Analysis of combinations of glazing properties to improve economic efficiency of buildings

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ABSTRACT

The ideal combination of low solar heat gain coefficient (SHGC) and high visible transmittance (VT) to maximize energy efficiency of buildings is difficult to achieve because the two quantities have a trade-off relationship. This study analyzed the combination to reduce the energy consumption of office and residential buildings, then proposed a guideline to improve the economic efficiency based on energy cost compared with initial investment cost. First, the glazings used in South Korea were investigated and the possible combinations of SHGC and VT were classified. Then the energy consumption of each combination was quantified. As SHGC decreased and VT increased, energy consumption decreased in the office building, but not in the residential building. Next, the economic efficiency was analyzed for each combination. The efficiency of the office building can be improved by weighting to favor energy consumption over investment cost. While due to nonlinear relationship of energy consumption between SHGC and VT in the residential building, the increased investment cost and decreased energy cost should be compared. This study can contribute to decision-making in ambiguous conditions, such as when the energy cost decreases but investment cost increases.

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1. Introduction

The building sector is large consumer of energy and natural resources (Motuziene et al., 2016). Especially, windows increase heat loss when applied to a building envelope (Kontoleon, 2015) and are responsible for approximately 20–40% of the total heat loss of residential buildings (Hee et al., 2015) and 13–35% of office buildings in South Korea (Jang et al., 2007). To decrease energy consumption, glazing that has low thermal transmittance and low solar heat gain coefficient (SHGC) but high visible transmittance (VT), have been developed. These properties are critical from the perspective of energy efficiency (Chen et al., 2017). However, SHGC and VT have a trade-off relationship, which is represented using the Light-to-Solar-Gain ratio (LSG) (Fathoni et al., 2016). The SHGC influences cooling energy and indicates the amount of solar heat that passes through the glazing (Lee et al., 2012). VT influences lighting energy and indicates the amount of natural light that can pass through glazing (Sharp et al., 2014).

Although many previous studies have analyzed energy consumption and economic feasibility according to glazing properties such as thermal transmittance, SHGC, and VT, few studies have simultaneously analyzed the SHGC and VT along with the economic effect. The purpose of this study is to analyze the possible combinations of SHGC and VT, and to quantify how the combinations affect energy consumption and economic feasibility. The comparisons of energy cost and initial investment cost are used to propose a guideline for selection of the economically-efficient exterior glazing for building. For analysis by building types, the analysis considers an office building for mostly-daytime operation, and a residential building for mostly-nighttime operation. The results of this study can be used as reference data to select economically-efficient building exterior glazing for four distinct seasons, because the combination of low SHGC and high VT is not always economically efficient. South Korea has four distinct seasons: it is hot and humid in the summer, but cold and dry in the winter.

This study is composed of two main steps (Fig. 1). First, the exterior glazing used in South Korea are investigated, and the possible combinations SHGC and VT are identified, then a sensitivity analysis of energy consumption is conducted for each combination. Next, the economic feasibility of actual glazing in terms of...
energy consumption that corresponds to the highest, median, and lowest energy combination is evaluated. The glazing costs, energy costs, CO₂ offset price, and real discount rate are included for economic feasibility. Lastly, to increase the economic efficiency of exterior glazing, a selection guideline is proposed by comparing energy cost and initial investment cost.

2. Literature review

Previous studies that analyzed the energy consumption and the economic feasibility depending on glazing types and properties can be classified as 1) analysis by climate type (Aguilar et al., 2017; Boudou, 2007; Yaşar and Kalfa, 2012); 2) analysis by orientation and building type (Jonsson and Roos, 2010; Lee et al., 2012; Singh and Garg, 2009; Urbikain and Sala, 2009); and 3) proposal of guidelines for energy management (Lee et al., 2013; Vanhoutteghem et al., 2015). Although the previous studies are similar to this study in that they analyze glazing types and glazing properties, the previous studies did not analyze the energy consumption and economic efficiency according to the trade-off relation between SHGC and VT. In addition, previous studies analyzed the glazing used in each country, and did not consider change of glazing properties. A sensitivity analysis of energy consumption depending on the combination of glazing properties could help a decision-maker to select economically-efficient glazing by comparing the energy cost and the initial investment cost.

