2656	1.3953
	-0.3887~1.9698	0.0841~3.3626	-0.3584~2.8874	-0.7108~2.7127	-0.5952~1.0411	-0.3309~2.2621	-0.2295~8.6915

<i>Clust.</i>	<i>Housing growth r. mean min.~max.</i>	<i>Change in r. of det. mean min.~max.</i>	<i>Change in r. of APT mean min.~max.</i>	<i>Change in r. of multi. mean min.~max.</i>	<i>R. of elderly in 2000 mean min.~max</i>	<i>Change in r. of eld. mean min.~max</i>	<i>R. of mid in 2000 mean min.~max</i>
<i>LR1:</i>	0.4022	-0.2033	0.0741	0.2166	0.0548	0.0789	0.2358
<i>162Ds</i>	0.0415~-0.9711	-0.4763~-0.0145	-0.1275~-0.4476	-0.0672~-0.5015	0.0364~-0.0978	0.0375~-0.1317	0.1823~-0.2794
<i>LR2:</i>	0.5215	0~-0.3949	0.3447	0.0681	0.0670	0.0679	0.2235
<i>26Ds</i>	0.1688~1.3186	-0.5485~-0.2662	0.1331~0.5568	-0.1189~-0.2416	0.0562~-0.0793	0.0365~-0.1102	0.1963~-0.2380
<i>LR5:</i>	0.6361	-0.3149	0.1009	0.2819	0.0580	0.0618	0.2220
<i>26Ds</i>	-0.1165~-0.9664	-0.5742~-0.1287	-0.0147~-0.2618	0.1030~-0.5162	0.0364~-0.0990	0.0296~-0.0864	0.1709~-0.2685
<i>LR6:</i>	1.0576	-0.2777	0.3281	0.1613	0.0523	0.0703	0.2349
<i>16Ds</i>	0.8077~1.3354	-0.3952~-0.1597	0.1451~0.6165	0.0166~-0.3261	0.0427~-0.0755	0.0559~-0.0946	0.2108~-0.2655
<i>LR7:</i>	1.5761	-0.4016	0.0317	0.5204	0.0429	0.0587	0.2268
<i>9Ds</i>	0.7956~2.6188	-0.5176~-0.2938	-0.1488~-0.1719	0.4467~-0.6814	0.0360~-0.0480	0.0406~-0.0800	0.1885~-0.2487
<i>LR8:</i>	0.9620	-0.5698	0.5298	0.0727	0.0696	0.0688	0.2309
<i>7Ds</i>	0.5843~1.3250	-0.7594~-0.3977	0.3408~0.7995	0.0494~-0.1187	0.0598~-0.1068	0.0534~-0.0868	0.2155~-0.2488
<i>LR14:</i>	0.6011	-0.3181	0.2030	0.1556	0.0588	0.0368	0.1991
<i>6Ds</i>	0.2571~1.0877	-0.4679~-0.1659	0.0293~0.3347	-0.0363~-0.3130	0.0417~-0.0801	0.0124~-0.0479	0.1533~-0.2300
<i>LR15:</i>	1.6769	-0.2643	0.2870	0.1022	0.0534	0.0750	0.2387
<i>6Ds</i>	1.3567~2.2748	-0.4896~-0.1510	0.1099~0.4401	0.0250~-0.2560	0.0485~-0.0578	0.0572~-0.0856	0.2245~-0.2502
<i>Total</i>	0.6259	-0.2682	0.1544	0.1925	0.0566	0.0728	0.2317
	-0.2038~4.9926	-0.9848~-0.0145	-0.1488~0.9922	-0.3594~0.6814	0.0360~0.1068	0.0124~0.1317	0.1533~-0.2794

(continued→)

(←continued)

<i>Clust.</i>	<i>Change in r. of mid. mean min.~max</i>	<i>R. of child in 2000 mean min.~max</i>	<i>Change in r. of chil. mean min.~max</i>	<i>R. of young in 2000 mean min.~max</i>	<i>Change in r. of young mean min.~max</i>	<i>R. of det. in 2000 mean min.~max.</i>	<i>R. of APT in 2000 mean min.~max.</i>
<b>LR1:</b>	0.0045	0.1815	-0.0797	0.3090	-0.0432	0.3941	0.2466
<b>162Ds</b>	-0.0462~0.0765	0.1115~0.2192	-0.1236~-0.0055	0.2285~0.4578	-0.1136~0.0323	0.0027~0.8030	0~0.5998
<b>LR2:</b>	0.0211	0.1665	-0.0601	0.3138	-0.0447	0.5820	0.2013
<b>26Ds</b>	-0.0052~0.0548	0.1318~0.1910	-0.1074~-0.0255	0.2850~0.3631	-0.0750~-0.0049	0.3205~0.9214	0~0.4402
<b>LR5:</b>	0.0007	0.1669	-0.0810	0.3289	0.0003	0.4657	0.1830
<b>26Ds</b>	-0.0568~0.0431	0.1165~0.2015	-0.1198~-0.0563	0.2587~0.4477	-0.0506~0.0490	0.1481~0.9794	0~0.5919
<b>LR6:</b>	0.0096	0.1728	-0.0543	0.3123	-0.0418	0.3147	0.2283
<b>16Ds</b>	-0.0282~0.0376	0.1226~0.2040	-0.0882~-0.0219	0.2687~0.3562	-0.0691~-0.0173	0.1649~0.5025	0.0052~0.5947
<b>LR7:</b>	0.0344	0.1672	-0.0677	0.3515	-0.0238	0.4098	0.1180
<b>9Ds</b>	-0.0014~0.0902	0.1076~0.2041	-0.0795~-0.0465	0.3009~0.4432	-0.0749~0.0199	0.2943~0.4986	0.0380~0.2812
<b>LR8:</b>	0.0212	0.1582	-0.0382	0.2964	-0.0483	0.7102	0.0965
<b>7Ds</b>	-0.0053~0.0503	0.1307~0.1715	-0.0913~-0.0020	0.2778~0.3448	-0.0662~-0.0322	0.5601~0.8987	0~0.2429
<b>LR14:</b>	0.0048	0.1489	-0.0715	0.3655	0.0586	0.3666	0.3043
<b>6Ds</b>	-0.0186~0.0310	0.1063~0.1756	-0.0983~-0.0475	0.2938~0.4536	0.0045~0.1140	0.1128~0.6368	0.0951~0.4610
<b>LR15:</b>	0.0110	0.1779	-0.0347	0.3007	-0.0506	0.2907	0.4062
<b>6Ds</b>	-0.0294~0.0402	0.1639~0.1927	-0.0831~0.069	0.2785~0.3204	-0.0749~-0.0351	0.1013~0.6146	0.2441~0.5392
<b>Total</b>	0.0092	0.1755	-0.0718	0.3138	-0.0362	0.4227	0.2305
	-0.0568~0.0902	0.1063~0.2192	-0.1236~0.0522	0.2285~0.4831	-0.1136~0.1140	0.0027~0.9794	0~0.5998



**Figure 1-10** Distribution of demographic and housing stock change

### **LR1: The general low-rise**

The LR1 low-rise residential districts belonged to districts whose vitality was

low in terms of house supply and demographic composition based on the mean values. Most districts experienced a population decline by 10 to 20%, even if the districts where redevelopment was underway partially were excluded. The aging progress was fast, as the age structure showed the declining trend of population in all age groups except for the elderly. This was revealed in not only mean values but also as the common trend of the low-rise residential districts that belonged to LR1, except for a few exceptional districts. In addition, LR1 low-rise residential districts showed the increase trend in the numbers of households and one-person households was somewhat weak and the increase rate of houses was relatively slower compared to those of the whole of Seoul and overall low-rise residential districts. The multi-unit housing rather than apartments in most LR1 districts replaced detached houses in terms of housing stock, and a considerable number of new houses were supplied; however, the number did not exceed the mean value of Seoul and the low-rise residential districts.

**Table 1-12** Districts of LR1: *The general low-rise*

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
LR1: 162Ds	부암동 이화동 창신2동 청운효자동 평창동 혜화동 장충동 다산동 보광동 용산2가동 이태원1동 이태원2동 청파동 효창동 후암동 마장동 성수1가1동 성수1가2동 성수2가1 동 송정동 용답동 구의1동 구의2동 군자동 자양1동 자양2동 자양4동 중곡1동 중곡3동 중곡4동 이문1동 장안2동 제기동 청량리동 휘경1동 망우3동 망우본동 면목2동 면목3,8 동 면목4동 면목5동 면목7동 면목본동 묵1동 묵2동 중화1동 중화2동 석관동 성북동 장위1동 장위2동 정릉3동 미아동 번1동 번2동 송중동 수유1동 수유2동 수유3동 우이 동 인수동 도봉1동 방학2동 쌍문1동 쌍문2동 쌍문3동 창2동 창3동 상계2동 상계3,4동 상계5동 갈현1동 구산동 녹번동 불광동 수색동 신사2동 응암1동 응암2,3,4동 증산동 남가좌2동 북가좌2동 연희동 홍은1동 홍은2동 홍제1동 홍제3동 망원1동 망원2동 서교 동 신수동 합정동
	목2동 목3동 목4동 신월1동 신월2동 신월3동 신월4동 신월5동 신월6동 신월7동 방화2 동 우장산동 가리봉동 개봉1동 개봉3동 고척2동 구로2동 수궁동 독산2동 독산3동 독 산4동 시흥1동 시흥3동 시흥4동 시흥5동 대림1동 대림2동 도림동 신길1동 신길3동 신 길5동 신길6동 노량진1동 노량진2동 사당1동 사당3동 사당4동 사당5동 상도4동 신대 방2동 난곡동 미성동 보라매동 삼성동 서림동 서원동 신사동 신원동 조원동 청룡동

반포4동	방배2동	방배3동	방배본동	양재2동	개포4동	논현1동	논현2동	삼성1동	거여1동
마천2동	방이1동	오금동	풍납1동	성내1동	성내2동	암사1동	천호1동	천호2동	천호3동

### **LR2: Conversion to APT-dominant for senior families**

LR2 and LR5, which were the second majority districts, exhibited a clear differentiation from LR1 in terms of population-household-housing viewpoints as well as the opposite direction of changes simultaneously. LR2 comprised low-rise residential districts where the overall population was declined as the population in children and the youth was significantly reduced and the increasing trend of age population was clearly weak. In addition, the numbers of households and one-person households increased minimally in those districts. In contrast, apartment-oriented new house supply was achieved at a considerable rate, which resulted in a significant increase in house number, and most LR2 districts had an apartment increase by more than 30% proportionally. Instead, proportions of detached and multi-unit housing were significantly reduced. As shown in Figure 1-10, most LR2 districts were closer to downtowns located in districts in the north of the Han River. They had a higher proportion of detached houses as of 2000, and a considerable number of them were districts where the New Town Project in Seoul was underway in the mid-2000s (Table 1-13). The change pattern of the population-housing stock implied that the houses supplied through redevelopment were not appropriate for households with one-person in their 20s and 30s or for families with children, but were preferred by older ages in a relative sense.

**Table 1-13** Districts of LR1: Conversion to APT-dominant for senior families

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)

LR2: 26Ds	송인1동 신당5동 신당동 동화동 한남동 금호2.3가동 왕십리도선동 왕십리2동행당1동
	답십리1동 용신동 전농1동 보문동 삼선동 장위3동 종암동 삼양동 송천동 북가좌1동
	충현동 공덕동 서강동 아현동 염리동
	상도2동 흑석동

#### **LR5: *Densification for the single***

In LR5, population increase occurred in all ages except for children. The increase in the number of households—in particular, the number of one-person households—was especially high. However, this cluster belonged to the low-rise residential districts, where the children population was the lowest proportionally as of 2015, as the number of children population was decreased the most. This result indicated that the young families with children left the districts, replaced with households with older population and one-person households in their 20s and 30s. The number of houses was also higher than the mean and the occupation rates of both of apartment and multi-unit housing were increased. In particular, new houses were supplied focusing on multi-unit housing. Thus, the LR5 districts were regarded as playing a role in absorbing the changes in population structure in terms of age and household size in Seoul. Note that the sizes of the newly supplied houses and residential environments were not suitable to those preferred by households with families with children. Some of the LR5 districts were located in old towns adjacent to the downtowns, and most of them had relatively lower land prices and were distributed around the outskirts of Seoul with good public transportation accessibility (Figure 1-10, Table 1-14).

**Table 1-14** Districts of LR1: *Densification for the single*

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
LR5:	송인2동 필동 남영동 사근동 능동 중곡2동 화양동 회기동 상봉2동 동선동 안암동 갈

26Ds	현2동 대조동 신사1동 역촌동 성산1동 연남동
	오류1동 가산동 상도3동 남현동 인현동 중앙동 행운동 방이2동 길동

#### **LR6: Development and Densification for families**

The LR6 group exhibited a higher population increase than that of LR5, and the increase rates of population in the elderly, middle-aged, and the youth were relatively higher, and there was a very low reduction rate of population in children. Originally, these districts were residential districts with lower population in old people, and the aging trend was limited. Thus, the increases in population and households were mainly due to the increases in one-person households in the youth, and particularly in three- or four-person households with children. The housing supply was heavily focused on apartments, and an occupation rate of multi-unit housing was also higher than the mean, such that the housing stock became twice on average for the last 15 years. Most of the LR6 districts were located in the outskirts of Seoul (Figure 1-10, Table 1-15), and many of them were underdeveloped areas such as slope lands adjacent to mountains or watershed spaces, as of 2000. The newly supplied apartments were mainly the results of the development on those lands. The multi-unit housing were constructed by replacing existing detached houses in the already developed residential lands. As a result, only a small number of detached houses remained in the LR6 districts.

**Table 1-15** Districts of LR6: Development and Densification for families

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
LR6:	성수2가3동 장안1동 휘경2동 정릉2동 정릉4동 방학1동
16Ds	등촌2동 방화1동 화곡6동 구로5동 방배1동 방배4동 서초1동 서초3동 마천1동 성내3동

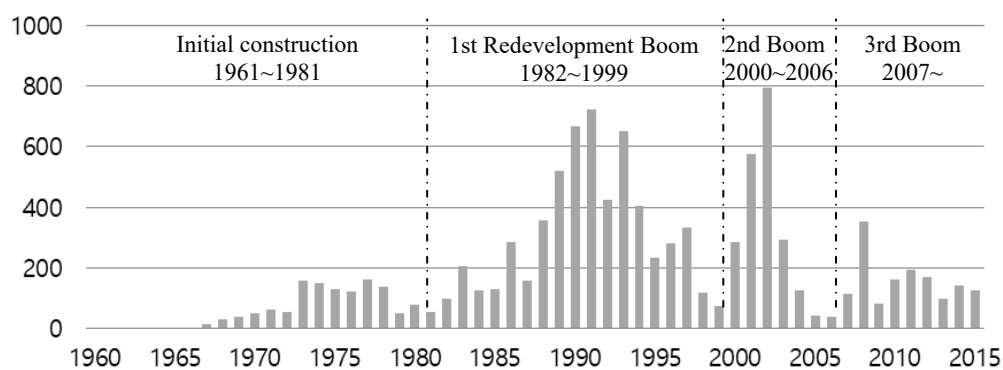


### **LR7: *Densification for the young***

The population increase in the LR7 districts was similar with that of LR5, but the characteristics of age structure and households were somewhat different. The low-rise residential districts in LR7 were originally regarded as a residential place with a lower proportion of population of old people and relatively young population. Since then, the population declines in children and the youth in their 20s and 30s were maintained at a relatively low rate. Thus, the population increase rate in the old and middle-aged people exceeded the mean of Seoul and all low-rise residential districts but LR7 still maintained the characteristic as a residential place for the young. The number of houses was increased at a larger rate than that of the population increase, and a considerable number of detached houses were replaced with multi-unit housing rather than apartments. The LR7 districts were located in the Gangseo region developed in the 1970s and Gangnam region developed in 1980s through the land compartmentalization and rearrangement projects (Figure 1-10, Table 1-16). These districts were planned residential places with relatively flat lands and grid-type urban structure. Their urban conditions were better than natural residential areas and slope lands in Gangbuk, which were why the districts were not considered as the redevelopment target. Thus, the constant land-based redevelopments occurred up until now thereby lowering a ratio of old houses and supplying houses preferred by the youth constantly (Figure 1-11).

**Table 1-16** Districts of LR7: *Densification for the young*

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
LR7:	-



**Figure 1-11** Construction year of residential buildings in Hwagok-dong

### **LR8: Redevelopment to APT for family & kids**

The LR8 districts where the population increased by more than 20% on average showed the noticeable influx of families who raised their children compared to the old people and the youth. Thus, the increases in the number of households and one-person households were very limited compared to the population increase. The number of houses increased significantly mainly supplied by apartments. LR8 was districts with the highest proportion of detached houses as of 2000, and most of the areas were regarded as old and deteriorated residential areas. However, they were redeveloped into a large scale of apartment complexes through urban planning rather than individual reconstruction. As a result, a proportion of apartments was more than half of all houses as of 2015 so that the low-rise residential districts were converted into apartment dominant residential places (Table 1-17).

**Table 1-17** Districts of LR8: Redevelopment to APT for family & kids

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)

LR8:	사직동 길음2동 월곡1동 월곡2동
7Ds	신길4동 영등포본동 난향동

#### LR14: University & IT town

The considerable population increase in the LR14 districts was due to the influx of the youth in their 20s and 30s, which was confirmed by the explosive increase in one-person households. This was related to rather specific circumstances of the LR14 districts located in the living sphere of the youth, such as universities and information technology industry complexes (Table 1-18). The proportions of old people, middle-aged people, and children were definitely lower in this region as of 2000. Since then, the population influx of the youth in their 20s continued. As a result, this residential area was characterized that the aging level and progress were the lowest and a proportion of children population was the lowest. The housing stock increase showed that apartments were more increased than multi-unit housing compared to means, and that now the proportion of apartments exceeded the majority. This meant that the newly supplied apartments were not affordable to young families and that the increased multi-unit housing accommodated mainly the youth in their 20s.

**Table 1-18** Districts of LR14: *University & IT town*

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
LR14:	신촌동
6Ds	구로3동 영등포동 상도1동 낙성대동 신림동

#### LR15: *Development of APT for family & kids*

These districts showed the steepest population growth region and populations of all ages were increased. In particular, the population increases in children and

their parent generation were remarkable compared to those of Seoul and all low-rise residential districts so that the proportion of children population was the highest. Although not only the number of households but also the number of one-person households increased significantly, these districts were family-oriented residential places where the proportion of one-person households was very low. In terms of housing stock, the occupation rates of both apartments and multi-unit housing were significantly increased while the increase in apartments were more dominant which was similar in LR6 and LR14. However, these districts were characterized by the proportion of detached houses being the lowest among major types of houses and they were low-rise residential districts with the highest proportion of apartments even as of 2000. Thus, these districts were considered as a region where the characteristics of low-rise residential districts were lost, but the change into apartment-dominant residential areas was already underway. The land conditions of LR15 and organizational urban characteristics were similar to those of LR7, in which all districts except for Imun-dong were located in the outskirt of the city in a slope land including mountains so that only some of them were developed as the low-rise residential districts (Table 1-19).

**Table 1-19** Districts of LR15: Development of APT for family & kids

Cluster	Districts in the area north of the Han River (Total 154 Ds)
	Districts in the area south of the Han River (Total 120 Ds)
LR15:	이문2동
6Ds	화곡3동 개봉2동 오류2동 성현동 양재1동

## 4. Discussion

The results of this study show that existing residential areas in particular low-rise residential districts experienced more dynamic changes than apartment-dominant residential areas. This implies that the low-rise residential districts were targeted for the internal urban structure change that raised the density of existing towns to accommodate the housing demand changes in Seoul since 2000.

The internal urban structure change of low-rise residential districts in Seoul occurred in three types, where the range of changes in population-housing was noticeable. The first type was the gradual re-construction at the individual parcel level in previously developed residential areas, thereby increasing the density of dwelling unit in towns significantly. Mainly, it absorbed the housing demand of one- or two-person households, and the relative increase of the elderly and the youth occurred exclusively or simultaneously according to the location within Seoul. The second type was to re-development existing deteriorated residential areas into large-scale apartment complexes. Mostly, mid-to-large homes were supplied so that the building density was considerably increased rather than the density of dwelling unit, resulting in more family-oriented residential areas. The third case was to have the development of block level as well as gradual re-construction in existing houses in the low-rise residential districts including underdeveloped areas. Thus, the density of dwelling unit and the building density were increased simultaneously, and various living arrangements were accommodated.

The characteristics of demography-housing change in the low-rise residential

districts in Seoul, which were verified in the analysis results, should be discussed regarding the following issues: dynamics of the change, its influencing factors, urban structural outcomes and social implications.

### **Dynamics in low-rise residential districts: uneven internal change**

The internal densification in terms of the population-housing viewpoint did not occur actively in all low-rise residential districts, and a significant variation among low-rise residential districts exists in terms of the direction and intensity. It is true that there was a remarkable change in population structure and physical housing environment in a considerable number of low-rise residential districts. However, more than half of the low-rise residential districts in Seoul had a insignificant population fluctuation, or showed a slight reduction in population, as well as new housing supply was also limited, resulting in them remaining as stagnant residential areas. In some districts, noticeable physical and social declines, rather than internal changes that raised the density, occurred.

The direction of change in the population-housing was also not represented by a single trend. The increase or decrease in population and housing stock were relatively in the same direction, naturally. However, the level of housing increase compared to population increase exhibited a significant difference between even low-rise residential districts where the internal change was revealed noticeably. Among districts with a significant increase in housing stock, some districts had a considerable increase in resident population, while a comparable number of districts showed a minimal increase.

Another characteristic that showed the dynamic of the low-rise residential

districts was that the contribution differed by housing type even between districts similar in terms of housing stock increase. It is the common phenomenon that the dominant housing type was replaced from the low-density detached house into high-density apartments, thereby supplying a large of new housing. However, the supply of multi-unit housing, which was a re-construction at the parcel level, and the supply of apartments, which was a re-development at the block level, produced very different outcomes in not only urban morphology but also home affordability, dwelling unit size, and lifestyle. Thus, the housing type of newly supplied houses was linked with another dynamics in terms of household characteristics and changes in the age structure behind the population increase.

These distinctive and diverse patterns of population-housing change categories tended to be revealed intensively in some low-rise residential districts. This proved that policies and regulations related to low-rise residential areas, which were intended to be applied universally, resulted in spatially uneven effects. Thus, the internal densification of urban structure in Seoul produced the dynamics of the low-rise residential districts in terms of the spatial distribution as well as the level and characteristics.

#### **Potential factors causing dynamics in low-rise residential districts**

In addition, the low-rise residential district groups that were characterized by their own distinctive features in the population-housing change also showed a considerable differentiation in conditions such as urban location, public transportation access, morphological characteristics, and existing housing stock characteristics. The large increase in houses or significant change in housing-type

composition exhibited that the existing spatial conditions, such as urbanization area rate, conditions of land lots and abutting roads, and existing housing stock types, were different from the average levels in many cases. Moreover, the remarkable changes in demographic characteristics of residents were closely related to the supplied housing type primarily, but they also had a clear difference in locational characteristics of the residential area such as accessibility to public transportation, and proximity to universities or IT complexes. This spatial dynamics of the changes in the low-rise residential districts implies that the general de-regulation to expand house supplies in the low-rise residential districts resulted in actual house supply at a very different level according to the circumstances of each residential neighborhood. It also indicates that there were factors that determined a change trajectory in the low-rise residential districts other than buildings and house-related regulations. However, the quantitative verification on this causal relationship was out of the study scope, and it will be dealt with in future work.

### **Spatial differentiation of residential areas by demographic characteristics**

The relationship between changes in residents' age structure and household characteristics and changes in housing type composition showed that the changes in the low-rise residential districts in Seoul were revealed in the direction of spatial differentiation according to the demographic characteristics. This spatial differentiation occurred along with the change in housing type and morphology. The increase in construction of apartments concentrated family-household residential areas, while the increase in construction of multi-unit housing



somehow concentrated one-person household residential areas spatially. On the contrary, some low-rise residential districts where various types of housing were supplied mostly maintained a balanced population composition. This implies that the embracing residential circumstances of low-rise residential districts that provided various-sized affordable homes were weakened by the biased housing supplies.

Particularly, the increase or decrease in child population is an index that clearly reveals the residential differentiation according to the life-course. The child population in low-rise residential districts was significantly reduced on average compared to that of apartment-oriented districts. However, some low-rise residential districts where apartments were supplied at a large scale had a very low decline rate in child population, or actually showed an increasing rate. On the other hand, some low-rise residential districts where detached houses were proportionally higher due to inactive house supply or multi-unit housing-oriented supply, showed rapidly reduced child population. This meant that the low-rise residential districts did not maintain a residential environment suitable to raise children.

