



# Prioritisation of old apartment buildings for energy-efficient refurbishment based on the effects of building features on energy consumption in South Korea



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## ABSTRACT

Since the 1970s the construction of high-rise apartments has been prolific across Asia. More recently, due to changes in legislation, there has been a growing trend towards refurbishment for those old apartments, however this has primarily focused on the economic benefits and rarely taken energy saving and the reduction of carbon emissions into account. Therefore, this study aims to evaluate what features in old apartment buildings need to be taken into account in refurbishment strategies. The method is three-fold: evaluating energy consumption in old apartment buildings; identifying effective building features on energy consumption; and ranking the effects of building features on energy consumption. The results show that old apartment buildings have consumed excessive energy for space heating and cooling. Maximum 43.65 kWh/m<sup>2</sup>/year in space heating and 5.70 kWh/m<sup>2</sup>/year in cooling were reduced as a result of the transformation of eight building features, accounting for 70.9% of total variance in factor analysis. Three most influential features, which should be used to priorities for refurbishment schemes, have been identified by multiple regression analysis: the conditions of building envelopes, heating methods and the sizes of building units. Therefore, the priority should be given to these three features.

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## 1. Introduction

In Asian countries that experienced dramatic economic growth such as Japan, Hong Kong, Singapore and South Korea [1], high-rise apartment building became one of the most dominant types of housing [2,3]. The refurbishment of those buildings is a common issue after more than 40 years of extensive construction of apartment buildings. This issue can be also extended to some countries such as China and Malaysia that have experienced the economic growth in recent years.

In South Korea, ranked 8th for Green House Gases (GHGs) emissions [4], for instance, the Government has attempted to reduce carbon emissions of the country by enhancing building regulations and policies. Apartment buildings were required to be energy-efficient since 2001 [5]. In 2009, a new law, 'Framework Act on Law Carbon Green Growth', required higher levels of energy efficiency in buildings [6]. Despite these attempts, energy consumption in residential buildings has not declined [7], and carbon emissions

in South Korea have also not reduced [4]. Several studies such as [8,9] have criticised this unwanted outcome. Particularly, Kim [9] claims ineffective energy reduction in residential buildings was due to energy consumption in old apartment buildings, which were excluded in the energy-efficient scheme. In the building stock of South Korea, the largest proportion of all building types is residential buildings, which amounts to 67.1% [10]. 58% of the residential building stock is apartment buildings [11], which is the most dominant proportion. 63% of apartment buildings were constructed before 2001 [11,12] when the higher levels of energy-efficient scheme were applied to buildings. In this aspect, the old apartment buildings constructed over 20 years ago, which occupies the largest proportion in the building stock of South Korea, were not counted to be energy-efficient.

There has been a controversial debate amongst policy-makers, building developers and residents in South Korea during the last decade as to whether old apartment buildings should be demolished or refurbished. However, policy-makers have proposed to refurbish old apartment buildings to contribute reducing carbon emissions rather than demolish those buildings. As a result, building regulations have been altered in recent years to encourage refurbishment and reduce demolition of old apartment buildings. The South Korean Government, for example, has permitted

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developers to increase the number of floors on top of apartment buildings in case of refurbishment [13]. This policy can represent the governmental intention to vitalise refurbishment.

Despite the governmental efforts, there are limits in current and recent literature in terms of creating effective strategies of refurbishment for old high-rise apartment buildings to reduce energy consumption. Firstly, great attention has been paid to economic profit rather than reducing energy consumption or carbon emissions. The concept of refurbishment in existing literature such as [14,15] was identified by maximising economic profit, and the strategies of refurbishment were focused on cost-effectiveness. Therefore, the strategies would not necessarily be beneficial to reduce energy consumption. Secondly, existing literature, engaging with energy efficient technologies, does not cover old apartment buildings that need to be refurbished [16–20]. It relies on the ‘Standard housing’ model which draws the thermal condition of buildings from simplified indices [21], assuming that building features affecting energy consumption in all apartment buildings are the same. However, the building features in old apartment buildings were changed by different design preferences in different periods and contexts. The existing literature does not take into account the transformation of building features in old apartment buildings that have been constructed in different periods and contexts [22–28]. This study argues that the transformation of building features affects energy consumption and needs to be taken into account when creating refurbishment strategies.