Several previous studies were restricted to specific climate types. Aguilar et al. (2017) analyzed thermal efficiency based on double-glazed windows of four types (clear, absorbent, Low-e, and reflective) used in Mexico. Boudou (2007) conducted an energy analysis to select a curtain wall and glass suitable for the climate of Tunisia. Yaşar and Kalfa (2012) analyzed the energy consumption and conducted economic analysis for a high-rise building by type of double-glazed window; i.e., tinted glass, clear reflective glass, low emissivity glass, and smart glass (one surface consists of a high-reflectivity glass, and other surface has a low-emissivity coating).

Other previous studies analyzed efficiency based on types and orientation of building. Jonsson and Roos (2010) suggested a strategy to adjust the combination of windows, depending upon a balance of climate, building temperature, and building orientation. Lee et al. (2012) analyzed the energy consumption, CO₂ emission, economic analysis, and determined the suitable glazing type for each orientation of high-rise building. Singh and Garg (2009) analyzed heat energy in the Indian climate in terms of thermal transmittance and SHGC, building type and orientation, and climate. Urbikain and Sala (2009) analyzed energy efficiency in terms of the climate and building types for the window and window frame’s thermal transmittance, absorptivity of the frame, SHGC, and infiltration.

Further studies proposed guidelines. Lee et al. (2013) proposed the chart for management of annual heating, cooling and lighting energy consumption according to glazing properties (thermal transmittance, SHGC, and visible transmittance), different window wall ratios, and orientations; the chart is intended to be used to guide selection of window systems for energy conservation. Vanhoutteghem et al. (2015) analyzed the relationship between size, orientation and glazing properties of façade windows, then presented the result as chart and proposed a method of combination to achieve minimum space heating, daylighting, and maximum thermal comfort.

Several of the previous studies were similar to this one, in that they analyzed the energy consumption and economic feasibility according to the combination of glazing properties (Grynning et al., 2013; Kull et al., 2015). However, analysis in the previous studies was based on the change of thermal transmittance and SHGC, not on the trade-off between SHGC and VT. Grynning et al. (2013) analyzed impact by the combination of thermal transmittance and SHGC on energy consumption and proposed a method of rating an energy saving. Kull et al. (2015) derived five different glazing types based on various thermal transmittance and solar transmittance, and analyzed energy efficiency of windows.

This study analyzes energy consumption depending on the combination of SHGC and VT, then analyzes the effect of the combinations on economic feasibility in two types of building. The result enables comparisons of economic efficiency according to energy cost and initial investment cost and can therefore be used to guide choices of building exterior glazing.

3. Basic settings for analysis

This section describes the input data required for analysis of energy consumption and economic feasibility. The major items include the range of glazing properties used on buildings in South Korea, characteristics of the buildings.

3.1. Possible combination of glazing properties

To determine the possible combinations of SHGC and VT, thermal transmittance was fixed, then the exterior glazing used in South Korea was investigated. The South Korean government recommends thermal transmittance = 1.5 W/(m²·K) when windows are directly exposed to the outside (MOLIT et al., 2009). Among the glazings that have thermal transmittance <1.5 W/(m²·K), the one with thermal transmittance = 1.38 W/(m²·K) offers the widest range of glazing collections with various SHGC and VT values. Thus, in this study, thermal transmittance was set to 1.38 W/(m²·K), then the available glazing products from three major glazing companies in South Korea were investigated. The three companies produce high energy efficient glazing products and import glazing products that they do not produce from the United States. SHGC = 0.4 and VT = 0.74 was the maximum considered, and SHGC = 0.17 and VT = 0.14 was the minimum (Table 1). In each combination, VT was decreased in increments of 0.1, because decrease of VT was not
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