Preferred location within cities and housing type would differ according to age, living arrangement, and characteristics of family members. Thus, the occurrence of spatial differentiation of residential area by demographic characteristics of residents is regarded as part of the urban evolution process. However, it is necessary to observe carefully which residents were concentrated in relatively poor residential environments. Among the spatial differentiation of low-rise

residential districts, a fixation process where low-income elderly households were densely populated in specific districts where aging detached houses were densely located (Lee et al., 2015) can be one example. The rapidly aging districts verified in this study included such problematic residential areas.

It is also difficult to see a residential area where one-person households were intensively increased as a healthy residential area in the long term. The acceptance of rapid increase in one-person households by the low-rise residential districts to some extent proved the adaptability of those districts. However, more or less spatially concentrated results of housing supply for one-person households may be a serious risk factor in such neighborhoods, depending on changes in the future housing demand (You & Kim, 2015). In other words, the change in housing stock in the low-rise residential districts during the recent 20 years is viewed as increasingly weakening the adaptability and sustainability for the future.

### **Re-urbanization and gentrification in low-rise residential districts**

It was not clear whether the change in the low-rise residential districts as a process of increasing the land-use intensity was in a one-sided direction between re-urbanization and gentrification. Assuming that the residents' age structure could be substituted partly for the purchasing power or payment ability of housing cost, it may be interpreted that both of re-urbanization and gentrification occurred in the low-rise residential districts in Seoul.

The neighborhoods with a significant influx of one-person households and youth population among the low-rise residential districts where new houses were

heavily supplied did not show a big economic difference between previous and new residents, and thus they could be seen as part of re-urbanization that accommodated the newly increasing housing demand. On the other hand, the neighborhoods with a considerable drop in child and youth populations while multi-person households increased were likely to experience gentrification. The former was related to the supply of multi-unit housing, while the latter was linked with the apartment-oriented housing supply. This interpretation is difficult to prove because data such as housing prices or rents were not available in the spatial unit of this study. Thus, it requires additional research such as sample survey.

It is true that the low-rise residential districts in Seoul contributed to accommodating the pressure due to the change in housing demand. However, it may not be concluded that the re-urbanization in the low-rise residential districts strengthened the housing stability by lessening the burden of housing cost or maintaining affordability at least. Although the housing stock in Seoul has significantly increased mainly in the low-rise residential districts, the home ownership rate did not improve at all, and a proportion of the deposit-base rent, which was a tenure type with more stable and less housing cost burden in South Korea, declined steadily. Thus, the internal densification in the low-rise residential districts required more in-depth clarification in terms of whether it played which role in terms of housing welfare in Seoul.

#### **Implication and further study**

The general regulatory approach to the low-rise residential districts, which was

difficult to regard as a particular pattern from the policy viewpoint, is likely to be effective again only in some specific low-rise residential districts. In the worst case, it may cause undesirable developments in the unexpected direction in sites with different conditions from the intended policy target. Thus, it is necessary for the low-rise residential districts to have a planning approach whereby site-specific solutions are applied only to the specific neighborhood.

More detailed empirical studies may be needed to accommodate such a planned approach that limits the private property right somewhat unequally in the low-rise residential districts. As discussed in this study, existing conditions of each low-rise residential district affected the trajectory of changes differently afterward. It is necessary to verify how various spatial and social circumstances such as property location, urban morphology, existing housing types and aging level, existing population composition, as well as housing price and rent and economic level of residents in the low-rise residential districts have effects on the change in the future.

# Chapter 2

## Revealing the mechanism of urban morphology affecting residential energy efficiency in Seoul

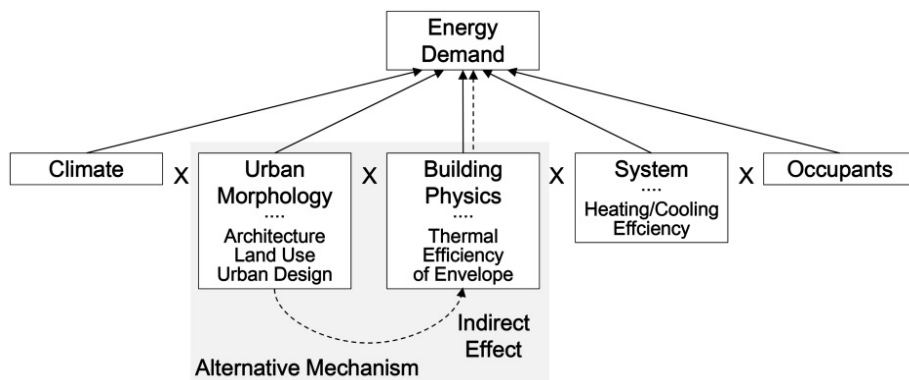
### 1. Introduction

The rapidly growing energy use in many cities around the world has raised substantial concerns over limited supply capacity, heavy air pollution, and climate change. Previous studies identified that the amount of energy consumption in buildings has been increasing rapidly compared to other sectors like industry and transportation (Steemers, 2003; Ratti et al., 2005; Ewing & Rong, 2008; UN Habitat, 2008; Kaza, 2010). Among many types of buildings, the contribution of residential buildings towards total energy consumption has been steadily increasing. For instance, residential energy use occupies about 27.5% of global energy consumption (UN Habitat, 2008) ; this ratio varies by regions, such as 40.7% in London, 30% in New York, 53.8%<sup>3</sup> in Seoul, and 31.9% in Tokyo (DBEIS, 2016; EIA, 2015; SMG 2015; TMG, 2016). Therefore, the residential sector is increasingly viewed as a priority sector in urban planning to reduce energy consumption and to improve efficiency.

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<sup>3</sup> The combined energy consumption in domestic and commercial sector

Many relevant studies have commonly pointed towards climate conditions, urban and architectural morphological attributes, the passive behavior of the building envelop, heating/cooling system efficiency, and occupants' energy use behavior as main factors influencing energy demand (Figure 2-1). Among these factors, many studies attempted to quantitatively reveal the role of the building and urban environmental aspects, such as density, building orientation, dominant housing type, the shape of a building (Steemers, 2003; Holden & Norland, 2005; Ratti et al., 2005; Ewing & Rong, 2008; Okeil, 2010) and vegetation (McPherson & Simpson, 2003; Ko & Radke, 2014; Calcerano & Martimelli, 2016). More recently, the effects of comprehensive urban contexts including the social environments were examined beyond a few physical variables (Deakin et al., 2013, Rode et al., 2014; Chen, Matsuoka & Liang, 2017; Li, Song, & Kaza, 2018).



**Figure 2-1** Factors affecting the energy demand of a building (Ratti et al., 2005; Salat, 2009) and potentially important indirect effects of urban morphology

However, the explanatory power of urban morphology as a singularly influencing factor of residential energy demand still leaves room for further investigation. Especially, the indirect mechanism of urban morphology through other energy demand factors remains underexplored, while many studies often

assumed that the five factors independently influence on energy demand (Figure 2-1). In reality, the energy determining factors are correlated with each other (Salat, 2009) and as Ratti et al. (2005) pointed out, a number of indirect but influential mechanisms of urban morphology variables combined with occupants' behavior, building physics or building systems should not be overlooked. In this respect, previous studies focusing on the independent effects of urban morphology were likely to underestimate their comprehensive effects (Ratti et al., 2005; Silva et al., 2017).

Another reason for having to understand the wider role of urban morphology was due to its known effect associated only with the thermal engineering mechanism. Previous literature largely contributed to revealing how the characteristics of buildings and their outdoor environment—such as spacing between houses, road widths and building height, surface-to-volume ratio, building depth and vegetation—caused differences in microclimatic conditions, solar gain and heat loss, which in turn affected the energy needs for air-conditioning and lighting (Steemers, 2003; Ratti et al., 2005; Ewing & Rong, 2008; Okeil, 2010; Rode et al., 2014; Ko & Radke, 2014; Calcerano & Martimelli, 2016; Chen, Matsuoka & Liang, 2017; Li, Song & Kaza, 2018). Here, urban morphology was narrowly defined in terms of physical attributes only. Meanwhile, the non-physical mechanism of urban morphology often remains unexplored. For instance, the specifics of land-use and architecture—including detailed building use, age and the history of renovation, extension, and conversion—can serve as important variables in explaining the differences in energy demand.

Furthermore, some simulation studies were conducted as a high-resolution approach, but they often covered a small number of urban blocks, while dealing with a few simplified variables instead of reflecting the complex urban contexts (Steemers, 2003; Ratti et al., 2005; Rode et al., 2014; Calcerano & Martinelli, 2016). On the other hand, empirical studies encompassing individual building characteristics were scarcely attempted due to the difficulties of securing reliable data (Swan & Ugursal, 2009; Min et al., 2010; Ko, 2013). Because most of the empirical studies used spatially aggregated data into units ranging from the zip-code level to the city-level (Kahn, 2000; Ewing & Rong, 2008; Kaza, 2010; Min et al., 2010), the results were also limited in deriving applicable planning policies at a building or a block scale.

Against such background, this research aimed to identify alternative mechanisms of urban morphology affecting the building-level energy demand at an urban scale. Especially, this study focused on the indirect effects of urban morphology on energy demands through building physics, as shown in Figure 2-1. The mechanism of urban morphological factor works in a different way depending on the climate condition and the compactness of a city. Thus, the case study of a densely developed residential area in Seoul tried to contribute to expanding the knowledge about heating energy demand due to severe winter cold, rather than other energy demand—lighting and particularly cooling in tropical or arid regions.

Through better understanding how the urban context contributes to the building energy demand, urban planning would be able to provide more concrete solutions



to the building energy issues. Particularly, the empirical verification process which properly reflected the complex context of old towns would lead to a reliable set of evidence for managing existing urban areas. Diverse approaches ranging from direct interventions such as energy efficient refurbishment to urban design measures on an urban block level can be effectively targeted. This attempt focusing on exiting urban areas would be associated with more sustainable strategies for cities under the situation requiring the smart shrinkage than the growth or expansion. Furthermore, identifying the spatial distributions of low-efficiency housing is also related to addressing significant social and welfare issues such as empty homes and fuel poverty, in which urban planning should actively engage.

## **2. Hypotheses and Research Questions**

The scopes of urban morphology with regard to energy, occasionally incorporating building physics or building design, varied among relevant literatures. For instance, Baker & Steemers (2003) involved “plan, section, orientation and façade design” as part of building design parameters affecting the energy use of different buildings by a factor of 2.5. Ratti et al. (2005) followed the framework of Baker & Steemers (2003), while surface-to-volume ratio and “passive zone” were defined as the main parameters of urban morphology in their study. Salat (2009) also differentiated the building factor as the thermal performance of building envelope from the morphology factor. In addition, Anderson et al. (2015) categorized all of the orientation, shape, compactness, shading and passive condition of a building as architectural design features. On the other hand, several studies understood building parameters such as the size, type and age of a residential building as the socioeconomic aspects of the built environments (Santin et al., 2009; Min et al. 2010; Brounen et al., 2012; Estiri, 2015). Unlike these previous studies examining the direct effects of urban or building variables on energy use, this paper attempts to identify the indirect role of urban morphology via building physics. Here, two factors were defined as follows.

Building physics was defined as the thermal efficiency of building exterior which incorporated the material, the level of insulation and air-tightness of building envelopes and then directly determined the heating energy load of a residential building. The thermal efficiency in the study was evaluated based on

the degree of heat leakage during extreme cold weathers. The measure was adopted from the non-invasive investigation method of infrared thermography (Appendix 2-A).

On the other hand, the study defined urban morphology as architectural characteristics, land-use, and the urban spatial conditions of a given parcel. Here, the architectural attributes included the built year, construction method and details, design and maintenance features of a residential building, which were expected to directly determine building physics (Healy & Clinch, 2004; Choi et al., 2004; Salat, 2009; Kim et al., 2013; Hwang et al., 2015; Aksoezen et al., 2015). Thus the physical form variables such as the surface-to-volume ratio or building depth affecting heating demand irrespective of the thermal efficiency of building envelopes were not included.

The second urban morphological factor of land use captured the spatio-economic dimension of the property. In previous studies, land use variables such as floor area ratio (FAR) or housing types were often regarded as physical parameters examining the thermodynamic effects or were interpreted with occupants' characteristics and their energy consumption behavior (Steemers, 2003; Ewing & Rong, 2008; Kelly, 2011; Rode et al., 2013). In this study, land use was understood as the mode of utilizing land by landowners in order to maximize the rent (Alonso, 1964) under certain urban spatial conditions. The building use, FAR, and ownership type were incorporated into land use variables, which were supposed to affect decisions on the construction, design and maintenance of a building via cost and revenue, and to accelerate or decelerate

the process of thermal deterioration.

The urban spatial factor encompassed the locational conditions and urban design features of a building site. Differences in accessibility to public transport and amenities, and features of a block like subdivision and alleys are understood to determine the usability of the property in relevant studies (Moudon, 1986; Charles, 2013; Kokubun & Hato, 2013; Kwon et al. 2014; Won et al. 2015). Such urban variables could allow verifying the role of the urban spatial factor reflecting the actual urban context of a neighborhood.

According to the definitions of building physic and three factors of urban morphology and the potential relations among them, the research tried to reveal the indirect role of morphology influencing energy demand. The following hypotheses were proposed.

- **Three dimensional characteristics of morphological factors – architectural, land-use, and urban spatial characteristics – directly explain the difference in the thermal efficiency of individual buildings.**
- **Land-use characteristics indirectly affect the thermal efficiency of individual buildings via specific architectural elements.**
- **Urban spatial attributes indirectly affect the thermal efficiency of individual buildings via land-use characteristics and architectural elements.**

Figure 2-2 conceptualizes the relationships embedded within the hypotheses. In the paper, the significance of the specified relationships was empirically tested with a unique dataset created through surveying individual residential buildings from a typical low-rise residential area in Seoul, which has undergone a long-

term transformation in its urban grain and land use.

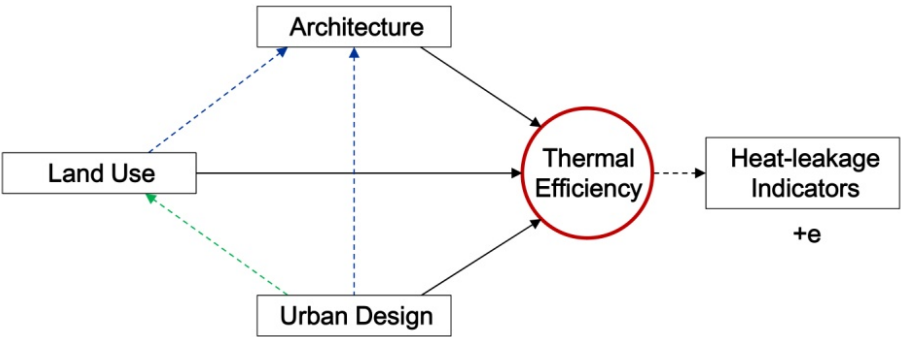


Figure 2-2 Key frame of research

### **3. Research Methods**

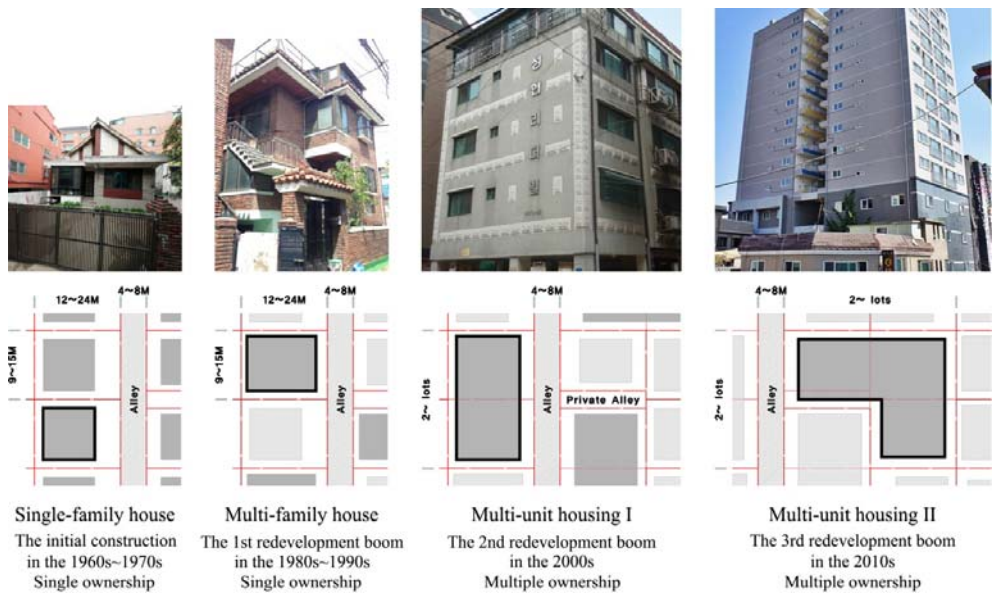
#### **3.1. Analytical models**

A full structural equation model (SEM) was selected to reveal the multiple paths through which three categories of morphological variables influence the thermal efficiency of residential buildings as shown in Figure 2-2. The method is an analytical tool capturing the causal relationships among multiple variables by estimating both direct and indirect effects (Kelly, 2011). Although many empirical studies focusing on residential energy issues have used a regression model as a statistical analysis tool to verify the independent effects of explanatory variables (Ewing & Rong, 2008; Kaza, 2010; Min et al., 2010; Kavousian et al., 2013), identifying the complex mechanism involving direct and indirect paths cannot be achieved through regression analysis alone (Kelly, 2011). Some recent studies (Estiri, 2015; Belaïd, 2017) proved the usefulness of SEM as a statistical tool to reveal the complex mechanism of residential energy demand.

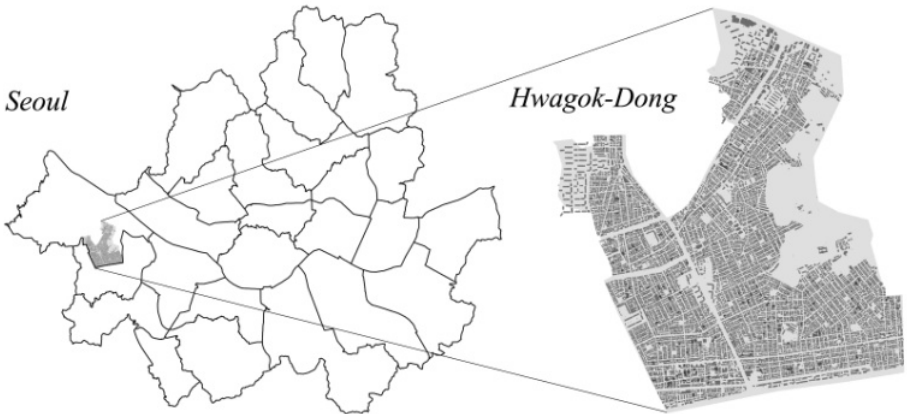
#### **3.2. Study area**

Low-rise residential districts (LRDs) in Seoul, South Korea are mostly comprised of densely clustered houses with one to five floors, accommodating nearly half of total households in the city. LRDs in Seoul were developed during the rapid expansion period of the city since the 1940s and were originally planned for single-family detached houses. However, due to the nation-wide housing shortage in the late twentieth century, LRDs have experienced multiple redevelopment booms (Figure 2-3), by which the initial small detached houses have been gradually replaced by various housing types with a higher density.

Additionally, spontaneous formation of commercial streets and markets has led to the changes in the building use. As a result, the neighborhoods in LRDs transformed from a homogeneous appearance to the current mixture of various land use patterns and architectural types.



**Figure 2-3** Typical housing types of Seoul LRDs in each redevelopment boom period



**Figure 2-4** Location of the study area, Hwagok-Dong and its urban fabric

The study area is *Hwagok-Dong* shown in Figure 2-4. The area is a typical LRD in the southwest of Seoul, featuring a relatively old residential area with small parcels and a grid-iron layout with narrow alleys. The neighborhood was fully developed in the late 1960s and has maintained its initial urban structure overall, but various changes at a parcel level have accumulated over the last 50 years. As a result, about 15% of the initial buildings, mostly single-family detached houses, remained while the rest were demolished and rebuilt afterwards. Thus, various building types and land uses were found in the study area as shown in Table 2-1.

**Table 2-1** Building types and uses in the study area

Building Types	Residential				Non-residential	Total
	Apart- ment	Multi-unit	Multi- family	Single-family		
N. of Buildings	398	4,770	2,722	3,378	1,541	12,809
(N. of shop-house)	(95)	(581)	(376)	(641)		

### 3.3. Sampling and data collection

In order to effectively collect data on individual buildings at a city scale, this study used the stratified sampling method, which is a survey design that allows better representing a large-size population with a relatively small-sized sample (Scheaffer et al., 2006; Thompson, 2012).

According to the 2015 census, *Hwagok-Dong* was a highly-dense residential neighborhood with an area of 5.6 km<sup>2</sup>, 80,800 households, and an approximate population of 201,800 (Statistics Korea, 2015). A total of 10,672 residential buildings existed within the area (Figure 2-5) after excluding all buildings in



commercial zones and high-rise apartment complexes with the different land use patterns and morphological characteristics.



**Figure 2-5** Distribution of samples in the study area

Based on the stratified sampling theory, the targeted residential buildings in the study area were sorted into five strata by construction years and then randomly sampled within each stratum. The division of strata was determined depending on the time frame of the revision for the Korean residential insulation standards. For instance, the buildings in each stratum were constructed under the same insulation

standards and were expected to have similar thermal efficiency. The sampling probability for each stratum was shown in Table 2-2<sup>4</sup>. As considering the number of variables and parameters in the analytical models, 400 buildings were sampled for data collection (Wolf et al., 2013; Byrne, 2013). Finally, a total of 360 residential buildings were analyzed after excluding outliers and samples with missing data.

**Table 2-2** Numbers of samples and populations by stratum

Strata (construction year)	S1 (1967~1980)	S2 (1981~1988)	S3 (1989~2000)	S4 (2001~2010)	S5 (2011~2015)	Total
N. of Population	1,241	1,410	4,714	2,579	728	10,672
N. of Samples	76	89	96	69	30	360

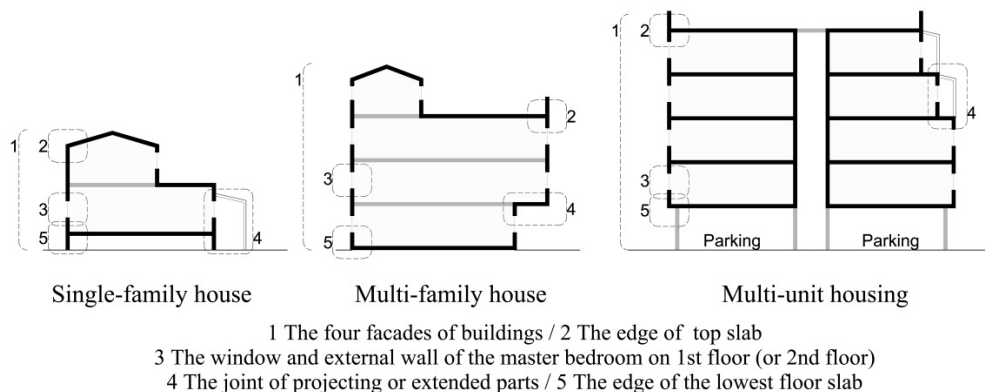
The dataset of the samples was collected by individual buildings and consisted of the following three categories: 1) infrared images of each building, 2) information related to architectural attributes and land use, and 3) the urban design conditions of the building site. The data were obtained from the official documents, Seoul GIS data and supplementary field surveys (Table 2-3).

**Table 2-3** Data Sources and Collected Information

Infrared survey (2016)	infrared image / thermal information
Register of building (2015)	approval date / structure type / floor area ratio / floor area by use / ownership type
Seoul GIS (2015)	distance to a substation and an arterial road / number & width of roads faced to a building / land lot size / block design / height of adjacent buildings
Field survey (2016)	window frame type / outer-wall type / extension / repair / location of markets and commercial streets / slope of site

<sup>4</sup> S1 & S2 were expected to have low thermal performance, but occupied a small portion of the population. To collect sufficient samples from the old buildings, the unequal probability sampling method was applied. Such over or under-representation of each stratum was corrected through adopting the sample weight in the analysis.

The infrared images quantitatively represented the degree of heat leakage observed from the outside of a building (Dall'O et al., 2013). Using the infrared thermography method, the thermal performance of building envelopes for a large number of samples could be investigated in a relatively short period of time. The infrared survey was implemented and interpreted following the relevant Korean standard (KS F2829:2005, 2010), which corresponds to the international standards (ISO 6781, EN 13187). The related theory and application were described in Appendix A. The infrared imaging was carried out with *Fluke Ti95* and *Flir T420* infrared cameras in January and February of 2016 when the temperature fell below  $-5^{\circ}\text{C}$ , over 8 days from 9pm to 2am<sup>5</sup>. The thermal images were taken according to the guidelines described in Figure 2-6. Analytical software, *Smart View* and *FLIR ResearchIR* were used to read the thermal information from the infrared images.