This study, therefore, focuses on identifying old high-rise apartment buildings in South Korea which need to be refurbished to reduce energy consumption. Furthermore, the most efficient strategy of refurbishment will be identified by investigating building features and their effect on energy consumption in those apartment buildings. Three questions will be answered:

- What are the levels of energy consumption in old apartment buildings? Do these levels of consumption need to be reduced?
- Which features in old apartment buildings have affected the energy consumption?
- Which building features should be prioritised in refurbishment strategies in order to reduce energy consumption?

## 2. Methodology

The methodology is designed to analyse the impact of building features in old apartment buildings on actual energy consumption. The results will help to prioritise which building features can most effectively reduce energy consumption and thus guide the creation of refurbishment strategies. The method is threefold: evaluating energy consumption in old apartment buildings; identifying effective building features on energy consumption; and ranking the effects of building features to energy consumption.

### 2.1. Evaluation of energy consumption in old apartment buildings

Energy consumption in old apartment buildings was evaluated to determine the necessity of refurbishment to reduce energy consumption. The consumption in old apartment buildings was, therefore, compared to the consumption in apartment buildings which were certified as energy-efficient. To conduct this, old apartment buildings are defined by those which were constructed before 2001, a year when building regulations for the thermal conditions of apartment buildings was much intensified and building energy rating system was just established. Permission has already given for some of these buildings to be refurbished; others will be available to be refurbished in 2015 by a building regulation in South Korea [29]. In contrast, the comparison group of apartment

buildings were certified as energy-efficient in an energy rating system set by Korea Land and Housing Corporation in South Korea [30]. The three values of energy consumption in the both groups were compared: total end-use energy consumption; space heating and electricity consumption by construction years; and monthly energy consumption for space heating and electricity. The result is shown in Section 3.1.

### 2.2. Identification of building features affecting energy consumption

Building features in old apartment buildings were identified by reviewing previous literature and surveying existing old apartment buildings. To prioritise building features in refurbishment, this study was, particularly, focused on the transformation of building features rather than characteristics which are commonly found in all buildings. It is difficult to precisely divide time periods of each feature. Instead, this study used the dominant designs since the 1980s, as described in Fig. 1. Three distinctive trends are identified in the transformation of building features in old apartment buildings constructed before 2001.

First of all, the main purpose in the early stage of apartment construction was to accommodate a rapidly increased urban population and building features were chosen accordingly whilst building features in the late stage were transformed to acquire higher levels of privacy in each apartment building [25]. For example, between the mid-1970s and 1980s, large volume apartment clusters of more than 20 buildings were constructed as governmental-led projects [31]. During the 1990s, the size of apartment clusters was reduced when the government handed over apartment construction to private developers [31]. Total cluster areas were also changed with the transformations of the size of apartment clusters, but it was differently evolved as the higher requirements for public space with service facilities [32]. Moreover, apartment buildings constructed in the early stage were designed with longer lengths and smaller sized units. A maximum of 8–10 apartment units were placed on each floor; thus small unit sizes of less than 60 m<sup>2</sup> (70 m<sup>2</sup> including communal space) were constructed in the 1980s [26]. Since privacy has become a sensitive issue, buildings with a stair type whereby only two units share one vertical access points (called a ‘core’) are preferred [25].

Second, economic profit has also been a significant factor to transform the building features in old apartment buildings. For instance, three types of building layout can be identified [23,33–35]: the linear type where buildings are long and thin in plan and located parallel to one another; the square type where buildings are square in plan; and the grid type where buildings are located on a grid. According to Jeon [25], the linear type was the typical design type in the early stage of apartment construction in South Korea, but the design was changed to square and grid type to accommodate more buildings. The sizes of building units were also enlarged; thus the most dominant unit size became about 85–100 m<sup>2</sup> (about 100–120 m<sup>2</sup> including communal space) [26].

Third, some building features were transformed by stringent policies and the development of technologies. The thermal conditions of envelopes in old apartment buildings have been determined by a building regulation [36]. The regulation determining the thermal conductivity of materials and the thickness of insulations required was firstly established in 1980. Since 1980, there have been two significant revisions to the regulations in 1984 and 1987, and in 2001, a significant improvement was made. Therefore, buildings constructed before 1980 have no thermal insulation in their envelope which created a poor thermal environment for residents. The second revision, implemented in 1987, required all apartment buildings to be equipped with double glazing. Despite the dramatic increase in apartment construction in the 1990s [11],

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