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The effect of external walls on energy performance of a Korean traditional building

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ABSTRACT

As one possible approach to improving the energy performance of the eco-friendly Korean traditional building, this study develops an energy simulation model to investigate the influence of five types of alternative walls – a mud brick wall, a cement brick wall, an ALC block wall, a CRC board wall, and a chaff charcoal wall – on the energy performance of Korean traditional buildings in three different climate zones in South Korea – a central region, a southern region, and a Jeju Island region. The results of the simulation study indicate that the cement brick wall provides the highest energy saving and the mud brick wall provide the lowest energy saving for all three climate regions. For five types of alternative walls, the Korean traditional building with small window area shows a better energy performance than the traditional building with large window area in all three climate regions. The results of this study can be used as basis data for estimating the potential energy saving with the replacement of alternative walls under the regional climate consideration.

1. Introduction

At the 2015 United Nations Climate Change Conference in Paris, 195 developed and developing nations agreed to make an effort commitment to mitigate the impact of carbon dioxide emissions on global warming, with the goal of a global temperature increase limitation of 2 °C (The United Nations Framework Convention on Climate, 2015). Since the international Kyoto Protocol treaty, as the ninth largest source of carbon dioxide emissions in the world (Korea Energy Economic Institute (KEEI), 2009), the South Korean government has made continuous effort commitments to decrease annual carbon emissions in all industries (Sonnenschein & Mundaca, 2015). One of the largest industries in South Korea, the construction industry is a major source of raw material and energy consumption, at approximately 40% of the total raw material and 30% of the total energy consumed in South Korea (EPA, 2006). Due to the impact of the building sector on both the economy and the environment, the South Korean government has established and implemented various environment policies and regulations to mitigate the environmental impacts of the building sector in terms of energy efficiency and carbon emission reduction (Kim, Cho, & Kim, 2013).

In response to the government's increasing concerns about energy efficiency and carbon emissions in the building sector, the potential value of Korean traditional buildings has been recently revitalized. This type of structure is eco-friendly in terms of construction methods, building construction materials, and landscaping methods (Kim, 2013). Since the Korean traditional building, called Han-Ok, is mainly constructed by manpower using natural building materials – clay, stones, and wooden materials (Kim, 2013), it can be considered as an alternative residential building to reduce the carbon emissions generated from the building sector in South Korea. One drawback of the Korean traditional building is that it is a non-insulated timber framework building, which is not energy efficient. To be more energy efficient, the Korean traditional building requires alternative building envelopes to improve thermal efficiency.

Various research studies have examined the effect of insulated walls on the energy performance of a residential building's operation stage. It has been demonstrated that thermally insulated building walls are an effective method for improving the energy performance of residential buildings by decreasing energy demands for cooling and heating (Ghrab-Morcos, 2005; Griego, Krarti, & Hernández-Guerreron, 2012; Filippin, Flores, & Lopez, 2008; Gustavsson & Joelsson, 2007; Hasan, Vuolle, & Siren, 2011;

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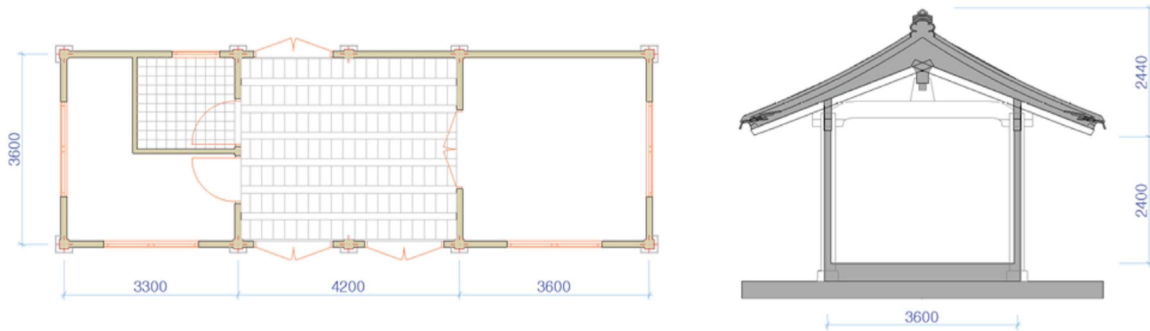

Fig. 1. The drawing of the Korean traditional building under the case study.

Ihm & Krarti, 2012; Ruiz & Romero, 2011; Tuhus-Dubrow & Krarti, 2010; Yao, 2012; Yu, Yang, Tian, & Liao, 2009; Znouda, Ghrab-Morcos, & Hadj-Alouane, 2007; Risholt, Time, & Hestnes, 2013). Some studies demonstrate that the thermal improvement of an external wall is more effective than the thermal improvement of an internal wall in the energy improvement of residential buildings (Kolaitis et al., 2013; Aste, Adhikari, & Manfren, 2013), while the energy consumption of a residential building in the cold regions is more influenced by an insulated wall (Ucar & Balo, 2010). A proper selection of thermal insulation improves the energy efficiency of a building by decreasing the rate of heat transfer (Kaynakli, 2012).