**Figure 2-6** Guidelines for taking infrared images of various building types

<sup>5</sup> These infrared survey conditions were set to avoid the influence of solar heat accumulated on the outer wall during day time and to capture the heat-leakage after enough heating.

### 3.4. Variables

A total of 27 variables were scaled following the definitions explained in Table 2-4. The dependent variable was  $T_{ef}$ , indicating the thermal efficiency of a residential building.  $T_{ef}$  was not an observed variable but the latent variable measured by six heat-leakage indicators. The six indicators were calculated from the infrared image analysis. Twenty of the variables were explanatory variables and were directly collected or observed.

**Table 2-4** Definitions of variables and descriptive statistics

Variables		Mean (S.E.)
<b>Dependent variable (Latent variable)</b>		
$T_{ef}$	Thermal efficiency of a residential building Degree of heat leakage   min.(good) ~ max.(bad) = -2~1.275	0.001 (0.566)
<b>Indicators</b>	$T_o$ : the outside air temperature, $T_i$ : the inside air temperature $T_{os}$ : the surface temperature of a building's envelope $F_w$ : wind correction factor, $T_h$ : height correction value ( $T_{os}$ of $TW$ - $T_{os}$ of adjacent wall)	
	Insulation performance of the frontage wall $TW = - (T_o - T_{os}) / (T_i - T_o) F_w$ min.(good) ~ max.(bad) = -0.21~0.167 $T_{os}$ = the average surface temperature of the master bedroom	0.004 (0.063)
	Heterogeneity of insulation performance of external wall $WHL = - ((T_o - T_{os\_hottest}) / (T_i - T_o) - (T_o - T_{os\_lowest}) / (T_i - T_o)) / F_w$ min.(homogeneity) ~ max.(heterogeneity) = 0.222 ~ 0.388	0.111 (0.055)
	Insulation performance of the side of top slab $RF = - (T_o - T_{os}) / (T_i - T_o) F_w$   min.(good) ~ max.(bad) = -0.891~0.356 $T_{os}$ = the highest surface temperature of the edge of roof + $T_h$	-0.019 (0.134)
	Insulation performance of window $WIN = - (T_o - T_{os}) / (T_i - T_o) F_w$   min.(good) ~ max.(bad) = -0.299~0.389 $T_{os}$ = the highest surface temperature of the window frame + $T_h$	0.002 (0.100)
	Insulation performance of the lowest floor $BOT = - (T_o - T_{os}) / (T_i - T_o) F_w$   min.(good) ~ max.(bad) = -0.2~0.626 $T_{os}$ = the highest surface temperature of the edge of ground floor + $T_h$	0.178 (0.138)
$HB$	Number of heat bridge problem elements   Joints of outer wall with inner wall and slab, lintel and projecting part 5-point Likert scale   0 ~ 4	1.279 (0.903)
<b>Explanatory Variables</b>		
<b>Architectural Characteristics (<math>As</math>)</b>		
$A_{year}$	Year of building construction min. ~ max. = 1967 ~ 2015	1993.877 (10.615)
$A_{ref}$	Degree of refurbishment No need = 1, window·door·roof outer wall refurbished = 2 window·door·roof refurbished = 3 window·door refurbished = 4, no refurbishment = 5	2.900 (1.579)
$A_{ext}$	Extension of building   no = 0, extension of dwelling space = 1	0.403 (0.491)
$A_{wal}$	Type of outer wall   concrete+outside insulation = 1	1.774 (0.722)

	brick+sandwiched insulation = 2, brick+no insulation = 3	
$A_{win}$	Type of window frame   PVC = 1, aluminum and PVC = 2 aluminum = 3, aluminum and wood = 4, wood = 5	2.396 (1.266)
$A_{exp}$	Presence of exposed structure   no = 0, yes = 1	0.736 (0.440)
$A_{pil}$	Building lifted by pilotis   no = 0, yes = 1	0.300 (0.458)
Land Use Characteristics ( $L_s$ )		
$L_{far}$	Floor area ratio   0 ~ 1	1.773 (0.663)
$L_{com}$	Ratio of non-residential floor area to total floor area   0 ~ 1	0.076 (0.187)
$L_{own}$	Ownership type   multi-ownership = 0, single ownership = 1	0.592 (0.492)
Urban Form Characteristics ( $U_s$ )		
$U_{loc}$	Location in neighborhood residential quarter = 0, commercial street = 1, market area = 2	0.150 (0.361)
$U_{sta}$	Distance to a subway station (m)   min. ~ max. = 100 ~ 1,700	756.787 (353.905)
$U_{rd}$	Distance to an arterial road (m)   min. ~ max. = 100 ~ 1,000	338.340 (209.956)
$U_{wrđ}$	Width of road faced to a building (m)   min. ~ max. = 0 ~ 44	5.127 (3.592)
$U_{nrd}$	Number of roads faced to a building   min. ~ max. = 0 ~ 2	1.225 (0.538)
$U_{lot}$	Land lot area (m <sup>2</sup> )   min. ~ max. = 80.01 ~ 830	202.747 (89.585)
$U_{bl}$	Subdivision type of block 2-row parcels = 0, 3 or 4-row parcels = 1	0.448 (0.497)
$U_{red}$	Disadvantage for redevelopment over 150 m <sup>2</sup> = 0 100~150 m <sup>2</sup> with possibility of plottage = 1 less 100 m <sup>2</sup> with possibility of plottage = 2 isolated parcel of less 100 m <sup>2</sup> = 3	0.558 (0.762)
$U_{lev}$	Difference of level in a lot (m)   min. ~ max. = 0 ~ 10	0.929 (1.327)

$T_{ef}$ , indicating *building physics*, was a unitless, conceptual variable inferred through the confirmatory factor analysis (CFA). Hence, although it was not an absolute index to inform the thermal efficiency by itself, it allowed for relative comparison within the study area. For example, a shop-house (Sample #329, Figure 2-7) built in 1983 had a  $T_{ef}$  value of 0.512, which was in the upper 20% of all residential buildings, showing highly poor insulation performance.



**Figure 2-7** Infrared image of Sample #329

The six indicators showed the substantial insulation performance of each part of a building; the external wall (*TW*), top slab (*TOP*), the lowest floor (*BOT*) and window frame (*WIN*), and the problematic thermal aspects such as the heterogeneous insulation performance of external walls (*WHL*) and the heat bridges (*HB*). These indicators were chosen based on the Korean insulation standards and related researches (Choi et al., 2004; Choi & Son, 2010). The five indicators, except for *HB*, were measured based on the thermal efficiency calculated using the external surface temperature of each part of a building (Appendix 2-A).

Of the building attributes (*As*), outer wall types (*A\_wal*), window types (*A\_win*), exposed structures without insulation (*A\_exp*), and piloti-buildings (*A\_pil*) composed the building envelope and reflected the prevalent construction method and materials, and typical design features of the time that the building was constructed. Thus, the year of construction (*A\_year*) was combined specific features of the envelope as well as represented the aging of a building. However, in a number of old buildings, at least some parts of a building such as windows or doors were replaced. In some cases, the insulation and waterproofing of the building envelope were partly improved. Accordingly, the relationship between the envelope variables and *A\_year* differed depending on building elements. For example, external walls was rarely replaced once housing construction was completed and thus *A\_wal* showed a fairly strong correlation (-0.796) with *A\_year*, while window type (*A\_win*), which was capable of being replaced, showed a moderate correlation (-0.413) with *A\_year* (Appendix 2-B).

Floor area ratio ( $L_{far}$ ) was calculated including the basement floors. This was to consider the intensity of land use rather than the absolute volume of the building. The variable was strongly related to the construction period and other building features within Seoul's urban context (Appendix 2-B). Non-residence ratio ( $L_{com}$ ) captured the commercial land use, which often yields higher rents than a residential use in the study area. Thus, both  $L_{com}$  and  $L_{far}$  implied the degree of potential reinvestment in the property. The ownership structure ( $L_{own}$ ), which was a binary variable, showed whether a residential building was in single-ownership or multiple-ownership (Figure 2-3). In other words,  $L_{own}$  represented the number of stakeholders and the resulting degree of autonomy in land-use change and reinvestment. In the study area, the average of  $L_{own}$  was 0.592, indicating that approximately 40% of the buildings were owned by multiple owners. It was a result of the redevelopment in Seoul LDR which has been accompanied with the change of ownership structure from single-ownership to multiple-ownership and thus the ownership type was combined with the building conditions as FAR did.

Of the urban design variables ( $Us$ ),  $U_{loc}$ ,  $U_{sta}$ , and  $U_{rd}$  were related to the locational conditions within the community layout, such as the proximity to commercial districts and public transits, which were decisive factors in land price and then affected land use and building conditions. Approximately 15% of the residential buildings in the study area were located in the market area or along commercial streets in the community. 60% of residences were within 800 m from a subway station and 300 m from an arterial road.  $U_{wrđ}$ ,  $U_{nrd}$ , and  $U_{bl}$  represented conditions of the roads abutted a building and the block & parcel

design. The descriptive statistics revealed urban design problems embedded in the study area, such as the presence of narrow alleys and inaccessible parcels from a road. Such conditions were often regarded to limit more intense land use.

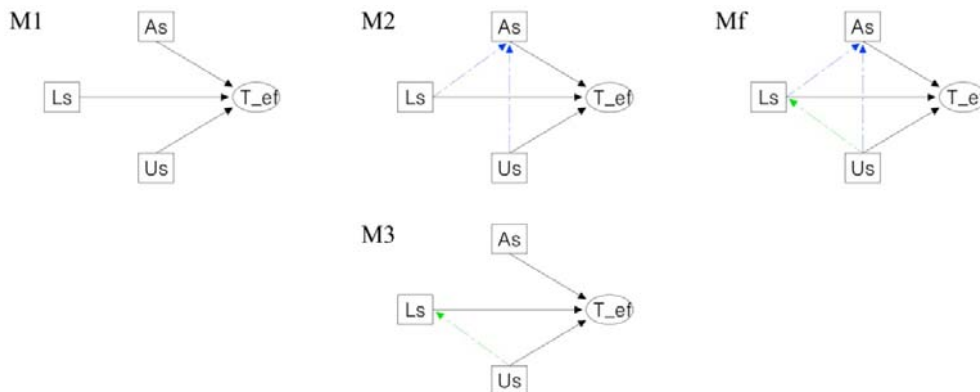
The size of a parcel ( $U_{lot}$ ) was a critical variable that determined the usability of the land property. And yet urban blocks in the study area were subdivided into relatively small parcels, which were not favorable for redevelopments in need of larger land. Therefore, redevelopments usually occurred through merging adjacent land lots. To account for this,  $U_{red}$  reflected the potential feasibility of redevelopment and was evaluated with a 4-point Likert scale as defined in Table 3. For example, a small parcel with a size of less than 100 m<sup>2</sup> was hardly redeveloped without being merged with adjacent parcels. If the adjacent parcels were recently redeveloped, a small, isolated parcel was likely to remain undeveloped for a long time.

### **3.5. Modelling**

The final data set of the stratified samples was analyzed using the following three steps (Figure 2-8). First, a simple structural equation model ( $M1$ ) was applied to examine the direct effects of urban morphological variables only. Second, full structural equation models ( $M2$  &  $M3$ ) were applied to examine all of the potential direct and indirect effects of explanatory variables via architectural variables ( $As$ ) and land use variables ( $Ls$ ). Consequently, both the effects of  $Us$  on  $Ls/As$  and the effects of  $Ls$  on  $As$  were evaluated. The reverse paths were not considered because they would be meaningless due to the chronological order of each phenomenon. Third, the final structural equation



model (*Mf*) compiled all of the significant variables and paths identified in the previous models. The analysis was performed with *Mplus 7.4*, using robust weighted least square (WLSMV) as an estimator for analyzing complex survey data (Muthén & Muthén, 1998-2015). All results were standardized for comparison between the variables regardless of variables' scale of units.



**Figure 2-8** Path diagrams of 4 models

## 4. Results

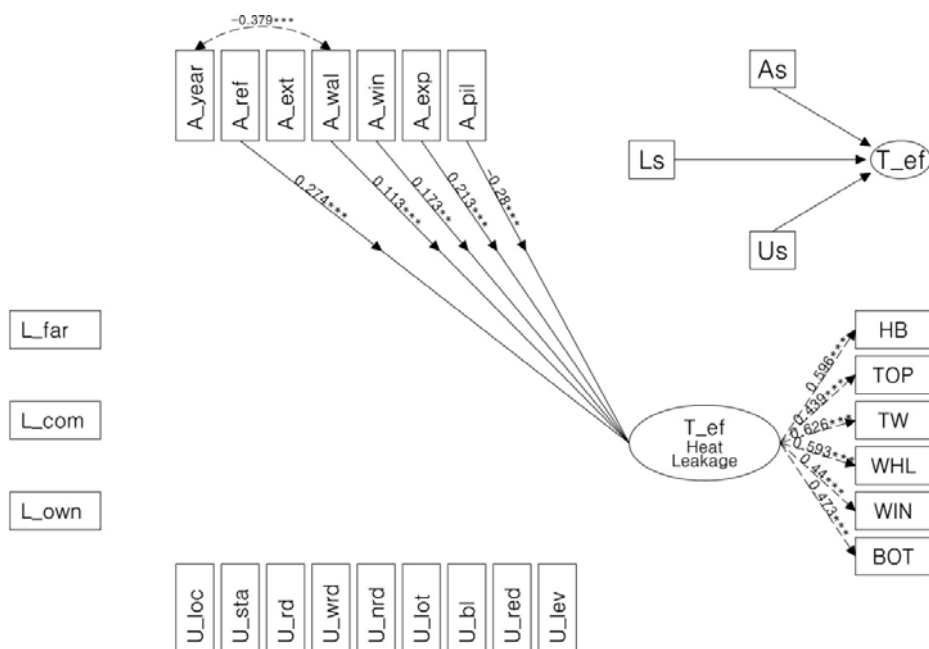
### 4.1. Roles of urban morphology in the mechanism of thermal efficiency

The results of four SEMs showed that the urban design characteristics (*Us*), land use characteristics (*Ls*), and architectural characteristics (*As*) directly and indirectly affected the thermal efficiency of a residential building (Figure 2-9). Fit indices illustrated that the final model (*Mf*) fitted well to the observed data (Hu & Bentler, 1999; Hair et al., 2010) even though indices of intermediate models (*M1*, 2 & 3) did not reach to the acceptable fit thresholds (Figure 2-9). The direct, indirect and total effect estimates of each variable in *Mf* were summarized in Table 5. The results of *Mf* directly supported the study's hypothesis, implying the

significant role of urban morphology affecting the thermal efficiency of housing, whereby urban morphology could indirectly contribute to heating energy demand in a residential building. This indirect path was one of the potential mechanisms in which Ratti et al. (2005) expected to identify as the hidden role of urban morphology.

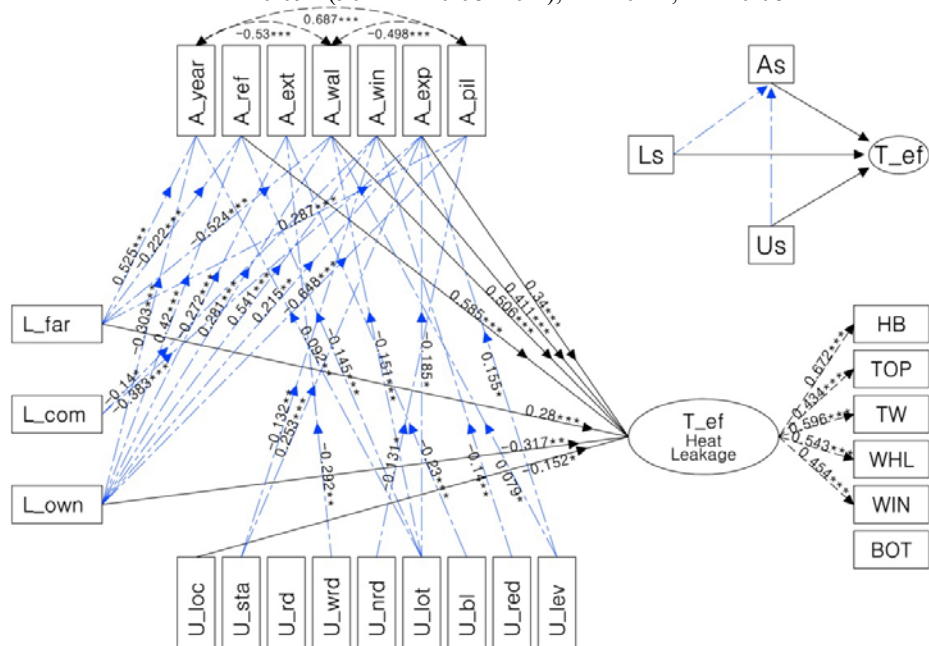
However, three categorical variables played different roles in the mechanism of how urban morphology affected housing thermal efficiency. Architectural attributes directly determined the thermal efficiency ( $T_{ef}$ ) of housing. Apart from the extension variable ( $A_{ext}$ ), all of the architectural variables were statistically significant, and in most of the cases, the absolute value of standardized coefficient was above 0.2 and occasionally above 0.5 (Figure 2-9:  $M1$ , 2, 3 &  $MF$ ). Hence, it was fair to state that the individual architectural characteristics contributed towards meaningful differences in housing thermal efficiency. Except for a few variables, the effects of land-use and urban spatial characteristics on thermal efficiency ( $T_{ef}$ ) through direct paths were not apparent. Rather, the indirect contribution of  $Ls$  and  $Us$  to  $T_{ef}$  was significant (Figure 2-9:  $M2$ ,  $M3$  &  $Mf$ , Table 2-5).

**Figure 2-9** Results of SEMs: the standardized coefficients (\*:  $p < 0.1$ ; \*\*:  $p < 0.05$ ; \*\*\*:  $p < 0.01$ )



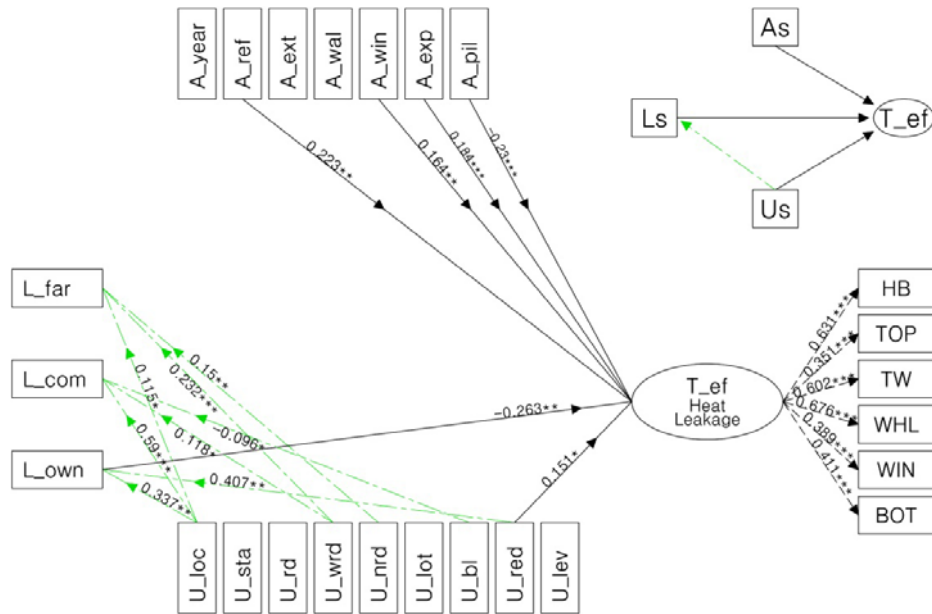
**M1: SEM (dependent variable =  $T_{ef}$ ) without indirect paths**

RMSEA: 0.092 (90% C.I. 0.084~0.1), CFI: 0.22, TLI: 0.08

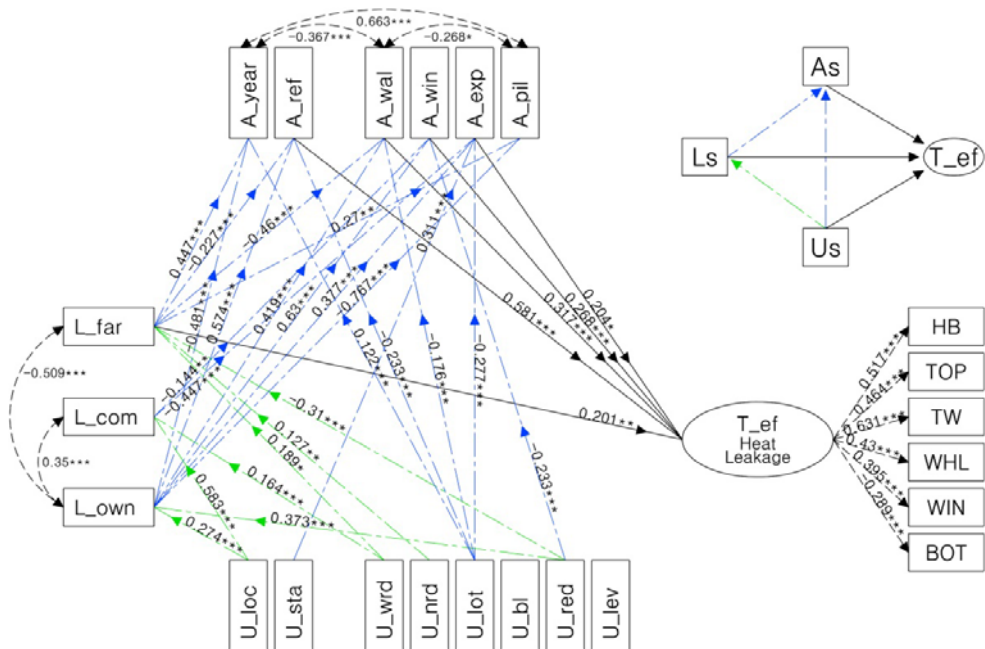


**M2: full SEM (dependent variable =  $T_{ef}$ ) with indirect paths via  $As$**

RMSEA: 0.095 (90% C.I. 0.087~0.104), CFI: 0.632, TLI: 0.294



**M3: full SEM (dependent variable =  $E_{ef}$ ) with indirect paths via  $L_s$**   
 RMSEA: 0.086 (90% C.I. 0.078~0.095), CFI: 0.384, TLI: 0.147



**Mf: full SEM (dependent variable =  $E_{ef}$ ) with indirect paths via  $L_s$  and  $As$**   
 RMSEA: 0.055 (90% C.I. 0.047~0.063), CFI: 0.931, TLI: 0.91

**Table 2-5** WLSMV direct, indirect, and total effect estimates of the final model - *Mf*

<i>U_loc</i>			<i>U_sta</i>		
Direct	Indirect	Total	Direct	Indirect	Total
<i>T_ef</i>	0.046(0.051)	0.046(0.051)		0.042(0.043)	0.042(0.043)
<i>A_year</i>	-0.139(0.048)***	-0.139(0.048)***			
<i>A_ref</i>	0.161(0.047)***	0.161(0.047)***			
<i>A_wal</i>	0.122(0.045)***	0.122(0.045)***			
<i>A_win</i>	0.089(0.048)*	0.089(0.048)*	-0.080(0.060)		-0.080(0.060)
<i>A_exp</i>	-0.157(0.042)***	-0.157(0.042)***	0.311(0.072)***		0.311(0.072)***
<i>A_pil</i>	-0.231(0.070)***				
<i>L_far</i>	-0.017(0.056)	-0.017(0.056)			
<i>L_loc</i>	0.583(0.036)***	0.583(0.036)***			
<i>L_own</i>	0.274(0.071)***	0.274(0.071)***			
<i>U_wrd</i>			<i>U_nrd</i>		
Direct	Indirect	Total	Direct	Indirect	Total
<i>T_ef</i>	-0.054(0.024)**	-0.054(0.024)**		-0.010(0.014)	-0.010(0.014)
<i>A_year</i>	0.084(0.046)*	0.084(0.046)*		0.057(0.030)*	0.057(0.030)*
<i>A_ref</i>	-0.043(0.026)*	-0.043(0.026)*		-0.029(0.018)	-0.029(0.018)
<i>A_wal</i>	-0.087(0.047)*	-0.087(0.047)*		-0.058(0.031)*	-0.058(0.031)*
<i>A_win</i>	-0.024(0.013)*	-0.024(0.013)*			
<i>A_exp</i>	-0.073(0.029)**	-0.073(0.029)**			
<i>A_pil</i>	-0.113(0.112)	-0.066(0.124)	-0.021(0.078)	0.034(0.023)	0.013(0.085)
<i>L_far</i>	0.189(0.099)*	0.189(0.099)*	0.127(0.065)**		0.127(0.065)**
<i>L_loc</i>	0.164(0.060)***	0.164(0.060)***			
<i>L_own</i>					
<i>U_lot</i>			<i>U_red</i>		
Direct	Indirect	Total	Direct	Indirect	Total
<i>T_ef</i>	-0.247(0.069)***	-0.247(0.069)***	0.022(0.083)	0.212(0.066)***	0.234(0.085)***
<i>A_year</i>	0.122(0.043)***	0.122(0.043)***		-0.318(0.049)***	-0.318(0.049)***
<i>A_ref</i>	-0.233(0.049)***	-0.233(0.049)***		0.284(0.050)***	0.284(0.050)***
<i>A_wal</i>	-0.176(0.038)***	-0.176(0.038)***		0.299(0.045)***	0.299(0.045)***
<i>A_win</i>			-0.233(0.074)***	0.235(0.060)***	0.002(0.069)
<i>A_exp</i>	-0.277(0.070)***	-0.277(0.070)***		0.140(0.041)***	0.140(0.041)***
<i>A_pil</i>				-0.370(0.067)***	-0.370(0.067)***
<i>L_far</i>			-0.310(0.060)***		-0.310(0.060)***
<i>L_loc</i>					
<i>L_own</i>			0.373(0.080)***		0.373(0.080)***
<i>U_bl</i>			<i>L_far</i>		
Direct	Indirect	Total	Direct	Indirect	Total
<i>T_ef</i>	0.019(0.014)	0.019(0.014)	0.201(0.096)**	-0.278(0.085)***	-0.077(0.095)
<i>A_year</i>			0.447(0.042)***		0.447(0.042)***
<i>A_ref</i>			-0.227(0.062)***		-0.227(0.062)***
<i>A_wal</i>			-0.460(0.044)***		-0.460(0.044)***
<i>A_win</i>	0.011(0.009)	0.011(0.009)			
<i>A_exp</i>	0.035(0.026)	0.035(0.026)			
<i>A_pil</i>	0.069(0.084)	0.071(0.083)	0.270(0.108)**		0.270(0.108)**
<i>L_far</i>					
<i>L_loc</i>	-0.078(0.055)				
<i>L_own</i>					
<i>L_com</i>			<i>L_own</i>		
Direct	Indirect	Total	Direct	Indirect	Total
<i>T_ef</i>	-0.11(0.101)	-0.240(0.077)***	-0.041(0.205)	0.712(0.126)***	0.671(0.123)***
<i>A_year</i>			-0.481(0.041)***		-0.481(0.041)***
<i>A_ref</i>			-0.574(0.055)***		-0.574(0.055)***
<i>A_wal</i>			0.419(0.042)***		0.419(0.042)***
<i>A_win</i>	-0.144(0.066)**	-0.144(0.066)**	0.630(0.063)***		0.630(0.063)***
<i>A_exp</i>	-0.447(0.075)***	-0.447(0.075)***	0.377(0.078)***		0.377(0.078)***
<i>A_pil</i>	-0.027(0.066)	-0.027(0.066)	-0.767(0.081)***		-0.767(0.081)***
<i>A_year</i>	<i>A_ref</i>	<i>A_wal</i>	<i>A_win</i>	<i>A_exp</i>	<i>A_pil</i>
Direct	Direct	Direct	Direct	Direct	Direct
<i>T_ef</i>	-	0.581(0.112)***	0.268(0.080)***	0.204(0.110)*	-

Note: All estimated effects are in standardized units. Standard errors are in parenthesis. (\*:  $p < 0.1$ ; \*\*:  $p < 0.05$ ; \*\*\*:  $p < 0.01$ )

$L_s$  and  $U_s$  exerted significant influence particularly on architectural variables. Through these paths, the variable eventually affected housing thermal efficiency. The absolute values of the coefficients of  $L_s$  and  $U_s$  having the significant indirect and total effect on  $T_{ef}$  were mostly higher than 0.2 in the final model (Table 2-5). Additionally, urban spatial variables consistently showed influence on land-use variables and the significant coefficients were between 0.096 and 0.59 in absolute value (Figure 2-9:  $M3$  &  $Mf$ , Table 2-5). In conclusion, the urban spatial conditions of parcels brought about differences in land use, and the urban conditions coupled with land-use features influenced the architectural characteristics of buildings which in turn determined their thermal efficiency.

#### **4.2. Direct effect of Architectural Characteristics**

Houses with relatively poor thermal efficiency in the study area were old and had not been properly refurbished afterwards ( $A_{year}$ ,  $A_{ref}$  &  $A_{win}$ ). Although the coefficients of the variable of building age ( $A_{year}$ ) in  $M1$ , 2, 3 &  $Mf$  were not directly estimated due to its correlation with other variables ( $A_{wal}$  &  $A_{pil}$ ), the building age could be interpreted to have negative effect on thermal efficiency<sup>6</sup>. The difference in thermal efficiency between old and new houses might become larger than the natural rate of deterioration by building age due to strengthened housing insulation standards over time and the relatively short redevelopment cycle of the study area at about 20 years.

The degree of refurbishment ( $A_{ref}$ ) was a strongly influential factor

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<sup>6</sup> In analysis excluding  $A_{wal}$  and  $A_{pil}$ , the coefficient of  $A_{age}$  was between 0.272~0.479, and also significant.

explaining differences in the thermal efficiency with the coefficients between 0.213 and 0.581. In the study area,  $A_{ref}$  decreased with the construction year (Appendix 2-B), indicating that efforts toward improving thermal efficiency and extending a building's life span were lacking in the area. Also, because housing maintenance was largely left to the responsibility of the homeowner in low-rise residential districts, systematic improvements were hardly expected. Thus reinvestment after the initial construction, such as refurbishment of the building envelope or renovation accommodating a new building use, differed greatly among individual buildings. For example, sample No.17 was built in as early as 1969, but its  $T_{ef}$  value was within the upper 35% at 0.229. Also, buildings from Strata 1 needed less of refurbishment than those from Strata 2 and they showed slightly higher efficient in terms of thermal performance. Hence, it was clear that a building's thermal efficiency did not necessarily deteriorate proportionately with the building age. Conversely, buildings that were appropriately repaired would be able to maintain good thermal efficiency for a longer period of time (Lee, 2006; Kim & Son, 2010). The window type ( $A_{win}$ ) also contributed to thermal efficiency, but was irrespective of the building age ( $A_{year}$ ) since replacing such building elements was relatively easier (Appendix 2-B).

Other architectural characteristics related to low thermal efficiency included exposed structures without proper finishing or insulation and masonry buildings. Two relevant variables,  $A_{exp}$  and  $A_{wal}$  had coefficients over 0.2 in the models. Exposed slabs, beams, and lintels which caused huge heat loss as shown in Figure 2-10 were commonly found among the detached houses in Strata 1 and 2. This was because the exposed structure was a typical feature derived from the

construction method using concrete and masonry at that time. The type of outer wall ( $A_{wal}$ ) was the most influential architectural variable on housing thermal efficiency. The analysis revealed that the thermal efficiency of the masonry wall with internal or sandwiched and then, intermittent insulation was inferior to the concrete wall with external and continuous insulation. Similar to the problem of exposed structures, the wall type was also closely related to the building construction year since it exemplified the typical construction methods of the time.

Building extension ( $A_{ext}$ ) did not significantly influence thermal efficiency while piloti-type buildings ( $A_{pil}$ ) were excluded in some models due to the high collinearity with other variables. However, these two variables significantly affected the thermal efficiency indicators  $HB$  and  $BOT$  respectively. In other words, while buildings with extension showed entirely satisfactory thermal efficiency, heat loss was still found in the boundary between the extension and the original building. Similar problems were identified in the lower parts of the second floor of piloti buildings that had been built after 2000 (Figure 2-10).



**Figure 2-10** Infrared images (exposed structure / extended part / piloti-building)

#### 4.3. Indirect & direct effects of Land Use

Land-use characteristics acted as critical factors determining architectural



features (Figure 9: *M2* & *Mf*), eventually leading to differences in thermal efficiency among residential buildings as confirmed by the indirect effects of *Ls* in Table 2-5. Among them, an ownership type (*L\_own*) substantially affected all of the architectural attributes with strong significance and then the indirect effect of *L\_own* on *T\_ef* was over 0.7. More specifically, single-ownership buildings were older and their exterior elements were not optimally insulated (*A\_year* & *A\_exp*). This was related to the change in housing supply in recent years, moving from single-family detached houses with single-ownership to multi-unit housings with multiple-ownership. Also, single-ownership buildings were more in need of a refurbishment than multi-ownership buildings as confirmed by the strong effects of *L\_own* on *A\_ref* and *A\_win* with coefficients of over 0.5. Such inadequate refurbishment efforts of single-homeowners would be explained with the potentiality of redevelopment. In study area, old single-family detached houses were usually considered preferential properties for redevelopment even compared against similarly old multi-unit housings with the complex ownership.

On the other hand, in the models of *M2* and *M3*, the direct effect of the ownership structure (*L\_own*) on thermal efficiency occurred in the opposite way from its indirect effect through architectural variables. *L\_own*'s direct coefficients of -0.317 in *M2* and -0.263 in *M3* indicated that if all architectural characteristics were assumed to be same, multi-ownership buildings were more likely to have poor thermal efficiency. In other words, deterioration of the thermal efficiency of multi-units housings was faster than that of single-ownership housing when other conditions were assumed to be similar. This was because single-owned buildings were more carefully managed by the owner, whereas multi-owned housings often

experienced difficulty in making decisions on maintenance among a number of owners.

The FAR,  $L_{far}$ , also explained the building age ( $A_{year}$ ), the level of refurbishment ( $A_{ref}$ ), and the type of outer wall ( $A_{wal}$ ) in  $M2$  &  $Mf$  and thus influenced the thermal efficiency of housing with the indirect effect coefficient of -0.278 (Table 2-5). Due to the repeated redevelopment activities, FAR had been continuously increased in the study area. Therefore, recently redeveloped buildings usually showed higher FAR and at the same time better thermal efficiency due to adoption of tighter insulation standards. Meanwhile, buildings with lower FAR were considered older and built under less strict insulation standards, leading to poorer thermal efficiency. Nonetheless, appropriate refurbishments had not been implemented in these housings. This implied, similar to the ownership variable, that the lower the land-use intensity the higher the expectancy for redevelopment.

However,  $L_{far}$  also directly affected thermal efficiency in the reverse direction to its indirect influence via  $As$  (Figure 2-9:  $M2$  &  $Mf$ ) and thus  $L_{far}$ 's direct effect and indirect effect on  $T_{ef}$  canceled each other out as shown in Table 5. While the indirect estimate of  $L_{far}$  on  $T_{ef}$ , indicating the degree of heat leakage, was negative via  $As$ , the direct estimate of  $L_{far}$  was positive when  $As$  were controlled for. In other words, holding all of the building attributes constant, a building with higher FAR showed lower thermal efficiency. The reason seemed to be that a building with higher FAR generated higher total rent and thus the rent-gap was not sufficient enough to trigger redevelopment, even though the

building has undergone a certain extent of deterioration.

Also, several architectural characteristics were identified to be subordinated to the building use. The ratio of non-residence,  $L_{com}$ , affected the window type ( $A_{win}$ ) with the coefficient of about -0.14 and structure exposure ( $A_{exp}$ ) with the coefficient of about -0.4 in  $M2$  and  $Mf$ . The results demonstrated that when other  $Ls$ , and  $Us$  were kept constant, windows were more thermally efficient in buildings with a higher ratio of non-residence.  $L_{com}$ , together with FAR, represented the amount of potential revenue from the property. Hence, the commercial building use could be assumed to bring adequate profit which led to refurbishment rather than redevelopment. Also, a lower  $L_{com}$  was associated with more exposed structure, meaning that heat bridges were likely to be present. This was because, as mentioned before, the exposed structure was a typical feature of single-family detached houses. Comparatively, shop-houses usually implemented a continuous exterior finishing and insulation.

#### **4.4. Urban Spatial Condition Effect via Architectural & Land Use Characteristics**

The direct effects of urban spatial characteristics ( $Us$ ) on the thermal efficiency of a residential building were limited to a small number of variables and were not found to be consistent. On the other hand, the urban condition effects on the architectural characteristics and land-use were clearly evident (Figure 2-9:  $M3$  &  $Mf$ ) and of those,  $U_{wrđ}$ ,  $U_{lot}$  and  $U_{red}$  were identified to have significant indirect effects on  $T_{ef}$  (Table 2-5). The most influential urban variable, land lot area ( $U_{lot}$ ) was statistically significant for a number of architectural variables

rather than land-use variables, and showed the indirect effect on  $T_{ef}$  via  $As$  with the coefficient of -0.247 (Figure 2-9 & Table 2-5). When land-use and other urban conditions were kept constant, the smaller the land lot area the older the building was with inadequate refurbishment. Furthermore, thermally inefficient wall types were used for buildings on smaller parcels and there was a higher possibility of exposed structure among them. This showed that old, mostly single detached houses in small parcels were left due to the disadvantages of redeveloping parcels below a certain size. In contrast, larger parcels indicated larger housing size and hence higher property values with higher quality housing and maintenance.

Disadvantage for redevelopment ( $U_{red}$ ) showed multiple influential paths on the thermal efficiency of a residential building.  $U_{red}$  explained the architectural and land-use characteristics of the property and then indirectly explained its  $T_{ef}$  with the coefficient of 0.212 (Figure 2-9 & Table 2-5). Also,  $U_{red}$  held substantial influence on  $As$  via  $Ls$  (Table 2-5). Isolated small parcels surrounded by redeveloped properties showed lower FAR and tended to be single-ownership properties. Hence, these were likely to be small-size detached houses which had been built in the initial period of development in the study area. However, the windows of these isolated houses were relatively satisfactory. It could be understood that the homeowners expecting no chance of redevelopment attempted to maintain their houses.

In addition, the urban fabric features ( $U_{wrđ}$  &  $U_{nrđ}$ ) and the location-related condition ( $U_{loc}$ ) caused the differences in land uses between the parcels (Figure 2-9). First, the intensity of land use, FAR ( $L_{far}$ ), was subordinate to the road

conditions adjacent to a parcel ( $U_{wrd}$  &  $U_{nrd}$ ). Parcels abutting on a narrow road or not accessible from roads remained with low FARs. The width of the road ( $U_{wrd}$ ) also explained the ratio of the non-residence ( $L_{com}$ ) in conjunction with the location condition ( $U_{loc}$ ). Parcels which were adjacent to a wider road and situated along the commercial street or within the market area were likely to accommodate more commercial use. Such parcels conducive to commercial land use were more likely to be single-ownership properties ( $L_{own}$ ). This was due to the adequate rent profits and then the relatively high property price, which hindered redevelopment that often converted single-ownership properties into multi-ownership housings. Also  $U_{wrd}$ ,  $U_{nrd}$  &  $U_{loc}$  indirectly affected the architectural features via land-use variables, although the final effects of the urban conditions on  $T_{ef}$  were statistically weak (Table 2-5). The indirect effects of the three urban variables on  $As$  implied that better road conditions were strongly associated with relatively new and well repaired buildings, and wall-types and structures securing better insulation performance via higher FAR and commercial use, or single ownership.

## **5. Discussion and Implications**

This study empirically examined how urban morphology, defined through architectural characteristics, land-use patterns, and urban spatial elements, affected building physics indicating the thermal efficiency of individual housing envelope. Contrary to a usual assumption in prior simulation studies, the results demonstrated that urban morphology and buildings physics were not independent of each other. Furthermore, the role of urban morphology which brought about the difference in building physics was evident in the research, which could be summarized into the following three mechanisms.

### **5.1. Delay of Redevelopment**

The fundamental mechanism whereby urban morphology contributed to the different housing thermal efficiency was that certain urban spatial conditions delayed the redevelopment of old buildings which perpetuated its already low thermal efficiency. In particular, the irrational layout of neighborhood blocks and street networks, and unfavorable parcel conditions could limit higher land-use or simply make it non-profitable. In the study area, urban design conditions which curbed redevelopment of deteriorated houses included bad connection to a road and small size of parcels. Certainly such penalizing mechanism resulted from Seoul's architectural regulations such as building separation for fire safety, building-height restrictions for sunlight or parking regulations. Thus, unfavorable urban conditions for reinvestment would differ according to a city's relevant situation. Nevertheless, it would be common that the inflexible planning approach in terms of building codes and zoning system causes the delay of redevelopment

on parcels with specific conditions through limiting the building usage, size and form. In case of Seoul, such problems are often found particularly in old towns unfitted to current regulations and leading to abandoned property issues.

These disadvantageous urban conditions discouraging redevelopment of deteriorated houses can expand into a larger urban scale in further studies. For example, the uneven provision of public services can be also a factor which prevents reinvestment in certain areas. The demand for space differs depending on the accessibility of basic urban functions including public transportation and community services such as education, commerce and medical services, which then subsequently influences reinvestment decisions that maximize land-use. Moreover, although not considered as variables in this study, site environmental conditions such as topography and geological characteristics, as well as pollution or noise may also hinder redevelopment on a local scale. For instance, steep inclines, rocky terrain or soft soil of landfills can easily increase construction costs. It is also not uncommon to find residential districts next to railroads, motorways, power plants, power transmission facilities, etc. in large Asian cities where land-use is relatively intense. This was inevitable in the past when severe housing shortages were critical. However, such conditions bring about the decline of these areas today under changed housing demands.

For the above-mentioned reasons, substantially deteriorated houses that are likely to receive little private investment should be the target for public intervention. These problematic properties are likely to sporadically appear over time in the existing urban areas, and hence, parcel-level solutions are required

that differ from the approach of large-scale urban renewal projects. Also, more site-specific and flexible design approaches should be allowed to promote higher utilization of parcels not corresponding to standardized regulations (Ben-Joseph, 2005). In a case that hardly encourage the private sector, the public can actively buy these properties and utilize it for public purposes which would induce local vitalization or regeneration. Furthermore, bold policy measures through demolition and migration in advocacy of shrinking cities can be implemented depending on the size, level of severity and agglomeration of these areas that are being left out in the spontaneous reinvestment process.

## **5.2. Lack of Refurbishment**

The low thermal efficiency of old housings left due to unfavorable urban conditions can be meaningfully improved through refurbishment. However, the study area showed such private effort was also reliant on the urban spatial conditions and current land-use. Similar to delaying redevelopments, disadvantageous urban conditions and consequent lower land-use also hindered refurbishments. The immediate cause for such lack of refurbishment might be the inability to pay for such endeavors. This was because of the low land-use and hence low levels of revenue due to the disadvantageous location of the parcel, which implied that profit expected from refurbishment would not be sufficient. The mechanism was compounded with economic and demographic characteristics such as low-income or senior households which could further expand to the problems of fuel poverty (Healy & Clinch, 2004; Meijer et al., 2012).

In the study area, another urban spatial factor which deterred refurbishment of



old housings was, contrastingly, the high potential of redevelopment. Underused parcels with satisfactory conditions had sufficient rent-gap, and hence the strong expectations of higher land-use through redevelopment. This led to the intentional giving up of refurbishment efforts to prolong the lifespan of the current building. The same mechanism can apply for areas that are designated as urban renewal zones, and in the worst case scenario, when redevelopment projects are postponed low thermal efficiency can become a long-term problem. However, the energy efficiency improvement program by the public has often excluded such dwellings from beneficiary.

The non-physical condition that was compounded by urban morphology such as property ownership and tenure type also was revealed to affect the systematic implementation of refurbishment. In the study area, single-ownership rather than multiple-ownership was directly and indirectly associated with lack of refurbishments. In other cities as well as Seoul, housing management and maintenance also differed depending on whether a property was owned by the public or private and had a single-ownership or a multi-ownership structure (Healy & Clinch, 2004; Hills, 2012; Meijer et al., 2012). In addition, the different right to the property management between owner-occupants and tenants could be a reason to hinder necessary measures (Healy & Clinch, 2004). Voluntary refurbishment was also contingent to the specific country's housing management policies. In the case of Korea where most relevant policies are centered on apartment complex housings, effective management of single-detached houses are left outside relevant regulations and thus more difficult to induce. Furthermore, depending on the housing and energy policies, measures to improve thermal

efficiency can be more prevalent in the public sector than the private sector or vice versa.

The physical and non-physical factors behind the lack of voluntary refurbishment implied that policies targeting the improvement of housing thermal efficiency needed to diversify. Selective and direct thermal improvement support programs that rest on the economic status of households only cover a part of the problem. In certain cases, a financial system that induces refurbishment may be a better solution as opposed to offering grants. Furthermore, depending on the situation, it may be necessary to mandate a certain level of thermal efficiency in private rental housing. Moreover, professional consulting that considers the building condition and costs should be publicly provided to maximize the effects of refurbishment.

### **5.3. Thermally Vulnerable Design**

Regarding differences in heat loss, various building design elements were investigated in this paper. For instance, the type of outer walls and windows, and construction methods of structure and finishing were such significant elements. At the same time, however, the thermally critical features appeared to be combined with the characteristics of land use and other spatial conditions. In fact, building form characteristics such as surface-to-volume ratio, building depth, and the size and orientation of windows dealt in previous studies are also not designed independently of surrounding urban morphologies; rather, the urban fabric such as the block and parcel features are conditions that control building forms. Furthermore, pressures from spatial demands such as housing shortages which

determine land-use and subsequent building forms can become priority issues that override problems of energy efficiency. Therefore, the guideline for energy efficient design of building should be elaborated to work together other building design factors within complex urban context. For example, insulation standards, and advices for openings and interior plans can differ depending on various conditions from the shape and orientation of parcels and blocks, and the density of a neighborhood to detailed building uses.

Also, the thermally vulnerable architectural features are not improved with ease particularly in existing urban areas even though the related guidelines and regulations have been developed. Unlike new towns or redevelopment districts, buildings in already developed areas were not built at a time and would be redeveloped following each building's timeline. Thus, buildings in which construction methods and details, and insulation materials with lower thermal performance were applied might last for a long period of time although such buildings do not meet the latest standards. In addition, the building elements with insufficient thermal performance are found not only among old residential buildings; but they can be also found among relatively new houses built under relaxed regulations in the aftermath of wars or rapid urbanization to reduce construction costs (Salat, 2009). It means that houses with lower thermal efficiency would not be necessarily redeveloped earlier. Therefore, the thermally vulnerable features in existing housing stock should be categorically defined and tackled through the elaborated policy design to apply the latest energy efficiency guidelines and regulations to existing buildings as to newly built houses.

Furthermore, preferred design elements depending on the main building use and size can cause variance in thermal efficiency regardless of the building age. The curtain walls of high-rise apartments, the inevitable heating bridges of small masonry houses, and the high ceiling of large suburban houses are design elements that worsen the heating/cooling conditions of a building (Baker & Steemers, 2003). These problems call for a comprehensive qualitative evaluation system as well as stricter thermal efficiency standards for more various design features.

# **Chapter 3**

## **Who lives in and owns cold homes? A case study of fuel poverty in Seoul**

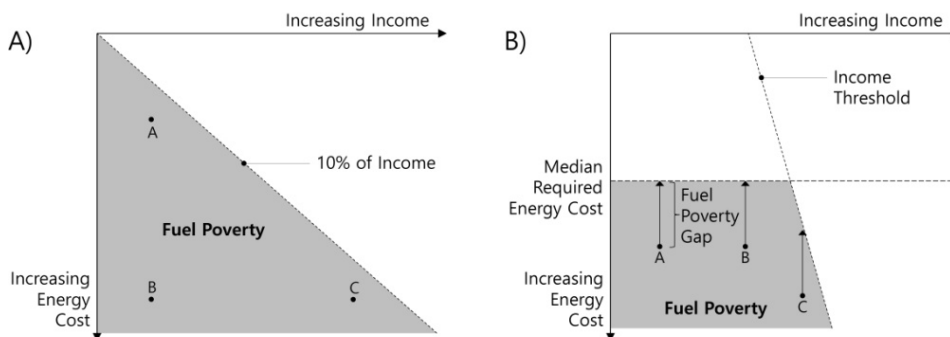
### **1. Introduction**

Fuel poverty has been discussed since the latter half of the last century mainly in developed countries where winter heating is essential. The problems of fuel poverty have often been associated with the issues of energy and household poverty. From an environmental perspective, sustainable energy use was emphasized under the threat of energy shortages and climate changes, whereby strong commitment to reducing energy consumption and CO<sub>2</sub> emissions was highlighted. From a regional perspective, economic inequalities among the residents in developed countries became a controversial issue, which undermine the universal use of energy as a vital condition in our lives such as housing or medical care (Simcock & Mullen, 2016). Against the backdrop, fuel poverty is a complex problem involving both the physical condition of housing and the economic conditions of residents who have limited capability to pay the energy costs (Healy & Clinch, 2002; Healy & Clinch, 2004; Mayer et al., 2014).