Several research studies have investigated the impact of insulation materials for an energy efficient residential building. The research studies found that expanded polystyrene is the proper insulation material in terms of economic aspect (Anastaselos, Oxizidis, & Papadopoulos, 2011; Asadi, Silva, Antunes, & Dias, 2012; Asadi, Silva, Antunes, & Dias, 2012), and cellulose fiber wool is the proper insulation material in term of environmental aspect (Dylewski & Adamczyk, 2011), while fiberglass is the proper insulation material in terms of both economic and environmental aspects (Fesanghary, Asadi, & Geem, 2012; Bichiou & Krarti, 2011; Lollini et al., 2006).

In addition to insulation materials, some studies consider the optimum thickness of insulation as the most cost-effective method of increasing the energy performance of residential buildings (Lollini et al., 2006; Audenaert, Boeck, & Roelants, 2010; Gong, Akashi, & Sumiyoshi, 2012; kapsalaki, Leal, & Santamouris, 2012; Morrissey & Horne, 2012). Since the proper thickness of insulation decreases the thermal bridge effect (Friess, Rakhshan, Hendawi, & Tajerzadeh, 2012; Smeds & Wall, 2007) and the overall thermal transmittance (Hamdy, Hasan, & Siren, 2011) of a residential building, the operation energy consumption of a residential building is reduced, which further mitigates its environmental impact (Citherlet & Defaux, 2007; Beccali, Fontana, Longoa, & Mistretta, 2013). The thickness of insulation is influenced by climate (Ucar & Balo, 2010), insulation material (Ucar & Balo, 2010), energy price (Mohammad & Sharples, 2013), fuel type (Kaynakli, 2008), and the building's orientation (Dominguez, Sendra, León, & Esquivias, 2012; Jaber & Ajib, 2011a; Konstantinou & Knaack, 2013). As the environmental impact of building envelopes is becoming increasingly important, recent studies consider the impact of environmentally friendly walls – an electricity generation wall (Marszai & Heiselberg, 2011; Verbeeck & Hens, 2005; Yu, Yang, & Tian, 2008; Stazi, Mastrucci, & Perna, 2011) and green wall (Wong & Baldwin, 2016)—on the energy performance of residential buildings.

Along with the insulation material and the optimum thickness of insulation, the window-to-wall ratio value is an important factor effecting on the energy performance of a residential building in terms of the thermal energy exchange rate through an external wall (Susorova, Tabibzadeh, Rahman, Clack, & Elnimeiri, 2013). Since a window with a large window area increases the energy consumption of residential buildings (Cheung, Fuller, & Luther, 2005), some research studies investigate the influence of the window-to-wall ratio value on the energy consumption of a residential building (Tuhus-Dubrow & Krarti, 2010; Kaynakli, 2008; Gasparella, Pernigotto, Cappelletti, Romagnoni, & Baggio, 2011; Jaber & Ajib, 2011b). Due to the large influence of the climate conditions on window-to-wall ratio value, it is recommended that the acceptable value of window-to-wall ratio is between 20% and 60% (Jaber & Ajib, 2011a).

A review of the relevant literature on the energy performance of thermally improved buildings indicates an insulated building envelope can improve the thermal efficiency of a building by increasing the heat gain from the building and decreasing the heat loss from the building (Yun, Jeong, Han, & Youm, 2013). However, to date, little research has been conducted on estimating the energy performance of a Korean traditional building during its operation phase. Thus, the objective of this study is to utilize an energy simulation model to analyze the energy performance of the Korean traditional building at the operation stage of its entire life cycle with five types of alternative walls—a mud brick wall, a cement brick wall, an autoclaved aerated concrete (ALC) block wall, a cellulose fiber reinforced cement (CRC) board wall, and a chaff charcoal wall. The results of this study can be used as reference data for builders and policy makers to estimate the energy efficiency of a Korean traditional building with alternative walls in order to improve the energy performance of Korean traditional buildings.

2. Methodology

This study estimates the energy performance of a Korean traditional building with five types of insulated walls – a mud brick wall, a cement brick wall, an ALC block wall, a CRC board wall, and a chaff charcoal wall – during the building's operation stage to estimate the energy savings of each insulated wall compared with a traditional mud-plaster wall at three different regions – a central region (Zone 1), a southern region (Zone 2), and a Jeju Island region (Zone 3). In the building operation phase, the energy is required from the electricity usage for cooling, heating, lighting, and appliance use, as well as the natural gas usage for heating.

2.1. A traditional Korean building

In order to investigate the operation energy consumption of a Korean traditional building with alternative walls, as shown in Fig. 1, this study models a Korean traditional house with traditional mud-plaster walls located in Bukchon Han-ok Village in Seoul, consisting of two buildings including two main halls, five bedrooms, one kitchen, and two bathrooms over the area of 77.13 m^2. As shown in Fig. 2, each Korean traditional building under the case study has 4.9 m of height, 3.6 m of width, and 11.1 m of length. The