Previous studies on fuel poverty often focused on the financial capacity of a household, emphasizing whether the residents can afford to pay the costs of warming their house. Thus, fuel poverty was defined as the inability to pay energy costs required for maintaining the optimum internal temperature in relation to the household income, which is conventionally considered 10% of the total income (Boardman, 1991). However, whether such criterion accurately calculates the degree of fuel poverty is a contentious matter (Healy & Clinch, 2004; Fahmy et al., 2011; Moore, 2012; Liddel et al, 2012; Mayer et al., 2014). This is because the number of households considered fuel poor changes drastically depending on the methods of estimating household income and fuel price. Also, the number of fuel-poor households may be underestimated in cities and regions where living costs like housing rent and transportation fees are considerably higher than energy costs (Mayer et al, 2014). Furthermore, the simplistic measure of comparing heating cost with income fails to recognize the variation in the response of individual households (Brunner et al., 2012; Middlemiss & Gillard, 2015; Chard & Walker, 2016; Mould et al., 2017). The previous criteria of fuel poverty do not distinguish the mid-to-higher income households and lower income households who pay energy cost over 10% of their income (Figure 3-1-(1)). In an effort to improve the targeting of fuel poverty policies, Hills (2012) suggested the *Low Income High Cost (LIHC)* fuel poverty index, which defines the range of fuel poverty according to the level of income and energy cost. This excludes those households with a fairly high income or with a small energy bill (Figure 3-1-(2)). However, *LIHC* measures only the size of the fuel poverty gap. Using the index, the differences in income and energy costs

among different households with the same fuel poverty gap like the cases of *A*, *B*, and *C* in Figure 3-1-(2) cannot be identified. Furthermore, since the method does not reflect on the actual energy use, it is difficult to understand the weight of hardships endured by affected households.

Some relevant studies and investigations introduced various indexes which attempt to refine the predictions of fuel poverty and policy targeting. For instance, many researchers showed that fuel poverty is strongly related to the dwelling, demographic, and socioeconomic attributes (Healy & Clinch, 2002; Healy & Clinch, 2004; Morrison & Shortt, 2008; Hills, 2012; Fahmy et al., 2011; Middlemiss & Gillard, 2015). According to these studies, fuel poverty is apparent in dwellings with inefficient thermal attributes, often occupied by low-income, tenant households without adequate heating and voluntary energy-saving measures. While these variables are often adopted at the policy level, the variables did not explain the whole spectrum of inadequately heated dwellings (Hutchinson et al., 2006). Therefore, actual fuel poverty can be often found among other than the social groups or dwellings that have been conventionally targeted as fuel poverty (Meijer et al., 2012; Brunner et al., 2012).



**Figure 3-1** Previous definitions of fuel poverty  
(1) 10% rule (Boardmans, 1991; Left) and (2) LIHC indicator (Hills, 2012)

Against such backgrounds, this research questioned the relationship between thermal efficiency, energy costs, and tenure type in the urban housing context of Seoul, South Korea, of which fuel poverty had been scarcely dealt in the academic field. The study empirically investigated the actual energy consumption in response to different thermal efficiencies of residential buildings depending on households' tenure types and the dwelling owner responsible for heat efficiency improvements. Based on this, the study tried to explore the dynamics of cold-homes, which were not distinguished by the household's ability to pay fuel costs. This would allow for a deeper understanding of the fuel poverty within the context of Seoul in which residential environments and heating requirements are different from other cities. Also, the results may contribute to refining the solutions to the problem of fuel poverty. In order to do this, the following factors were further investigated in the paper.

### **1.1. Tenure, Ownership and Actual Heating**

Tenure type has been recognized as an important factor in fuel poverty dynamics in previous studies. As a rule, tenure type is largely divided into owner-occupancy and rent, which are respectively subdivided into mortgaged ownership and outright ownership, and public rent and private rent (Healy & Clinch, 2004; Hills, 2012). Here, tenure type is associated with the differences in the manner that a house is maintained but also is indicative of the economic status of a residing household. Within this context, fuel poor are often considered to be the households living in rented housing (Baker et al., 2003; Hutchinson et al., 2006; Morrison & Shortt, 2008; Fahmy et al., 2011). However, the severity of fuel



poverty by tenure type can have different bearings depending on whether the absolute number or the ratios of fuel-poor households are considered. For example, Healy & Clinch (2004) showed that while by ratio, rental households were more vulnerable to fuel poverty. But in terms of the absolute number of fuel-poor households, owner-occupant housings were more severely affected in Ireland. A more recent study from Netherlands (Meijer et al., 2012) revealed that although housings in the rental sector were overall older than owner-occupant housings, 60% of dwellings built before the 1940s were occupied by owners. Therefore, the danger of fuel poverty due to low thermal efficiency could be more apparent among the owner-occupant dwellings.

Furthermore, the rate and number of fuel-poor households and the severity depending on tenure type may differ across countries and regions due to the housing stock, supply, and housing welfare policies. In the above-mentioned research by Healy & Clinch (2004), it was found that fuel poverty rate was higher for those living in public rental housing than in private rental housing. On the contrary, the rate of fuel poverty was relatively low in public rental housing in England since the energy efficiency of social housing was reasonable good despite the low-income level of dwellers in the housing units (Hills, 2012). In the case of Seoul, in which the public rented sector accounts for only 5% of the total housing stock (SH, 2017), the problems of fuel poverty are predominantly found in the private rented sector (The Seoul Institute, 2009). Meijer et al. (2012) also showed that the quality and the degree of aging of owner-occupied stock varied from one city to another according to the variations in housing-related policies. Hence, the characteristics of fuel poverty in regards to tenure type may be a

convoluted matter.

In addition, the fuel poverty discourse insofar only considers the current occupier, while the owner of the dwelling, who is an important stakeholder in the problem of fuel poverty, is overlooked. Fuel poverty policies neglecting the issue of tenure do not incorporate a number of complicated situations. For instance, cumulative investment for improving heat efficiency in a house does enable a better living environment and reduces potential heating costs. But the effect of improvement is physically fixed to the dwelling unit. Therefore, a temporary occupant living in rent housing is not likely to heavily invest in energy-saving measures. Also, the fuel poor household who received thermal improvement supports may become vulnerable again when they decide to move to a different dwelling, and the benefits may be retained by a next tenant who is not eligible for such support due to higher income (Hills, 2012; KIHASA, 2016). Additionally, in countries like South Korea, tenants occasionally hesitate to apply for the thermal improvement support program due to the concern that such supports may lead to the rise in rent after the lease term (KIHASA, 2016). These only come to show the deficient delivery of fuel poverty support based on the economic status of residents.

Last, the amount of actual heating energy consumption is an overlooked index in many studies evaluating fuel poverty. Current fuel poverty is often identified based on the required energy cost for properly heating a house, not the amount of actually consumed energy. However, the required cost is not always payable by

the residents, even though the cost is smaller than the fuel-poverty threshold<sup>7</sup>. And at times, it may not be the most rational expenditure even for households that are able to pay the extremely high fuel costs due to the inefficient physical condition of dwellings, such as residences with large windows or envelope in a high-rise tower or large suburban houses. Therefore, there are not a few household tolerating insufficient heating in thermally inefficient dwellings despite not being a fuel poor in terms of income standards. This means that the definition of fuel poverty based on estimated cost does not always capture all the sparingly heated houses. In practice, there is the substantial gap between theoretical energy demand and actual consumption and low energy-efficient dwellings consume less than predicted energy whereas decent houses use more than estimated (Majcen et al., 2013a; Visscher et al., 2016). Also, even within the fuel-poor groups, the actual severity of cold home may not be assessed only with estimated energy cost. Hence, actual heating energy consumption should be taken into account to properly measure the hardship of underheated homes.

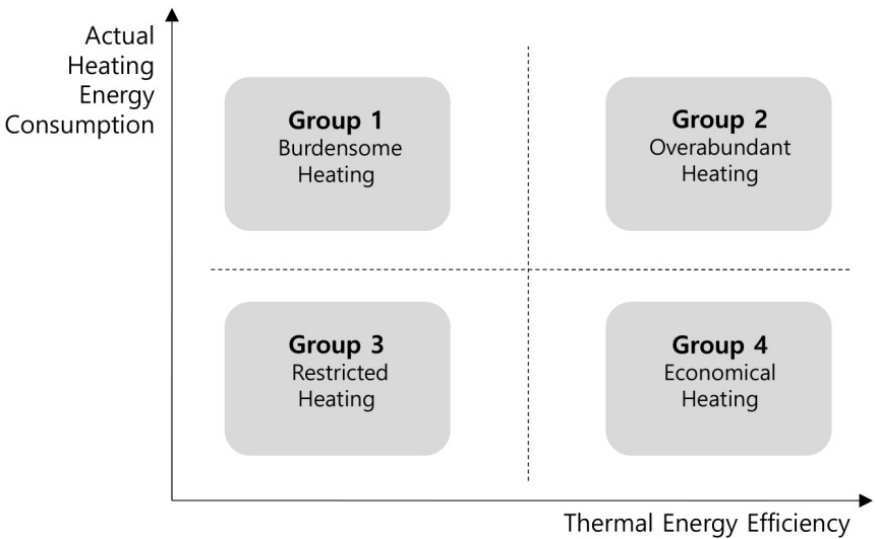
## **1.2. Research Questions**

In order to overcome the limitations of the existing fuel poverty framework, it is necessary to understand fuel poverty in relation to 'cold home' as its fundamental phenomenon. Hence, this paper tried to examine fuel poverty based on the direct indicators of underheated homes, such as 1) thermal efficiency and 2) actual heating energy consumption. Here, the thermal efficiency of a dwelling

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<sup>7</sup> There are efforts to refine standards by considering the number of household members, age, etc., however, the ability to pay heating costs depending on individual conditions is not fully reflected.

indicates the heat insulation performance of its building envelope, which affects the heating energy cost required to maintain proper indoor temperatures. Theoretically, thermal efficiency is a condition of a cold home irrespective of resident attributes. Thus this is a judging criterion for the necessity of thermal efficiency improvements regardless of the dweller being eligible for public support. The actual heating energy consumption means the amount of heating energy per square meter used in a dwelling indeed, not estimated for the optimal internal environment at given conditions of the dwelling's thermal efficiency. Accordingly, it can be considered as the other cold home condition that is subordinate to the resident attributes. The combination of these two empirical indicators describes the various types of heating experience as explained in Figure 3-2, which consequently involves very different heating-related discomfort in each group.



**Figure 3-2** Four heating experience groups by thermal efficiency & heating energy consumption

The specific research questions are as follows:

- **What are the actual heating tendencies of residents living in a house depending on different thermal efficiencies of dwelling?**
- **How different are the housing thermal efficiencies and the actual heating energy consumption by tenure type?**
- **Who owns and lives in a house with low thermal efficiencies?**

These questions were empirically answered through a newly collected dataset built based on parcel-level field surveys of 360 residential buildings located in a low-rise residential area in Seoul, South Korea. Based on the results, this research aimed to reveal the complex status of cold homes embedded in each heating group, which might not be captured by the current criteria of fuel poverty. In the study, specific conditions of households and dwellings that need to be included within the fuel poverty policy framework were suggested in the urban context of Seoul.

## 2. Method and Data

### 2.1. Fuel Poverty Context of Seoul and the Study Area

Fuel poverty has only been recently discussed in Korea after the *2007 Energy Welfare Charter*. Policies for fuel poor households have been expanding since the revision of the *2014 Energy Act* by which public initiatives have been recognized to ensure the universal use of energy. Although the discussion of fuel poverty is underway in South Korea, the relevant national plan defined about 1.2 million households spending more than 10% of their income on lighting and heating as fuel poor, which accounted for 6.3% of national households (MTIE, 2014). Under the same criterion, the fuel-poor ratio in Seoul was reported to be about 10.3% (The Seoul Institute, 2009). Fuel poverty was often understood as an aspect of economic hardships, largely limited to the suffering experienced by low-income households (The Seoul Institute, 2009; KIHASA, 2016). For instance, detailed investigation of fuel poverty problems in Seoul was aimed at only low-income households, as households below the near-poverty threshold<sup>8</sup> are eligible for public supports (The Seoul Institute, 2009). Consequently, ‘energy voucher’ which subsidizes the minimum heating costs for the fuel poor is one of the top priority policy tools. Also, the benefiting from the energy efficiency improvement projects are narrowly defined using the means test for general welfare<sup>9</sup> (KIHASA, 2016) rather than evaluating the physical conditions of dwellings. Furthermore, in metropolitan areas like Seoul, housing costs are notably higher which may result

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<sup>8</sup> It indicates 50% of the median income and considers both of a household’s property and income.

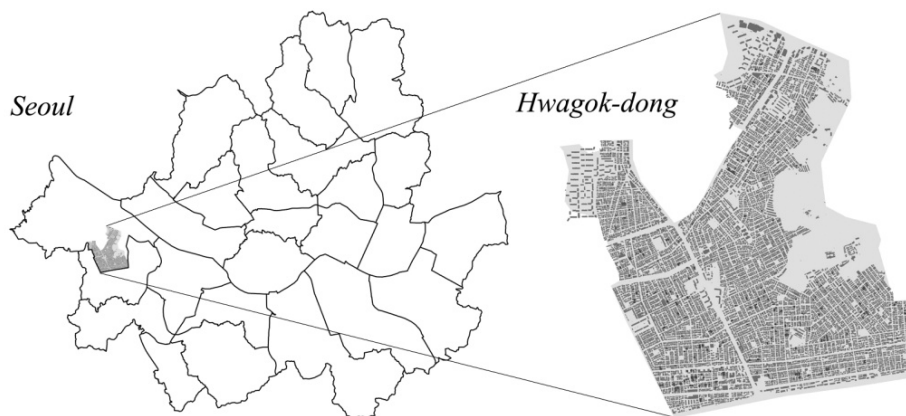
<sup>9</sup> The criterion of fuel poor households that are subject to thermal efficiency improvement support is 50% below the median income.

in the underestimation of the size of fuel poverty (The Seoul Institute, 2009; Moore, 2012; KIHASA, 2016).

Cities in Korea at a number of different scales have experienced urban decline and housing deterioration, leading to some heat-related vulnerability experienced by residents (Kim & Ryu, 2015; Lee et al., 2016). Particularly, low-rise residential areas in Seoul had been formed during the rapid urbanization stage and thus they have been treated as old urban areas in need of urban renewal since the 2000s (Shin & Kim, 2016). However, the regeneration impetus is lacking due to the stall in Seoul's population growth and the outflow of young people to new urban areas. Also, regulations against the haphazard redevelopment of low-rise residential areas had been alleviated over the decades to meet the high demand for housing, which resulted in the production of high-density, low-quality housing and inconvenient housing environments where narrow alleys are occupied with cars and public open spaces are lacking. Furthermore, regulations related to thermal efficiency had only been introduced in the 1980s in Korea, which were applied only in recent years for housing types other than apartment complexes. In many low-rise residential areas without a housing management organization, energy efficiency improvement efforts are left to individual homeowners, which hinder systematic management that is often found in large apartment complexes. For these reasons, dwellings with incompetent thermal efficiency are mostly found in low-rise residential areas, and the majority of fuel poor households are also identified in these areas (The Seoul Institute, 2009; KIHASA, 2016).

The study area (Figure 3-3) is a typical low-rise residential area in Seoul which

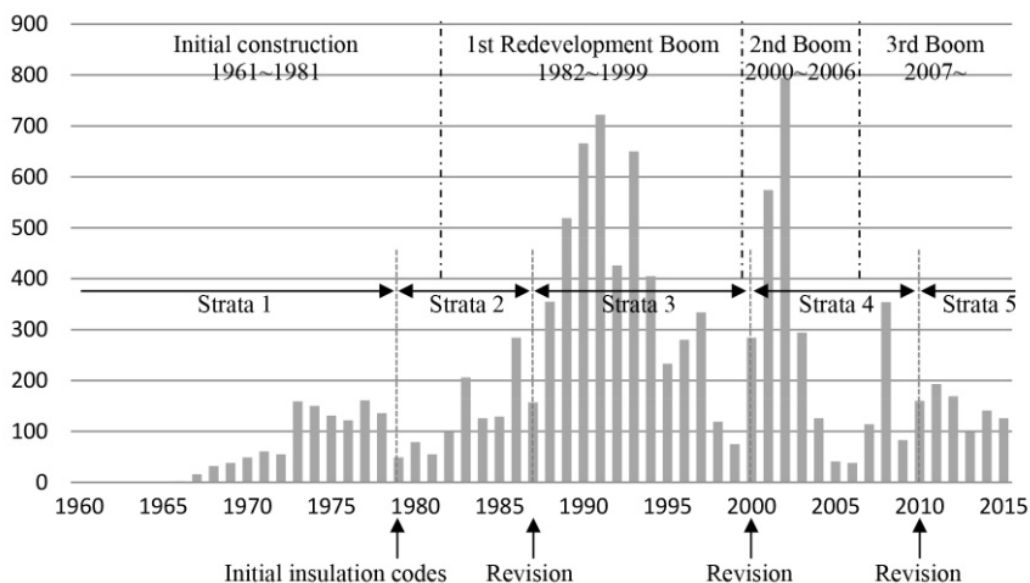
had been developed during the rapid urbanization period of the 1960s. As the study area was excluded from large-scale redevelopment, there had been gradual reconstruction activities on a parcel-level only after 20 years since the initial construction as shown in Figure 3-4. This resulted in a densely developed housing area with diverse building ages and building types ranging from the initial one-story houses to newly-built five-story housings. Compared to the rest of Seoul, the overall building age is slightly lower<sup>10</sup>, and in terms of the socioeconomic profile, the study area can be considered to be a residential district for mid-to-lower income households. The percentage of benefit recipients is also 4.5% which is slightly higher than the 3.3% of Seoul (SMG, 2015).



**Figure 3-3** Location of the study area, Hwagok-Dong, and its urban fabric

<sup>10</sup> The percentage of houses older than 20 years is 39% in Gangseo-gu, of which the study area belongs to, while the overall percentage is 42% for Seoul (Statistics Korea, 2015 a).





**Figure 3-4** Construction year of residential buildings in Hwagok-dong

## 2.2. Sampling and Data Collection

In 2015, the number of residential buildings in the study area was 10,672, of which 360 were finally sampled. In order to effectively represent a large-size population with a relatively small-sized sample, the stratified sampling method was used (Scheaffer et al, 2011; Thompson, 2012). The unequal sampling by stratum also allowed over-sampling old houses which were likely to be thermally inefficient. The total population of buildings was divided into five strata depending on the building age in accordance with the amendment of the building act in regards to insulation performance (Figure 3-4). The number of samples was designated for each stratum as shown in Table 3-1. For analyzing samples with unequal probabilities, sampling weights were applied accordingly by stratum.

**Table 3-1** Numbers of samples from each stratum

	<i>Stratum 1</i> Built between 1967~1980	<i>Stratum 2</i> Built between 1981~1988	<i>Stratum 3</i> Built between 1989~2000	<i>Stratum 4</i> Built between 2001~2010	<i>Stratum 5</i> Built between 2011~2015	Total
N. of Population	1,241	1,410	4,714	2,579	728	10,672
N. of Samples	76	89	96	69	30	360

The data used in this research can be organized into five categories: thermal efficiency, heating energy consumption, building features, tenure type, and ownership attributes of each sampled building. The detailed information was directly collected from official documents of building and ownership registry and field surveys except for heating energy consumption which came from the official secondary data of the gas usage in each building (Table 3-2).

The thermal efficiency of individual housing was defined as the degree of heat loss through the building exterior<sup>11</sup>. Heating systems such as boilers and pipelines were not incorporated in the study due to the difficulty of data collection. To evaluate heat loss, the non-invasive investigation method of infrared thermography was utilized (Dall'O' et al, 2013, Appendix 3-A). The problem of heat loss or insulation differs depending on the different parts of a building, leading to the difficulty of defining with a single variable or measuring and summing up the thermal problems on the same scale. Hence, the various thermal problems were evaluated separately with six thermal indicators, which measured the heterogeneous insulation and heat bridges as well as the thermal efficiency of the outer wall, the roof, the lowest floor and the window frame. The comprehensive thermal efficiency of individual dwellings was then eventually

<sup>11</sup> There are no official thermal efficiency data of residential buildings such as the UK's SAP in Korea, except for newly constructed apartment complexes. Hence, thermal efficiency data was directly collected through measuring from infrared surveys.

based on the indicators through confirmatory factor analysis (Appendix 3-B & 3-C).

**Table 3-2** Data Source and Collected Data

Thermal Efficiency	Field survey (Jan. & Feb., 2016) - Infrared images of 360 houses by Fluke Ti95 and Flir T420 infrared cameras
Heating Energy Consumption per residential floor area	The official <i>City Gas</i> data by buildings - Infrared images of 360 houses by Fluke Ti95 and Flir T420 infrared cameras Register of building (December 2015) - Total floor area for residential use
Tenure Type Owner-occupied / Tenant-occupied	Register of building & ownership (December 2015) - Address of owner
Ownership Characteristics Owner / Possession	Register of building & ownership (December 2015) - Owner's age and sex - History of transactions - Ownership type
Architectural Characteristics	Register of building & ownership (December 2015) - Approval date, building type, structure type, area of site, total floor area and floor area by stories & use Field survey (May & June, 2016) - Type of outer wall insulation - Improvement of window, door, roof & outer wall - Empty home

The heating energy consumption was calculated based on the LNG gas consumption data per building, which is the main energy source for heating and cooking in Seoul including the study area<sup>12</sup>. Heating energy consumption was induced based on the differences between LNG consumption under extreme cold and hot weather conditions of December and July, and consumption per square meter was used as a variable based on the interior floor area of the dwelling unit<sup>13</sup>.

<sup>12</sup> 97.4% dwellings in Seoul are served with LNG (SMG, 2015).

<sup>13</sup> The indoor space of dwellings in South Korea, apart from bathrooms, is generally heated through the floor heating system. According to the Seoul Institute's sample investigation report (2009) on low-income households, all investigated dwellings adopted the floor heating, mostly using LNG boilers (92.5%). Hence heating requirements are determined by t

Data regarding occupation and ownership includes tenure type, the age of the owner, and the length of ownership, which are important factors of housing management and improvement (Montgomery, 1992; Healy and Clinch, 2004; Littlewood & Munro, 1996; Baker & Kaul, 2002; Meijer et al, 2012). The age of the owner, in particular, is considered to be a potentially determining factor for housing demand based on housing life-cycle or life-course (Morrow-Jones & Wenning, 2005).

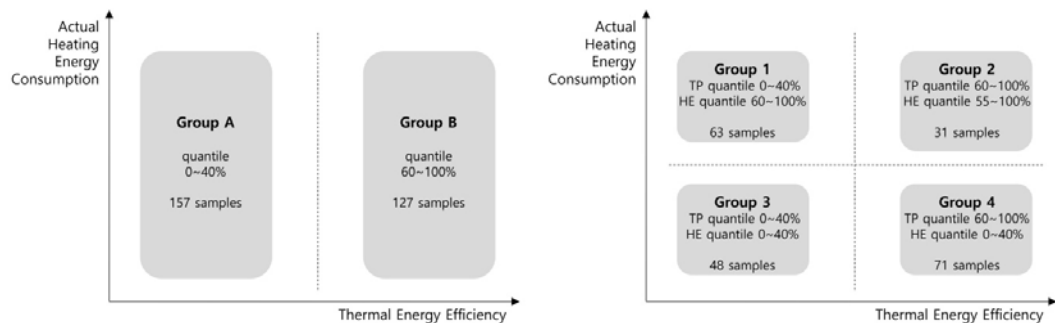
### **2.3. Analysis**

This research analyzed the thermal and building database of 360 low-rise dwellings in order to reveal the relationship between heating experiences against building and ownership attributes and tenure type. First, through descriptive statistics and correlation analysis, the overall distribution and relation between variables were explored and distinctive heating groups were identified in terms of thermal efficiency and heating cost of dwellings (Figure 3-5). The study then compared the groups with markedly different thermal efficiency and heating consumption. Analysis of variance (ANOVA) was adopted to confirm statistically significant differences in characteristics of building, ownership and tenure type between the groups and eventually to Figure out the dominant features of each group. Here, ANOVA was implemented in two stages. First, ANOVA between *Group A*, dwellings with inadequate thermal efficiency, and *Group B*, dwellings with sound thermal efficiency was attempted to examine differences according to thermal efficiency. Under the given conditions of thermal efficiency, the actual

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he internal area of the dwelling. Non-heated rooms were not considered as the size of housing in the study area was relatively small, and the data was difficult to obtain.

heating cost was identified, and then the heating tendency was interpreted with the differences in the dominant architectural characteristics, the ratio of owner-occupancy, household head's age and ownership career between two groups. Second, ANOVA was used to investigate the differences based on heating energy consumption inherent in each thermal efficiency group. The comparison between *Groups 1* and *3*, the subgroups of *Group A*, and between *Groups 2* and *4*, the subgroups of *Group B* identified causes for different heating expenditure despite similar thermal efficiency. Lastly, outlying cases within each group were investigated. Based on such findings, the potential fuel poverty households embedded in each heating group were understood.



**Figure 3-5** Group A & B by thermal energy efficiency / Group 1, 2, 3 & 4 by thermal energy efficiency and heating energy consumption

In dividing the groups, the study used comparative ranking among dwellings in the study area, as opposed to an absolute standard, to set up the thermal efficiency and heating energy criteria.<sup>14</sup> As shown in Figure 5, the groups were divided, based on the percentile to ensure a clear difference between each group while

<sup>14</sup> Adequate thermal efficiency and energy consumption can vary greatly depending on the characteristics of housing, residents, and the microclimate. Therefore, establishing an absolute criterion is not only difficult but unfitting (Moore, 2012; KIHASA, 2016). Furthermore, housing should be considered as a product that is allocated on a relative basis within a moderately closed local market.

exceeding the minimum of 30 samples required for the ANOVA analysis<sup>15</sup>.

**Table 3-3** Definitions of variables and descriptive statistics of full samples (N=360)

Variables		Mean (S.E.)
$Ef^a$	Thermal efficiency of a residential building min. ~ max. = -1.275 ~ 2	-0.001 (0.566)
$E$	The amount of LNG consumption for heating per m <sup>2</sup> min. ~ max. = 27.8 ~ 275.5 MJ/m <sup>2</sup> $E = (\text{LNG consumption in Jan. 2015} - \text{LNG consumption in Jul. 2015}) / (\text{total floor area} - \text{non-residential floor area})$	99.146 (40.343)
<b>Architectural Characteristics</b>		
$A\_year$	Year of building construction min. ~ max. = 1967 ~ 2015	1993.877 (10.615)
$A\_ins$	Insulation type of outer wall outside = 1, sandwiched = 2, no insulation = 3	1.774 (0.722)
$A\_ref^b$	Necessity of refurbishment no need = 1, window·door·roof·outer wall refurbished = 2, window·door·roof refurbished = 3, window·door refurbished = 4, no refurbishment = 5	2.900 (1.579)
$A\_far$	Floor area ratio   0 ~ 1	1.773 (0.663)
<b>Housing Types</b>		
$H\_sgl-f$	Single-family detached house   0 or 1	0.182 (0.386)
$H\_mul-f$	Multi-family detached house   0 or 1	0.416 (0.493)
$H\_mul-u$	Multi-unit housing   0 or 1	0.402 (0.490)
$H\_size$	Size of a residential unit min. ~ max. = 12.16 ~ 215.57 m <sup>2</sup>	66.965 (22.642)
<b>Tenure &amp; Ownership Characteristics</b>		
$T$	Tenure Type tenant occupied = 0, owner occupied = 1	0.583 (0.493)
$O\_age$	Age of Owner (The Year of Owner's Birth)	1954.443 (13.605)
$Over\ 60s$	Ratio of Owner over 60s	0.585 (0.027)
$O\_per$	Ownership Period (The Year of Purchase)	2002.605 (9.451)
$O\_tye$	Ownership Type multi-ownership = 0, single ownership = 1	0.592 (0.449)

<sup>a</sup>  $Ef$  is a latent variable. Indicators used for its measurement is available in Appendix 3-B.

<sup>b</sup> Necessity of refurbishment refers to the building parts that need improvement with respect to the current insulation standard, such as windows, doors, and roofs.

<sup>15</sup> To ensure a minimum of 30 samples for the ANOVA analysis, dwellings using up to the upper 45% of heat energy consumption was included in *Group 2*.

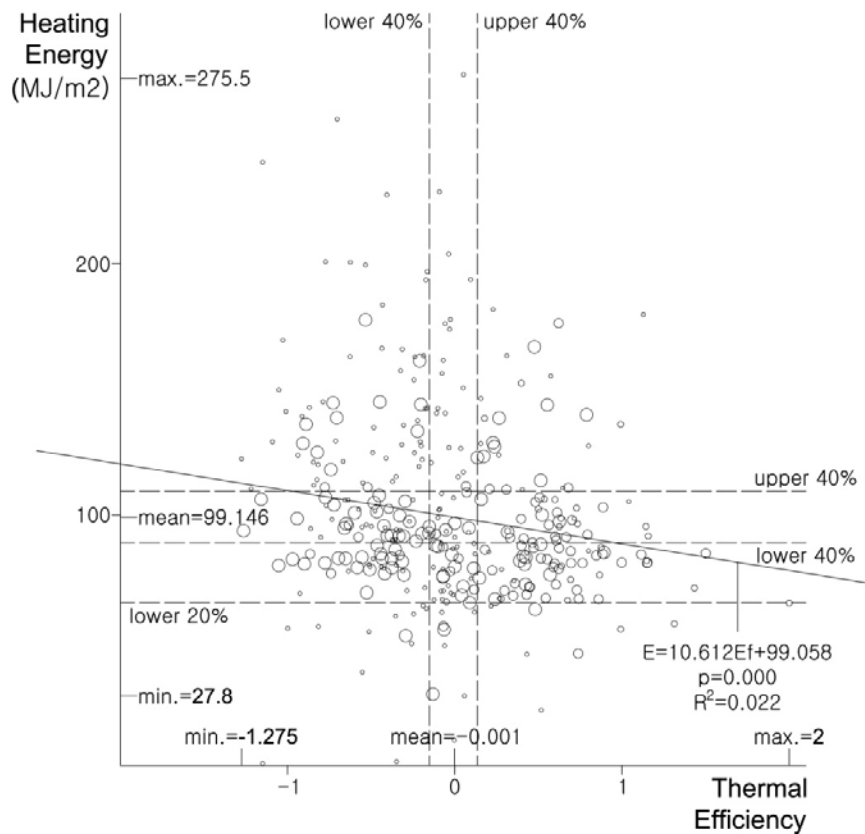
### 3. Results

#### 3.1 Low correlation between actual heating and thermal energy efficiency

The correlation between heating energy consumption ( $E$ ) and housing thermal efficiency ( $E_f$ ) was low (Table 3-4). As shown in Figure 6, the distribution of  $E$  was concentrated in a certain range but was plotted irrespective of  $E_f$ . Despite the stark difference in thermal efficiency between two thermal efficiency groups A & B, the slight difference in heating energy between the groups should be noted (Table 3-5). Therefore, it cannot be simplistically said that thermally efficient housing used heating energy economically, nor that housing with poor thermal efficiency expended large energy costs in order to reach comfortable indoor temperatures. Meanwhile, the large heating energy variances were observed between the subordinate groups (i.e. *Groups 1* and *3*; *Groups 2* and *4* in Table 3-6). Both *Group 1* and *Group 3* belonged to the bottom 40% of thermal efficiency, but the difference of heating energy per square meter between them was almost twice. A similar level of difference was observed between *Group 2* and *Group 4* while being in the top 40% of thermal efficiency identically. Moreover, no clear correlation was found between heating energy consumption and architectural attributes or housing types either (Table 3-4). This indicates that the variation of heating energy use in the study area was restrictively explained with building physics. Instead, it might be more dependent on specific conditions of the occupant as identified in case studies of other countries (Majcen et al., 2013b; Wolff et al., 2017).

**Table 3-4** Correlations between  $E_f$ ,  $E$ , and other housing characteristics (N=360, \* p<0.005)

	$E_f$	$E$	$A_{age}$	$A_{ins}$	$A_{ref}$	$A_{far}$	$H_{sgl-f}$	$H_{mul-f}$	$H_{mul-u}$	$H_{size}$
$E_f$	1.000									
$E$	-0.149*	1.000								
$A_{year}$	0.502*	-0.301*	1.000							
$A_{ins}$	-0.506*	0.274*	-0.796*	1.000						
$A_{ref}$	-0.577*	0.170*	-0.685*	0.690*	1.000					
$A_{far}$	0.356*	-0.264*	0.675*	-0.661*	-0.453*	1.000				
$H_{sgl-f}$	-0.137*	0.363*	-0.659*	0.603*	0.268*	-0.671*	1.000			
$H_{mul-f}$	-0.342*	-0.027	-0.097*	0.145*	0.418*	-0.021	-0.398*	1.000		
$H_{mul-u}$	0.452*	-0.245*	0.616*	-0.617*	-0.629*	0.549*	-0.387*	-0.692*	1.000	
$H_{size}$	-0.166*	0.068	-0.303*	0.308*	0.260*	-0.263*	0.258*	0.370*	-0.575*	1.000



**Figure 3-6** Thermal Efficiency ( $E_f$ ) & Heating Energy ( $E$ )

On the other hand, thermal efficiency showed strong linear correlations with architectural and housing characteristics (Table 3-4). Not unnaturally, older



houses showed lower thermal efficiency, meaning that more heat escapes a house through deteriorated and under-insulated parts of the envelope like crevices in and around windows and roofs. However, the strong relation, at the same time, proved that current efforts to maintain and improve thermal efficiency were insufficient in the study area. This was shown by the clear negative correlations between *A\_ref* – variable indicating the need for maintenance of windows, roof, and exterior walls – with construction year (*A\_year*) and thermal efficiency (*Ef*). Therefore, as emphasized by Healy and Clinch (2004), it is important to understand why rational housing maintenance did not frequently occur in the study area.

**Table 3-5** Results of ANOVA between *Group A* & *B* (\*\*\*)  $p < 0.001$ , \*\*  $p < 0.005$ )

Variables	<i>Group A</i> N <sub>A</sub> = 157 <i>Mean(S.E.)</i>		<i>Group B</i> N <sub>B</sub> =127 <i>Mean(S.E.)</i>		<i>Two-tailed</i> <i>P</i> value	
<i>Ef</i>	-0.533	(0.035)	0.586	(0.025)	0.000	***
<i>E</i>	105.945	(3.666)	93.303	(2.409)	0.001	**
<i>A_year</i>	1989.269	(0.759)	2000.979	(0.551)	0.000	***
<i>A_ins</i>	2.216	(0.061)	1.248	(0.046)	0.000	***
<i>A_ref</i> **	3.725	(0.163)	1.745	(0.114)	0.000	***
<i>A_far</i>	1.540	(0.069)	2.129	(0.052)	0.000	***
<i>H_sgl-f</i>	0.222	(0.034)	0.08	(0.019)	0.000	***
<i>H_mul-f</i>	0.594	(0.058)	0.223	(0.039)	0.000	***
<i>H_mul-u</i>	0.184	(0.055)	0.697	(0.040)	0.000	***
<i>H-size</i>	68.678	(2.342)	61.311	(1.751)	0.002	**
<i>T</i>	0.678	(0.063)	0.431	(0.046)	0.000	***
<i>O-age</i>	1951.354	(1.701)	1958.376	(1.261)	0.000	***
<i>Over 60s</i>	0.723	(0.062)	0.418	(0.046)	0.000	***
<i>O-per</i>	1999.454	(1.02)	2006.402	(0.633)	0.000	***
<i>O-tye</i>	0.816	(0.056)	0.309	(0.04)	0.000	***

### 3.2. Cold homes occupied by elderly owners

Those living in thermally inefficient housing turned out to be largely homeowners, while tenants usually lived in housing with better thermal efficiency.

As it is evident from Table 3-5, 70% of dwellers in *Group A* were homeowners, and 40% were owner-occupants in *Group B*. Moreover, owner-occupant households did not necessarily use more heating than tenant households. Table 3-6 shows that tenant type differences between *Groups 1* and *3*, and between *Groups 2* and *4* were insignificant. These tendencies were confirmed again when examining the thermal efficiency and heating energy use between the owner-occupied housing and tenant-occupied housing (Table 3-7). In short, despite the low thermal efficiency of owner-occupied housings, these households showed similar heating energy consumption to tenant households. Hence, it is considered that owner-occupant households lived in relatively colder homes. This rejects the common notion that low-income tenants in Korea are the fuel poor using less heating energy and living in thermally inefficient housing.

Furthermore, this invalidates the assumption that owner-occupied homes are usually better maintained because tenants do not have the right or means to voluntarily improve the heat efficiency of their dwellings in practice of Seoul regarding housing tenure. Rather, old and thus thermally inefficient buildings are inadequate for renting and thus occupied by the owners who cannot afford to move to better dwellings or improve current homes, while absentee owners often benefit through higher rents by ensuring thermally efficient homes.

The owners of thermally inefficient homes (*Group A*) were mostly retired senior citizens and among the owners, 72.3% were above the age of 60 (Table 3-5). When including those in their 50s, who were close to retirement, this Figure

rose to 85.5%<sup>16</sup>. A high percentage of elderly was particularly evident among owner-occupants which accounted up to 68% (Table 3-7). In short, nearly half of the low thermal efficiency housing was occupied by owner-occupants above the age of 60, which was approximately twice the area average<sup>17</sup>. This showed that a large number of elderly—arguably the more vulnerable in regards to cold weather—were concentrated in thermally inefficient homes in the study area.

This also explained why voluntary improvements by owners were lacking. The elderly in South Korea is known to be a financially marginalized group due to the lack of provisions for their old age such as pensions (The Seoul Institute, 2010). Against the backdrop of a sharp increase in housing price in the late twentieth-century and the strong drive for home-ownership, many elderly household assets have been tied to their current real estate<sup>18</sup> and therefore, elderly home-owners are likely to lack disposable income (Seoul Institute, 2010). As a result, the elderly homeowners' intention and ability to manage their home actively are difficult to anticipate.

In terms of ownership type, houses in *Group A* were predominantly detached housing with single ownership, while 70% in *Group B* were multi-unit houses with multiple ownership (Table 3-5). In Korea, the maintenance of housing is left

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<sup>16</sup> Although the demographical threshold of an elder is 65 in Korea, this paper broadly defined the senior group as the over 50s, who belong to Korean baby-boomers.

<sup>17</sup> According to the 2015 Census, household heads above the age of 60 in the area accounted for 26% (Statistics Korea, 2015b).

<sup>18</sup> In Seoul, the home-ownership rate of those above 60 is 44% which is higher than the most economically active population of the 40s and 50s (Statistics Korea, 2015c). The share of real estate in assets accounts for 51%, which is higher than other age groups (SMG, 2013). This coincides with the notion that equates home with ownership, preferring an asset-based welfare rather than pensions or other financial assets that could be endowed to future generations (Dupuis & Thorns, 1996).

to individual owners with the exception of apartment complexes, and in this sense implementing thermal efficiency improvement measures should be easier for single ownership houses in terms of decision making. However, due to the above-mentioned reasons, it was difficult to find active efforts among single ownership owners<sup>19</sup> in the study area.

Another reason for such neglect in maintenance was closely related to the building age and architectural characteristics of detached houses in *Group A*. The average building age of these houses reached up to 30 years which exceeded the normal redevelopment cycle for low-rise residential areas in Seoul, South Korea (Table 3-5 and Figure 3-5). The cycle of about 20 years for redevelopment is rather short from an international standard. But in South Korea, at least until 2007, low-rise residential settlements were able to be legitimately reviewed for redevelopment after 20 years from building completion. Old houses that were left undeveloped over a long period of time remained obsolete in many aspects. For example, the average housing unit area was larger than more recently developed housings<sup>20</sup>, and the interior of the houses also differed from current design tendencies. Furthermore, the housing FAR was lower than the allowed FAR and that of recently built housings. Therefore, rather than extending the lifespan of old houses through maintenance, redevelopment is more profitable and is thus a more favorable option for the owners.

The owner-occupants, who were the majority in *Group A*, have lived in their

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<sup>19</sup> Limited improvements were applied through partial maintenance such as replacing wind  
ows.

<sup>20</sup> The average housing unit area of sample houses built in the past ten years was 48.5m<sup>2</sup>.  
Such change is related to the decrease in household size.

respective homes for almost 20 years on average (Table 3-7). This is markedly longer than the average 5.9 years of residency in Seoul (Statistics Korea, 2004). This shows that 'aging in place' was prevalent among owner-occupants in the study area, albeit in thermally inefficient homes. This also implies that public support for thermal efficiency improvement is important not only for the physical well-being of the elderly but also to ensure their healthy social life in low-rise houses.

**Table 3-6** Results of ANOVA between *Group 1 & Group 3* and between *Group 2 & Group 4* (\*\* $p < 0.005$ , \*  $p < 0.01$ ,  $\dagger p < 0.05$ ,  $\ddagger p < 0.1$ )

Variables	Group 1 N <sub>1</sub> = 63 Mean(S.E.)	Group 3 N <sub>3</sub> =48 Mean(S.E.)	Two- tailed P value	Group 2 N <sub>2</sub> = 31 Mean(S.E.)	Group 4 N <sub>4</sub> =71 Mean(S.E.)	Two- tailed P value
<i>Ef</i>	-0.566(0.055)	-0.521(0.037)	0.409	0.444(0.059)	0.640(0.037)	0.001***
<i>E</i>	144.067(5.390)	76.713(1.442)	0.000***	130.045(4.327)	76.307(1.182)	0.000***
<i>A_year</i>	1986.382(1.592)	1989.444(0.718)	0.055†	1996.337(2.011)	2001.794(0.629)	0.007**
<i>A_ins</i>	2.326(0.098)	2.093(0.047)	0.017*	1.436(0.129)	1.221(0.058)	0.096†
<i>A_ref</i>	3.92(0.253)	3.746(0.168)	0.491	2.586(0.348)	1.500(0.130)	0.002***
<i>A_far</i>	1.353(0.115)	1.559(0.071)	0.075†	1.886(0.142)	2.172(0.059)	0.043*
<i>H_sgl-f</i>	0.421(0.082)	0.172(0.037)	0.002***	0.193(0.072)	0.055(0.015)	0.057†
<i>H_mul-f</i>	0.424(0.104)	0.68(0.063)	0.013*	0.537(0.100)	0.110(0.040)	0.000***
<i>H_mul-u</i>	0.154(0.081)	0.147(0.056)	0.928	0.269(0.091)	0.834(0.041)	0.000***
<i>H-size</i>	67.368(3.464)	71.913(2.716)	0.190	69.976(4.875)	59.156(1.941)	0.026*
<i>T</i>	0.764(0.102)	0.68(0.078)	0.407	0.392(0.115)	0.462(0.060)	0.545
<i>O-age</i>	1951.008(2.676)	1952.24(2.195)	0.645	1955.175(3.152)	1958.102(1.688)	0.353
<i>O-per</i>	1997.467(2.077)	1999.484(1.505)	0.331	2003.057(2.042)	2007.250(0.774)	0.040*
<i>O-tye</i>	0.867(0.080)	0.863(0.055)	0.956	0.769(0.090)	0.171(0.042)	0.000***

**Table 3-7** Results of ANOVA between Owner-occupied and Tenant-occupied housings (\*\* $p < 0.005$ , \*  $p < 0.01$ ,  $\dagger p < 0.05$ ,  $\ddagger p < 0.1$ )

Variables	Owner-occupied Mean(S.E.)	Tenant-occupied Mean(S.E.)	Two-tailed P value
<i>Full-Sample</i>	N <sub>0</sub> =223	N <sub>1</sub> =137	
<i>Ef</i>	-0.115(0.066)	0.157(0.049)	0.000 ***
<i>E</i>	100.035(4.057)	97.835(3.331)	0.588
<i>A_year</i>	1991.214(0.933)	1997.591(0.599)	0.000 ***
<i>A_far</i>	1.664(0.067)	1.927(0.049)	0.000 ***

<i>H_sgl-f</i>	0.247(0.032)	0.091(0.019)	0.000	***
<i>H_mul-f</i>	0.461(0.059)	0.353(0.042)	0.069	†
<i>H_mul-u</i>	0.292(0.057)	0.556(0.042)	0.000	***
<i>H-size</i>	70.546(2.566)	61.968(1.986)	0.001	***
<i>O-age</i>	1951.808(1.554)	1958.299(1.222)	0.000	***
<i>Over 60s</i>	0.681(0.059)	0.446(0.047)	0.007	***
<i>O-per</i>	1999.338(0.911)	2007.164(0.631)	0.000	***

### 3.3. Potential Fuel Poverty Embedded in Dynamics of Heating Experiences

Thermal efficiency and heating energy use tendencies of the four groups were compounded with the characteristics of housing, tenure and ownership type which formed very different fuel poverty contexts. First, *Group 1* was close to the fuel poor in the standard sense, characterized by the lowest thermal efficiency and the highest energy use. This was related to the high percentage of detached houses in the group with a greater building envelope compared to the floor area. The houses were older and in poorer conditions in terms of the type of insulation used and the degree of maintenance. Hence, the households were likely to be the fuel poor group who suffered from inadequate heating despite using relatively higher heating energy. However, the fact that owner-occupier households were the majority in *Group 1* (76%) and high energy costs were paid makes it difficult to define them as financially restrained households. In this sense, the determining factor of potential fuel poverty that persisted in the group is related to the physical deterioration of housing rather than the income levels of individual households.

Second, in *Group 3*, the coldness tolerated by households was more serious than other groups because of low thermal efficiency and low heating energy use. If heating expenditure was interpreted in relation to income levels, their disposal

income was probably insufficient to match the higher required heating for comfortable indoor temperature. Nevertheless, some households in the group might not be recognized as the fuel poor by the Korean criteria as their heating expenditure was relatively low. Still, the discussion of tenure type in relation to fuel poverty required caution since 68% of the dwellers in this group were owner-occupants.

Third, housings in *Group 2* were relatively thermally efficient. However, the high energy use in this group calls for more investigation. Examining the physical attributes, housings in the group showed better thermal efficiency than *Groups 1* and *3*, but lower efficiency when compared against *Group 4*. The age of buildings, type of insulation, and degree of maintenance also lay in between the attributes of *Groups 1, 3* and *Group 4*. In this respect, boiling and piping systems can be anticipated to be aging, although these components were not directly examined in this study. Hence, if appropriate improvement measures are not taken in the future, *Group 2* housings are at risk of falling into *Groups 1* and *3* with further deterioration.

Fourth, households in *Group 4* were likely to enjoy a comfortable internal environment at reasonable costs. A small proportion of problematic segments, however, still existed within this group. Despite sound thermal efficiency, there were households that use heating energy to a minimum, which could be a circumstantial evidence for fuel poverty as well. A considerable number of houses that used the least heating energy, in fact, showed tolerable or good thermal

efficiency (Figure 3-6)<sup>21</sup>. Among these cases, buildings older than 20 years had a lot larger housing unit area than the average unit area, and a high increase in electricity costs during the winter season was often observed. Thus, micro-heating with electric heaters in bedrooms or limited areas of the house was predicted in these housings in order to cut energy use. In other words, the factor for potential fuel poverty in *Group 4* was economically driven as opposed to being related to the physical deterioration of the housing.

### 3.4. Exceptional Cases

Despite the clear trends identified within each group of the analyzed 360 samples, there were also a small number of exceptional cases that required examining. These cases showed whether certain conditions prevented or accelerated the degradation of thermal efficiency of low-rise dwellings.

For instance, conditions that prevented thermal inefficiency were found in detached houses that had been properly repaired to maintain good thermal efficiency. Out of the 76 samples in *Stratum 1* (Table 3-1: built between 1967~1980) —built before the insulation regulation was established—12 houses that belonged to *Group B* exemplified such desirable management. Building components such as windows and roofing had been replaced in these cases, and the insulation performance of outer walls also exceeded *Stratum 1*'s average, indicating that extensive repairs including a supplement of wall insulation had been carried out.

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<sup>21</sup> For housings that belonged to the bottom 20% of heating energy use, the average estimated value of thermal efficiency was 0.089, which was higher than the total average.



The latter condition, which accelerated thermal inefficiency, was found in a small number of samples extracted from *Stratum 4* (Table 3-1: built between 2001~2010) but belonged to the low thermal efficiency *Group A*. While *Stratum 4* samples showed good thermal efficiency on average ( $Ef=0.389$ ), approximately 10% of the housings showed much lower thermal efficiency ( $Ef=-0.605$ ). The unusual thermal efficiency of these relatively new housings was mostly related to the heat outflow in thermal bridges, and the unevenness in insulation efficiency<sup>22</sup>. These occurred where the exposed structure or arbitrary extension caused problems in insulation and air-tightness, indicating that thermal inefficiency might arise due to architectural design rather than simply in relation to building age. Hence, support for professional consulting is more important in these cases instead of relying on the housing owners' ability or motivation to improve thermal efficiency.

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<sup>22</sup> Among the thermal efficiency indicators, in terms of the heating bridge variable (*HB*), the overall average for stratum 4 was 0.855, while the average of problematic cases was 2.375. For the unevenness in wall insulation (*W\_HL*), the overall average for stratum 4 was 0.091 while the average of problematic cases was 0.18.

## **4. Discussion**

While the results of the study delineated fuel poverty within the specific context of a neighborhood in Seoul, there are also general implications that extend beyond local considerations as follows.

### **4.1. Fuel Poverty in Demographic and Housing Policy Contexts**

The findings in the study suggested that fuel poverty needs to be considered with respect to the long-term changes in population and housing stock contexts. South Korea has experienced a rapid increase in urban population and economic growth, where housing was supplied on a massive scale with a strong promotion of home-ownership as shown in many Asian countries. The baby-boomers headed the high demand for housing and their housing accounts for a large proportion of the remaining housing stock. As this generation retires, dwellings owned by them can deteriorate in the next couple of decades due to the lack of willingness and ability to manage their homes (Meijer et al., 2012). Thus, rather than limiting this issue on an individual household scale, strong collective prevention measures at a neighborhood scale are called for.

More importantly, the appropriate maintenance of these housings is directly linked to the well-being and quality of life of the future elderly population in cities as a large number of baby-boomers will age in their homes in the following decades and spend more time at homes (Majcen et al, 2015b; Chard & Walker, 2016; van Hoof et al., 2017). Moving or flexibly managing homes according to housing life-cycles is not easy for older owner-occupants, and the cost of maintaining ‘empty nests’ that do not fit their household size or disposable

income conditions easily become burdensome. As a result, excessive energy costs are paid or, in adverse situations, cold internal temperatures are altogether tolerated. At the same time, housing deterioration including thermal inefficiency would only be accelerated in the future, which is particularly worrisome in rapidly aging societies such as Korea and other East Asian countries.

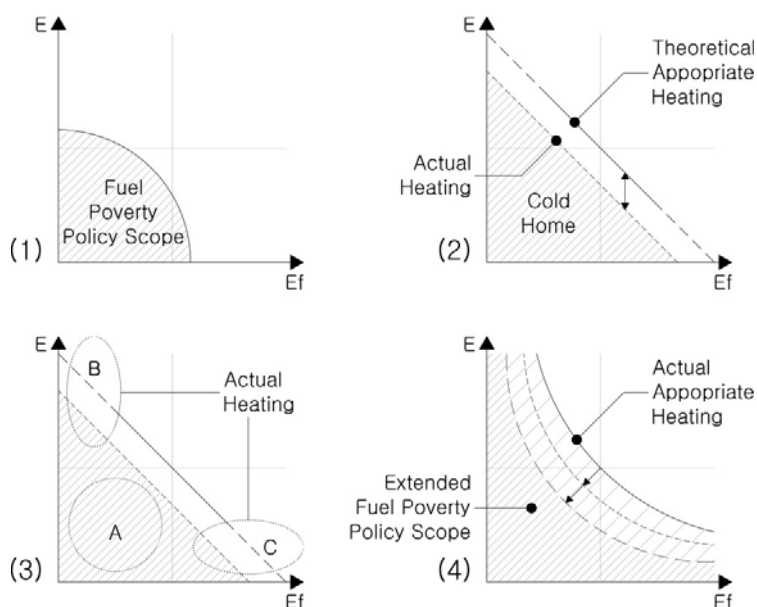
Moreover, the owner-occupant baby-boomer dwellings will become the housing stock for the next generation. Appropriate measures taken now would decide whether these housing stocks become marketable inventories or a troublesome urban legacy. Old houses left as inheritance are even discussed as a serious factor of empty homes (AURI, 2012; Empty Homes, 2017). It is because the baby-boomer dwellings do not match with current and near-future housing demands. Housing consumption tendencies of the younger generation are completely different from that of the baby-boomers due to the changes in industries and lifestyles, resulting in preference for cities to suburbs. The lack of housing purchasing power also characterizes the younger generation, which contrasts against the peak of home-ownership experienced by baby-boomers and backed by financial institutions (McKee, 2012). Such mismatch in supply and demand might actually mean that maintaining old homes as they were could be futile. Therefore, rather than limiting the solution for thermally inefficient housing to improvements of insulation, a comprehensive policy measure that considers the transformative housing market condition needs to be devised which is beyond the responsibility and capability of individual home-owners.

## 4.2 Extending and differentiating policy scope of fuel poverty

The variation of heating experience described through thermal efficiency ( $E_f$ ) and energy use ( $E$ ) revealed the dynamics of fuel poverty, which were not differentiated by Korean fuel poverty standards. The current fuel poverty range at policy level is sensitive towards differences in income levels but fails to reflect on the actual coldness of homes. Acknowledging that collection of large reliable data on internal temperatures of dwellings is difficult, cold homes could be sufficiently defined in terms of the dwelling thermal efficiency and actual heating energy use data. In other words, when large differences between the actual heating use and appropriate heating use in relation to the thermal efficiency of the dwelling are identified, the vulnerability of a cold home could be expected. However, the existing standard of Korean fuel poverty policy does not take the degree of coldness into account, but merely the household income and property. Therefore, as shown in Figure 3-7-(1) & (2), the current policy scope of fuel poverty does not fully cover such cold homes which should be brought into the fuel poverty discussion.

In theory, heating energy ( $E$ ) and thermal efficiency ( $E_f$ ) stand in a trade-off relationship. It is a mechanism where lower level building insulation causes more heat outflow and induces more heating in order to maintain a certain indoor temperature. However, in reality, the plotting of  $E_f$  and  $E$  values also distributes outside the trade-off line between  $E_f$  and  $E$  as demonstrated in the study area (Figure 3-6) and identified in empirical studies (Sorrel et al., 2009; Majcen et al, 2013a). Moreover, the slope of the  $E_f$ - $E$  trade-off line and the dispersion and pattern of actual distribution line would differ based on regional climates, housing

stock, and socioeconomic conditions. Nevertheless, the relative location on the  $Ef$ - $E$  plane such as area  $A$ ,  $B$  or  $C$  in Figure 3-7-(3), could be interpreted universally in relation to unusual heating, and the risk of fuel poverty inside, which is discussed below.



**Figure 3-7** Extended Fuel Poverty - Cold Homes  
 (1) Fuel poverty policy scope (2) Actual Cold homes range  
 (3) Problematic actual heating types (4) Extended fuel poverty policy scope

First, dwellings that belong in area  $A$  are the most vulnerable dwellings in terms of practically serious cold homes. Due to the low thermal efficiency of housing, the costs to ensure comfortable internal temperature are relatively high. At the same time, even the median fuel costs may not be payable by the residents, hence, the most of fuel-poor households by general definition correspond to area  $A$ .

Area  $B$  is characterized by extremely low thermal efficiency and higher energy

use that exceed theoretical estimates. This results from energy loss due to the low efficient utility system, not just heat leakage through the building envelope. Certain design characteristics are also significant factors that contribute to high energy use, which include high ceilings, excessive-glass facades, and heat bridges. Otherwise, the occupants' attributes such as age or household size explain such an energy consumption pattern (Majcen et al., 2015b, Visscher et al., 2016). Households in area *B* currently bear the relatively high energy costs, but there are cases of considerably decreased disposable income due to high energy expenditures. Thus, some households in area *B* can easily fall into area *A* if their economic status worsens. Therefore, area *B* should be actively included in the fuel poverty policy target. The only difference is that potential fuel poverty in area *B* should be tackled differently from the largely welfare-oriented measures of existing policy in terms of the goal and delivering. For instance, area *B* holding potential for energy reduction compared to area *A* needs policy instruments such as financial support to expedite refurbishments (Weiss et al., 2012).

Area *C* represents dwellings that show adequate thermal efficiency but very low energy use. Theoretically the *Ef-E* trade-off line should extend with the improvement of thermal efficiency, however, this was not observed in the real world. Empirical studies identified 'rebound effect' that indicates higher energy consumption in more efficient dwellings than theoretically estimated (Sorrel et al., 2009; Majcen et al, 2013a). Dwellings in the study area also demonstrated that heating energy use converged at a certain degree rather than decreased in proportion to the increase of thermal efficiency. This is because a certain level of minimum energy is required to supply hot water and to compensate for heat loss

through ventilation and air leakage. Accordingly, it is true that energy cost required for adequate heating in dwellings of area *C* is reasonable and affordable. However, it is estimated that even the minimum energy costs may not be expended by these households due to their low disposable income and the need to cover other housing costs or medical expenses. Moreover, there is a high possibility that potential fuel poverty belonging to area *C*, would increase under the worsening of shortages in affordable housing. Similar fuel poverty problems may be experienced by households living in public housing appropriately managed by the government or recipients of housing subsidies (Hills, 2012). Hence, the problem of fuel poverty in this group is not dependent on the housing itself but the household.

The multifaceted fuel poverty identified with the three categories is actually a continuous phenomenon as shown in Figure 3-7-(4). The lower left side of the *Ef-E* curve which considers the actual heating patterns rather than the theoretical trade-off line is the range of cold homes of which occupants are potentially fuel poor households. The further away from the curve, greater hardships are tolerated. Also, physical factors are dominant as fuel poverty phenomena approach the *E*-axis, whereas individual-economic factors are dominant when closer to the *Ef*-axis. Therefore, the location of plotting on the *Ef-E* plane summarizes the degree and characteristic of fuel poverty, which should be considered when various policy instruments are designed and targeted.

## Conclusion

The low-rise residential areas have contributed to the mitigation of housing shortage in Seoul through supplying various affordable housing. However, for the rapid housing provision with a limited public budget, the relaxation of regulations was repeated to encourage the spontaneous redevelopment by the private sector. As a result, the living environment in low-rise residential areas has been generally worsened, and furthermore there is little room for an additional relaxation of regulations. A new policy frame for sustainable management of low-rise residential areas can be established from revealing the spatially uneven and scattered problematic situations which have been ignored within the existing policy frame based on the general regulation. Thus, this study attempts to investigate empirically the dynamics of low-rise residential areas at the neighborhood level and even at the parcel level. Also, the dynamics is explained not only with the architectural and urban morphological factors; non-physical factors—land use, the property ownership, tenure types and residents' attributes—are also investigated as important variables to determine the use and reinvestment of an individual land lot. Finally the study calls for the site-specific planning approach from a series of researches as follows:

The first chapter, as a descriptive study for the second and third chapters, explores the diversity of low-rise residential areas in Seoul. Particularly, the study tries to capture the dynamics of demographic and housing stock changes in low-



rise residential areas beyond the evaluation of physical deterioration only. Among the various transitions occurred in low-rise residential districts since 2000, three types need to be noticed; the first one is the stagnated neighborhood linked with physical deterioration and ageing; the second one is the neighborhood accommodating one-person households through another densification, consequently worsening the living environment; the third one is the neighborhood losing the typical characteristic of low-rise residential areas and transformed to APT-dominant as accommodating ‘families’, often with higher income. The major trajectories of low-rise residential districts illustrate the neighborhoods have been losing their inclusiveness and adaptability regardless of the direction.

The study of the second chapter is based on the premise that urban morphology not only plays a direct role in residential energy demand but also has an indirect role through building physics. By empirically investigating a neighborhood in Seoul on a building-level, the study proved that architectural, land-use and urban design variables were important factors that significantly affected building physics. Particularly, the indirect but significant contribution of land use and urban design to building physics via architectural attributes was identified, which was rarely addressed in previous studies. The results showed that, above all, the specific locational and spatial conditions of an individual land lot and the resultant underuse of land inhibited changes of poor building conditions. Hence, unlike the implications of prior studies that could be achieved merely with the physical remedies of the urban fabric and building forms, this study discussed where thermally inefficient housings to be found and why to address diverse policy measures that would improve energy efficiency in existing urban areas.

Furthermore, it implied how the energy issue should be discussed in relation to larger discourses such as urban decline and regeneration.

The underlying limitation of this study resulted from the fact that the investigation was conducted only within a single neighborhood in Seoul. It means that the external validity of the detailed results from this study is limited. Hence, variables and indicators need to be elaborated beyond the local context. Broadly, on the basis of the climatic zone, and narrowly, on the basis of the morphological characteristics and location even within a city, different variables need to be included in the thermal efficiency mechanism.

Another limitation is that only the effects of morphology on building physics were examined in this study. Based on the basic premise of this research, the overall effect through the direct and indirect influential paths of morphology on energy demand needs to be quantitatively examined. Also, other energy demand factors such as the occupant aspects need to be studied in relation to urban morphology and building physics. For example, the reason for the lack of active refurbishment can be inferred to be a problem of owners or occupants who cannot afford such reinvestments. Including such considerations would better refine the understanding of energy demand in further studies. Last, policy contexts of urban/architecture/housing are also factors that may strengthen or weaken the mechanism of residential thermal performance problem, which is another dimension to be explored in future.

The research of the third chapter aimed to expand the knowledge on fuel poverty, surpassing the limitations of income and estimated energy costs, by

examining housing thermal efficiency and actual heating energy use, and by focusing on tenure type and ownership characteristics. The empirical evidence calls for reconsidering the stereotyped fuel poverty in Korean policy frame which relies on inadequate definitions and predictions. The study emphasizes that low-income families who rent thermally inefficient homes and are unable to cover high fuel costs are only a part of the population who do not enjoy comfortable indoor environments.

The main results of the research demonstrated that poor thermal efficiency was a direct attribute of the building condition. At the same time, inefficiency was clearly related to tenure type and ownership characteristics. In the study area, the majority of households living in cold homes due to lower thermal efficiency or insufficient heating were the elderly homeowners, who had rarely been received attention through the city's policy frame. This implies that a different targeting approach is needed in dealing with thermally inefficient homes which form a crucial part of the fuel poverty problem. The study also confirms that actual heating energy consumption in response to thermal efficiency varies greatly, and therefore, fixed criteria of energy consumption may be too rigid to capture the reality of fuel poverty.

The findings highlight two categories of fuel poverty that demand further attention in developed metropolitan areas including Seoul. First, the problem of elderly owner-occupied housings using excessive energy for heating needs to be tackled. While the decrease in home-ownership weakens the relationship between income and housing, the owner-occupant households with low disposable income

should no longer be neglected when considering fuel poor households. Second, the issue of occupants who live in relatively decent housing yet use extremely little heating needs to be managed as well. Due to technological advancements of building industry and greater public attention on climate and energy issues, the overall thermal efficiency of dwellings is expected to gradually improve over the years, including public housings where the most economically marginalized households are accommodated. However, restricted energy use will persist in poor households in the context of high living costs in metropolitan areas with continuously rising fuel costs.

The empirical investigation generally implemented in a neighborhood of Seoul, not targeting any specific group of households or dwellings, was differentiated from previous approaches of fuel poverty policy in South Korea. However, more empirical studies supported through larger universal data are required to further bolster the suggestions of the paper. Data on actual internal temperatures of homes and interviews with occupants and homeowners could also reinforce the findings of the research. As a conclusive remark, the study recognizes that the specific results of the paper are rooted in the context of Seoul, and therefore wider implications for other areas should be appropriated in recognition of actual thermal efficiency and heating experiences conditioned by the local housing market and policy contexts.

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## Introduction

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# APPENDIXES

## Appendix 1-A. Hierarchical clustering analysis result of the age structure in low-rise residential districts, Seoul

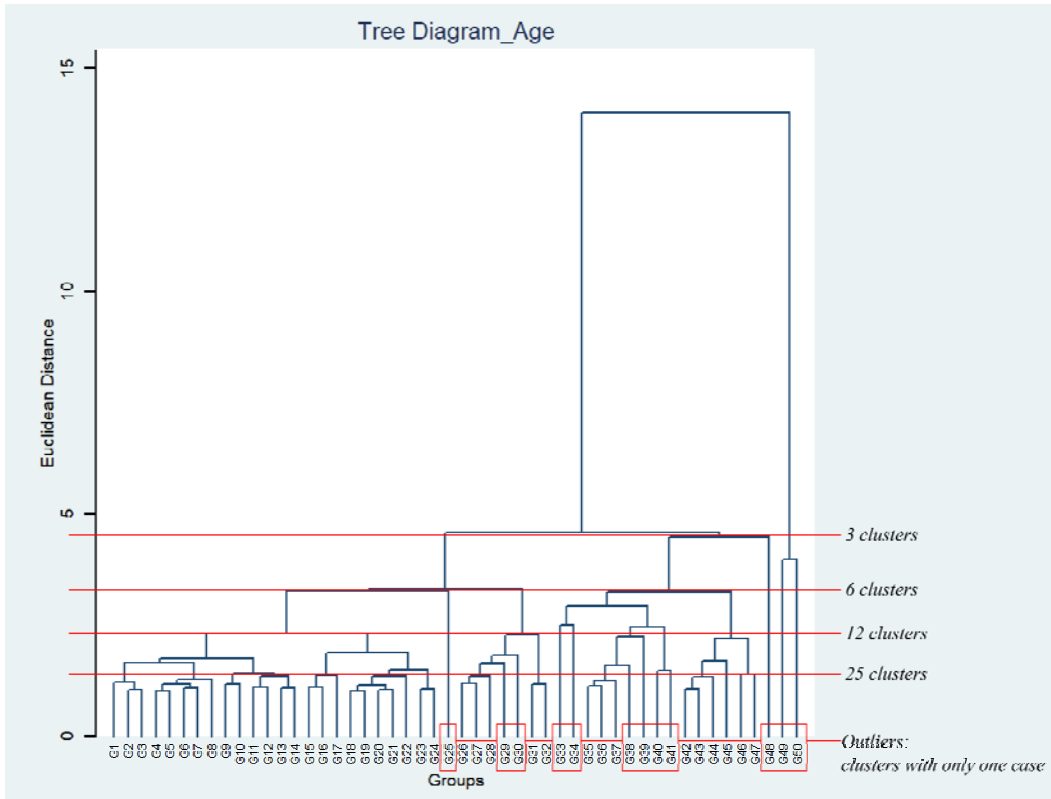


Figure 1-A1 Tree diagram – Age structure

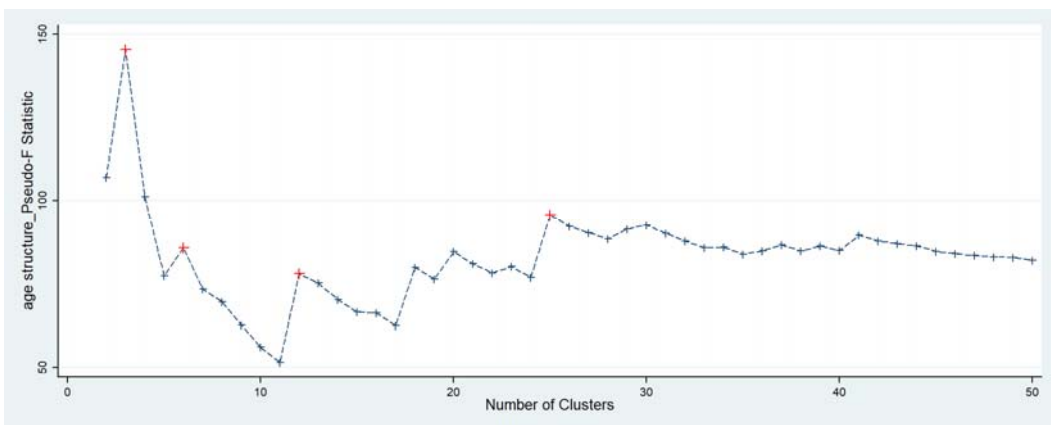
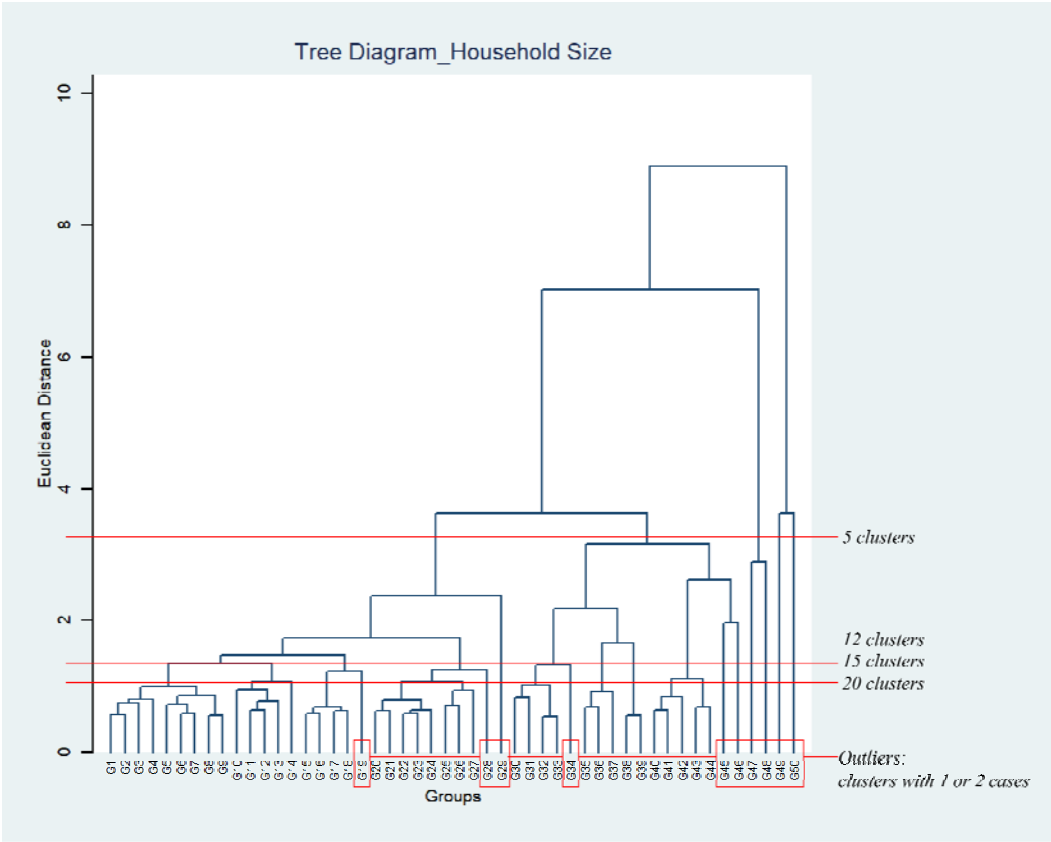


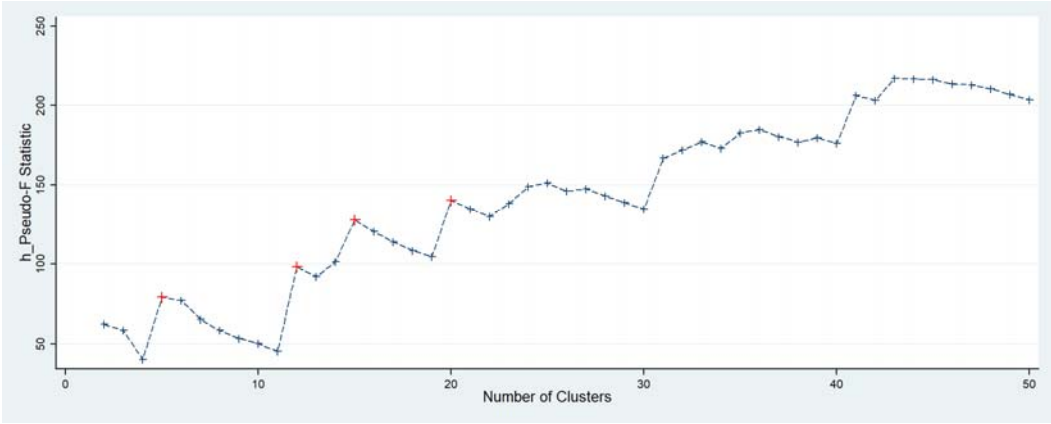
Figure 1-A2 Pseudo-F statistic versus the number of clusters at each step



# **Appendix 1-B. Hierarchical clustering analysis result of the household size in low-rise residential districts, Seoul**

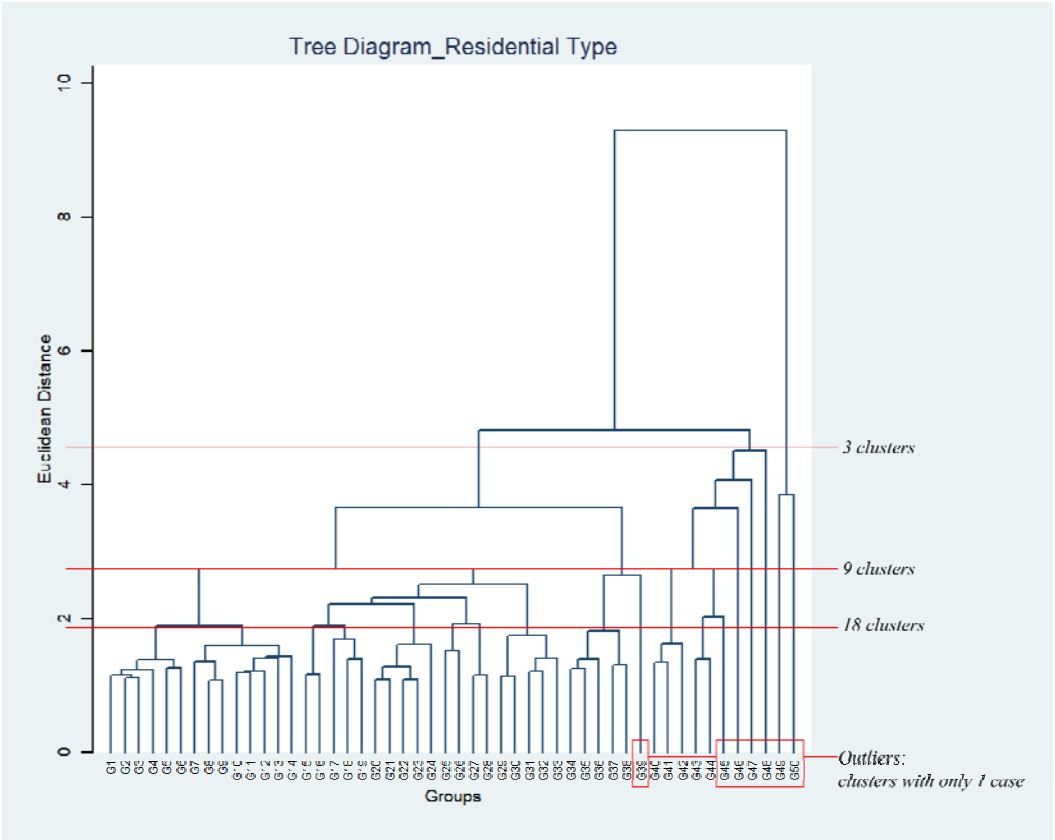


**Figure 1-B1** Tree diagram of household size clusters

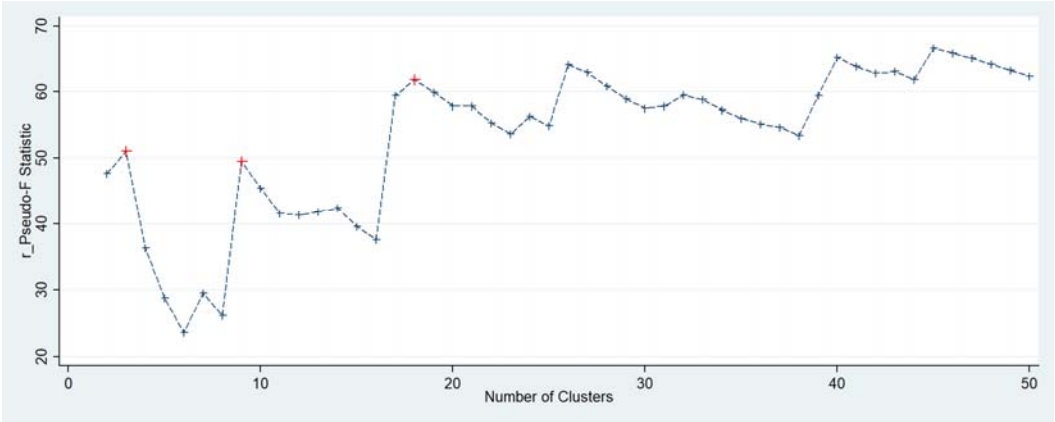


**Figure 1-B2** Pseudo-F statistic versus the number of clusters at each step

# **Appendix 1-C. Hierarchical clustering analysis result of the housing stock and residential type in low-rise residential districts, Seoul**

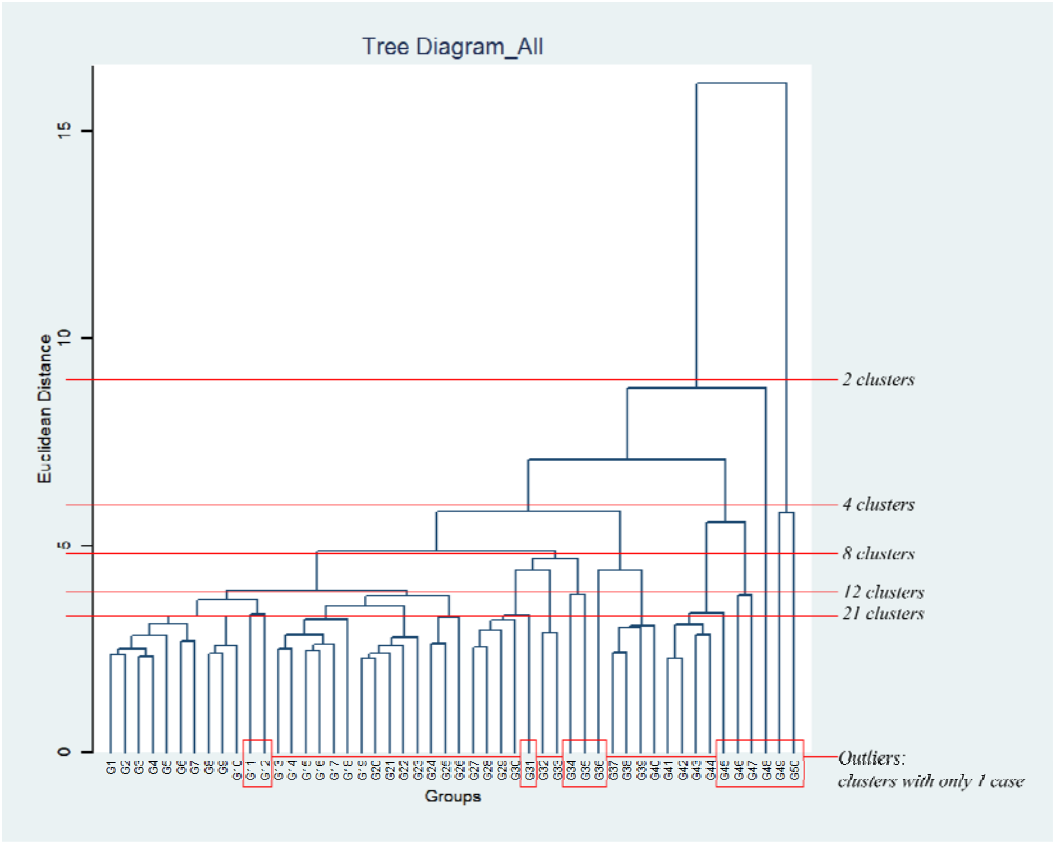


**Figure 1-C1** Tree diagram of housing stock and residential type clusters

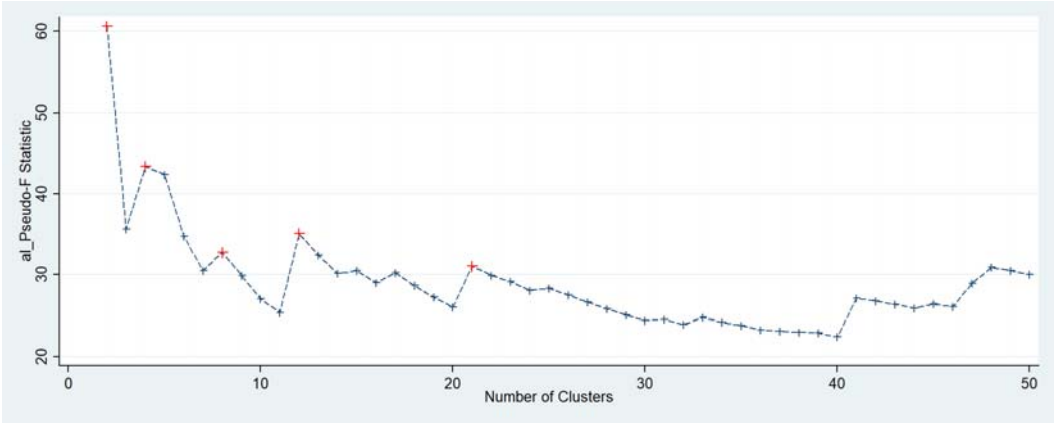


**Figure 1-C2** Pseudo-F statistic versus the number of clusters at each step

# **Appendix 1-D. Hierarchical clustering analysis result of the population and housing stock in low-rise residential districts, Seoul**



**Figure 1-D1** Tree diagram of population and housing stock clusters



**Figure 1-D2** Pseudo-F statistic versus the number of clusters at each step

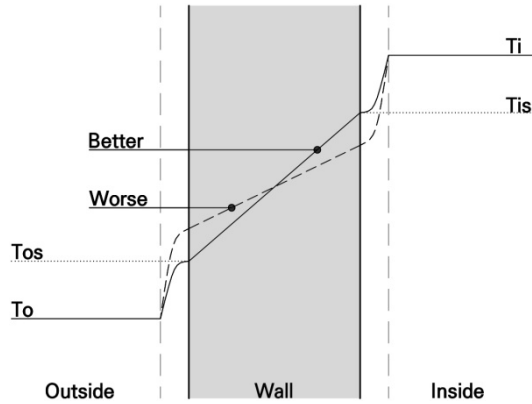
## Appendix 2-A. Thermal efficiency measurement using thermography

Using the infrared images, the insulation performance of external walls can be assessed based on the inside and outside air temperatures ( $T_i$ ,  $T_o$ ) and the surface temperatures ( $T_{is}$ ,  $T_{os}$ ) of the walls. The better the insulation performance is, the closer the surface temperatures of the wall will be to the internal and external air temperatures; if the insulation performance is low, the internal surface temperature is low and the external surface temperature is high as shown in Figure A.1. Such a principle can be represented with *TRD* equations (Eq. A.1) that calculates how close the surface temperature ( $T_{is}$  or  $T_{os}$ ) is to the air temperature ( $T_i$  or  $T_o$ ) as compared to the difference between  $T_i$  and  $T_o$ . When using infrared images taken from outside of the building, as in this study, the external surface temperature is adopted to calculate the thermal performance function (*TDRo*) and the *TDRo* is multiplied by the wind correction factor ( $F_w$ )<sup>23</sup> to revise the effect of wind velocity (Dall'O, 2013; KS F2829:2005, 2010). The *TDRo* value can range from 0 to  $-1$ , with 0 indicating perfect insulation performance and  $-1$  indicating no insulation performance, theoretically.

In this study, each  $T_{os}$  of 400 sample buildings was collected from thermal information of their infrared images. Due to the difficulty with direct data collection,  $T_{is}$  was assumed to be 20°C, which was about average indoor temperature of homes in the central region including Seoul during winter (Kim et al., 2013; Hwang et al., 2015; Land & Housing Institute of Korea, 2014). This assumption can make more and less measurement error in calculating *TDRo*.

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<sup>23</sup> Appendix B of KS F2829: <Correction Table for External Surface Temperature Difference Ratio (*TDRo*) Based on the Changes in Air Flow Rate>



**Figure 2-A1** The temperature distribution in the section of an external wall

**Eq. 2-A1** TDR equations

$$TDR_o = (T_o - T_{os}) / (T_i - T_o) F_w$$

$$TDR_i = (T_i - T_{is}) / (T_i - T_o)$$

$T_o$ : the outside air temperature (AWS<sup>24</sup> data of the study area at that time of survey)

$T_i$ : the inside air temperature = 20°C /  $T_{os}$ : the outside surface temperature of outer wall

$T_{is}$ : the inside surface temperature of outer wall /  $F_w$ : wind correction factor

Among six heat leakage indicators in this study, TW, RF, BOT and WIN were the TDRo of each part of the building. The heterogeneity in the insulation performance of the external wall (WHL) was estimated using the differences in TDRo value between two points with the highest and the lowest temperatures of the external wall surface. Here, the TDRo values were multiplied by -1 to make the indicators positive values. Also, in calculation of RF, BOT and WIN, Th was added to Tos of each part in order to correct the effect of the measured point's height.

<sup>24</sup> The Korea Meteorological Administration, <Detail meteorological observation data by Automatic Weather Station>, [http://www.kma.go.kr/weather/observation/aws\\_table\\_popup.jsp](http://www.kma.go.kr/weather/observation/aws_table_popup.jsp)

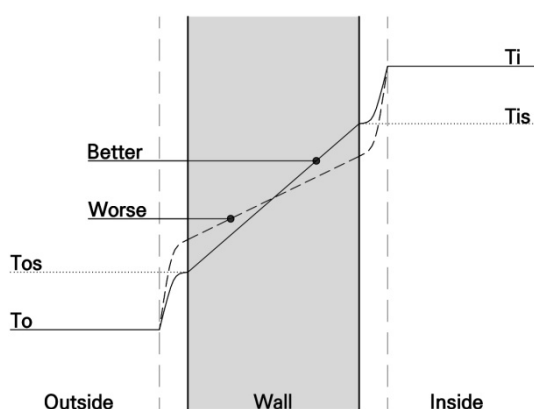
## Appendix 2-B. Correlation matrix of the variables

	A_year	A_ref	A_ext	A_wal	A_win	A_exp	A_pil	L_far	L_com
A_year	1								
A_ref	-0.685	1							
A_ext	0.216	-0.205	1						
A_wal	-0.796	0.690	-0.234	1					
A_win	-0.412	0.590	-0.181	0.374	1				
A_exp	-0.256	0.145	0.025	0.240	0.103	1			
A_pil	0.694	-0.741	0.223	-0.628	-0.474	-0.099	1		
L_far	0.675	-0.453	0.120	-0.662	-0.168	-0.173	0.465	1	
L_loc	-0.112	0.157	-0.119	0.125	0.086	-0.329	-0.191	0.087	1
L_own	-0.634	0.609	-0.189	0.627	0.418	0.123	-0.726	-0.535	0.294
U_loc	-0.068	0.083	-0.124	0.086	0.101	-0.194	-0.053	0.098	0.665
U_sta	-0.033	-0.049	0.026	0.062	-0.102	0.253	0.005	-0.051	-0.058
U_rd	0.075	-0.123	0.017	-0.075	-0.076	0.223	0.139	0.039	-0.260
U_wrd	0.109	-0.061	-0.156	-0.090	0.026	-0.248	-0.005	0.293	0.419
U_nrd	0.120	-0.087	-0.049	-0.135	-0.092	-0.142	0.050	0.269	0.192
U_lot	0.297	-0.356	0.031	-0.322	-0.186	-0.181	0.316	0.155	0.028
U_bl	-0.001	0.091	-0.148	0.155	0.003	0.069	-0.092	-0.145	-0.055
U_red	-0.381	0.344	-0.007	0.364	0.097	0.151	-0.344	-0.367	-0.059
U_lev	0.137	-0.161	0.028	-0.144	-0.090	0.122	0.167	0.140	-0.214

	L_own	U_loc	U_sta	U_rd	U_wrd	U_nrd	U_lot	U_bl	U_red
L_own	1								
U_loc	0.160	1							
U_sta	0.015	-0.039	1						
U_rd	-0.180	-0.231	0.412	1					
U_wrd	-0.054	0.450	-0.156	-0.239	1				
U_nrd	-0.144	0.175	-0.048	-0.051	0.336	1			
U_lot	-0.434	0.028	0.053	0.02	0.092	0.036	1		
U_bl	0.126	0.029	0.104	-0.048	-0.059	-0.147	-0.192	1	
U_red	0.447	-0.116	-0.018	-0.004	-0.231	-0.267	-0.519	0.334	1
U_lev	-0.252	-0.200	0.103	0.330	-0.097	-0.031	0.327	-0.125	-0.107

### Appendix 3-A. Thermal performance measurement using thermography

Infrared thermography method which allows estimating of the actual insulation performance of building envelop, is guided by the relevant international rules, ISO 6781 and EN 13187. This study adopted corresponding Korean standard KS F2829:2005 (2010)<sup>25</sup>.



**Figure 3-A.1** The temperature distribution in the section of an external wall

As shown in Figure 3-A.1, the insulation performance is defined with the inside and outside air temperatures ( $T_i$ ,  $T_o$ ) and the surface temperatures ( $T_{is}$ ,  $T_{os}$ ) of the outer walls and infrared image analysis provides the surface temperatures. More specifically, the outer wall with better insulation performance shows its inside and outside surface temperatures ( $T_{is}$ ,  $T_{os}$ ) respectively closer to the outside and inside air temperatures. In other words, when the outer wall is thermally inefficient, the internal surface temperature is relatively low and the external surface temperature is relatively high. Equations of  $TDR_o$  and  $TDR_i$  (Eq. 3-A.1) quantitatively compute the ratio of the differences between surface

<sup>25</sup> <Thermal performance of buildings - Quantitative detection of thermal irregularities in building envelopes - Infrared method>

temperatures and air temperatures to the difference between  $T_i$  and  $T_o$ . As this study took infrared images from outside of a building, TDRo was adopted and multiplied by the correction factor<sup>26</sup> to attenuate the effect of wind velocity (Dall'O et al., 2013; KS F2829:2005, 2010). The TDRo value can range from 0 to -1, theoretically. The closer to 0 means better insulation performance and the closer to -1 poor.

#### Eq. 3-A.1 TDR equations

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$$TDRo = (T_o - T_{os}) / (T_i - T_o)F_w$$

$$TDRi = (T_i - T_{is}) / (T_i - T_o)$$

$T_o$ : the outside air temperature (AWS<sup>27</sup> data of the study area at that time of survey)  
 $T_i$ : the inside air temperature = 20°C /  $T_{os}$ : the outside surface temperature of outer wall  
 $T_{is}$ : the inside surface temperature of outer wall /  $F_w$ : wind correction factor

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### Appendix 3-B. Infrared survey

The infrared images of 360 residential building samples were taken in January and February of 2016 when the temperature fell below -5°C, over 8 days from 9 pm to 2 am with Fluke Ti95 and Flir T420 infrared cameras. As the sampled buildings consist of various housing types with different shapes and sizes, the guidelines for infrared photographing were followed as Figure 3-A.2.

### Appendix 3-C. Measurement of six thermal performance indicators

The thermal performance of the individual residential building was evaluated based on six indicators in Table 3-C.1. These indicators were chosen based on

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<sup>26</sup> Appendix B of KS F2829: 2005, <Correction Table for External Surface Temperature Difference Ratio (TDRo) Based on the Changes in Air Flow Rate>

<sup>27</sup> The Korea Meteorological Administration, <Detail meteorological observation data by Automatic Weather Station>, [http://www.kma.go.kr/weather/observation/aws\\_table\\_popup.jsp](http://www.kma.go.kr/weather/observation/aws_table_popup.jsp)



Korean residential insulation standards<sup>28</sup> and other related research (Choi et al., 2004; Choi & Son, 2010)<sup>29</sup>. Among them, the four indicators - the external wall (*TW*), roof (*RF*), lowest floor (*BOT*) and window frame (*WIN*) - show the insulation performances of major parts of a building. The others - heterogeneity in the insulation performance of external wall (*WHL*), and the presence of heat bridges (*HB*) indicate the problematic aspect of heat loss. These six indicators were scaled from analysis of infrared images, which captured the highest, the lowest, and the average temperatures within a selected boundary of the building surface with analytical software like *Smart View* and *FLIR ResearchIR*.

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<sup>28</sup> These standards regulate the insulation performance of the external wall, highest floor (roof), lowest floor, and the window.

<sup>29</sup> From the research, heat bridge types caused by the general architectural and structural characteristics of Korean urban residences were referred.

## 국문초록

# 서울 저층주거지의 도시형태 및 인구학적 특성과 주거의 열 환경에 미치는 영향

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서울의 저층 주거지는 지난 반세기 급격한 도시화 과정에서 다양하고 저렴한 주택을 공급하며 서울의 주택난 해소에 큰 기여를 해왔다. 그러나 대규모 공공 채원의 투입 없이 단시간에 주택 공급을 확대하기 위해 체계적인 계획을 하기 보다는 관련 법규를 거듭 완화하여 민간의 자발적인 필지 단위 재건축을 유도하였고, 그 결과 전반적인 고밀화에 따른 거주 환경의 악화와 산발적인 쇠퇴에 직면해 있다. 따라서 과거와 같은 대규모 재개발이나 획일적인 규제 완화를 통한 필지 단위 재건축은 더 이상 저층 주거지를 위한 해법이 될 수 없다. 저층 주거지를 건전하고 지속 가능한 방향으로 관리하기 위해서는 저층 주거지의 역동성을 반영한 장소 기반의 계획적 접근이 필요하며, 본 논문은 이를 위한 실증적 기초를 마련하는데 목적이 있다. 특히 저층 주거지의 문제적 상황을 주택의 물리적 노후 자체에 한정 짓기보다는, 그 이면에 저층 주거지의 도시 형태적 특성은 물론, 개별 필지의 토지 이용, 소유권 및

소유주, 거주자 특성 등이 결부된 저층 주거지의 메커니즘 속에서 이해하고자 한다. 이를 위해 다음과 같은 세 개의 연구를 진행하였다.

첫 번째 연구의 목적은 서울 저층주거지의 인구와 주택재고 변화의 역동성을 규명하고 유형화하는데 있다. 1990년대 말 이후 서울의 인구는 정체기에 접어들었음에도 불구하고, 서울의 주거지는 2000년 이후에도 거주 인구와 도시 형태의 극적인 변화를 겪었다. 이 연구는 동 단위 자료를 기초로 주택 재고의 변화뿐만 아니라 인구 변화의 측면에서 저층주거지의 다양성을 탐색하였다. 기술통계와 군집분석 결과는 저층주거지가 내적 고밀화를 통해 서울의 고령화와 가구수 증가를 흡수하였지만, 그 기여의 정도는 다양한 주택 유형의 변화와 더불어 지역별로 상이하게 나타남을 확인한다. 저층 주거지의 균일하지 않은 전환은 결과적으로 거주자의 인구학적 특성에 따른 서울의 주거지가 공간적인 분화로 이어졌으며, 이는 일반규제의 조정이 아닌 세분화된 저층주거지 유형에 기초한 맞춤형 접근의 필요성을 제기한다.

두 번째 연구는 도시 형태가 주거용 에너지 수요에 미치는 영향에 대한 이해를 확장하는데 목표를 두며, 물리적 도시 형태의 직접적인 효과에만 초점을 둔 기존 연구의 한계를 넘어서고자 한다. 이 연구는 세 개의 도시 형태적 요인—도시 공간적 조건, 토지 이용, 건축적 속성—이 주거용 건축물의 열 효율성과 나아가 에너지 수요에 영향을 미치는 간접적 경로를 제안한다. 이 대안적 메커니즘을 확인하기 위해, 서울의 한 주거지를 대상으로 건물 단위의 실증 데이터를 구축하고 구조 방정식 모형을 이용하여 분석하였다. 도시 형태 모형은 주택 열 효율의 차이를 상당부분 설명하며, 건축적 속성이 미치는 직접적인 영향뿐만 아니라 도시 디자인 및 토지 이용 특성이 다른 변수들을 통해 간접적으

로 기여하는 바를 드러낸다. 예를 들어 필지의 불리한 도시 디자인적 조건들은 토지의 현저한 저이용과 결합되어 결과적으로 주거의 열 효율 개선을 지연시킨다. 재개발에 대한 기대나 복잡한 부동산 소유권 또한 재투자 노력을 저해한다. 끝으로 이러한 결과로부터 도출된 정책적 함의를 논의하였다.

세 번째 연구의 목적은 우리나라 도시 맥락에서 연료 빈곤에 취약한 거주자 집단을 확인하는 것이다. 그로부터 이 연구는 연료 빈곤 문제가 사회적, 공간적 맥락에 따라 다른 방식으로 나타나며, 따라서 가구 소득과 난방 비용 만으로 규정되는 단순한 기준을 넘어 보다 맥락화된 정책적 접근이 필요함을 강조한다. 추운 집의 본질적인 의미를 놓치지 않기 위해, 서울의 한 주거지를 대상으로 개별 주택의 열 효율과 실제 난방의 실증 데이터를 점유 유형과 소유자 특성에 따라 분석하였다. 결과는 실제 난방에너지 소비량이 주택의 열 효율이나 점유 유형과 명확한 관계가 없음을 보여주었다. 또한 오래된 단독주택과 같은 매우 비효율적인 주택들에 주로 적절한 유지관리를 위한 재정적 능력과 의지가 부족한 노인 소유주들이 거주하는 것으로 나타났다. 이러한 결과는 추운 집에 살고 있는 사람들이 항상 임대주택에 살고 있는 저소득층이라고 볼 수 없음을 시사한다. 주택의 열 효율과 난방 행태의 분석에 기초하여 잠재적인 연료 빈곤층의 새로운 유형들을 제시하였다.

주요어: 저층 주거지, 인구학적 변화, 주택 유형, 지불가능 주택, 주거용 에너지 사용, 도시 형태, 토지 이용, 구조방정식, 연료 빈곤, 열 효율, 실 난방소비, 점유 유형, 소유권, 서울

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