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Optimal design of a multi-story double skin facade

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ABSTRACT

The thermal characteristics of a cavity in a double skin facade (DSF) may vary according to the design of the DSF, since the DSF layers are generally fully glazed. Such thermal characteristics of the cavity influence the thermal load in adjacent air conditioned zones. Thus, the purpose of this study is to quantitatively analyze the impact of the initial DSF design, regarding window glazing type and cavity depth, on the energy consumption of adjacent conditioned zones. To this end, parametric and optimization studies on the DSF design were conducted based on a validation model. In the parametric study, the largest variation of energy consumption was the case when the window glazing type on the outside surface of the inner layer changes. Also, energy consumption decreased when the cavity depth of the DSF decreased. Finally, the model in which the optimal DSF design is applied resulted in a 5.62% reduction in energy consumption. These results suggest the significance of the initial DSF design on the thermal load of the adjacent conditioned zones.

1. Introduction

1.1. Background and purpose

Building technologies are expected to continue to develop along with industrial development. In particular, passive building technology is planned by an architect and is the first step for a building's energy reduction with a focus on design. The DSF system is such a passive building technology, where the cavity is placed between the inner and outer layers to perform functions of natural ventilation, solar radiation control, and insulation.

Despite many studies that have been conducted thus far, no clear guidelines have been developed on the design of the DSF. In most cases, the DSF is designed by referring to previous studies or design cases. However, in a building integrated with DSF, the thermal characteristics of the cavity may vary according to the surrounding environment and control, which has a significant influence on indoor energy consumption. As a result, the initial design of the DSF will be a significant factor that influences not only the energy consumption in a building but also the method and capacity of the HVAC system, going beyond any esthetic choice made by the architect.

Until recently, only a few studies have been conducted on DSF window glazing types and their subsequent thermal characteristics. In the hot and dry Egyptian climate, the single skin facade and DSF can either be favorable or unfavorable in terms of energy consumption, depending on the window glazing types [1]. In the Swedish climate of Northern Europe, cooling and heating energy also shows significant deviation depending on the DSF window glazing types [2]. Even though the studies mentioned here were case studies dealing solely with window glazing types, they provide quantitative analyses of energy consumption depending on window glazing types, which suggests the significance of the initial cavity design.

In a large number of studies on the DSF, the cavity depth varied, ranging from 15.4 cm to 120 cm [1,3–11]. The Belgium Building Research Institute (BBRI) [12] suggested that the cavity depth is in the range of 20–200 cm. The DSF cavity depth not only has a relation to maintenance but also influences natural ventilation through the cavity and the greenhouse effect. This is directly linked to the cooling and heating load of the adjacent conditioned zone. Therefore, a proper cavity depth depending on the climate of the area where the building is located needs to be considered.

Against this background, the purpose of this study is to suggest the optimal design for a multi-story DSF building in Korea. To this end, based on the verification model, a parametric study and optimization of window glazing types and DSF cavity depth were carried out.

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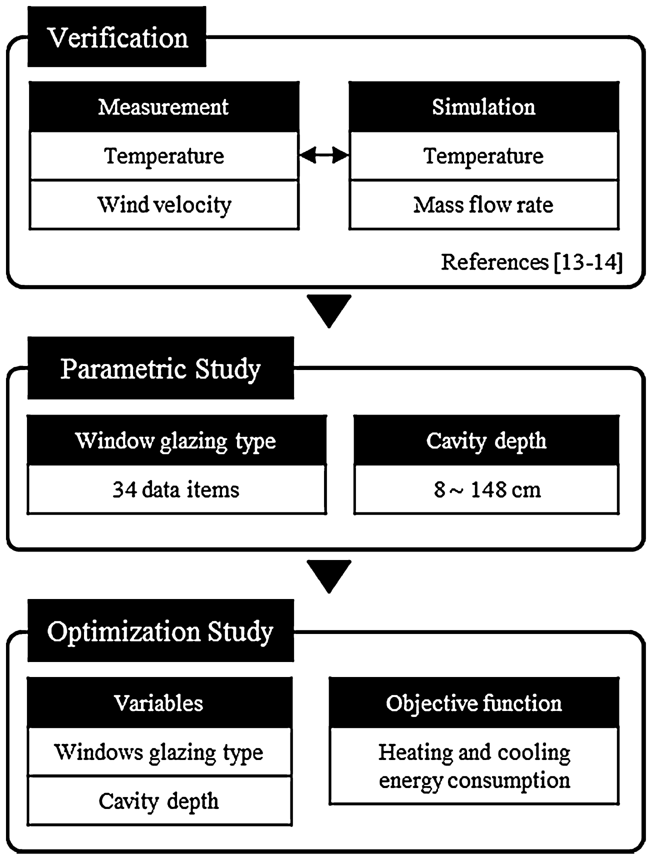

Fig. 1. Research process.

1.2. Methods

The research process of this paper is shown in Fig. 1. CFD simulation was carried out for wind pressure coefficient on the exterior surfaces of the DSF [13], and was applied to a validation model. Field experiment was conducted for the air and surface temperature and the wind velocity of the cavity in the period from February 20 to December 31. Also, weather data including dry bulb temperature, relative humidity, wind velocity, wind direction, and global solar radiation were measured in the same period. The validation model was developed comparing experiment and simulation data based on those measurement [14]. Based on the validation model, a parametric study was carried out. The optimal design for the DSF was suggested based on the results of the optimization study. EnergyPlus 6.0, with which the airflow network algorithm of AIRNET [15] is combined, was used as a simulation program. Genopt was used as an optimization study.

Fig. 2 shows the location of the sensors, an image of the cavity, and a view of the target building. Multi-story DSF is applied to the southern facades of the building. Single clear 8 mm and double-glazed low-e glass (Low E 6 mm – air 12 mm – single clear 6 mm) were applied to the outer layer and inner layer, respectively. The lower and upper vents are horizontally and vertically installed in the DSF, respectively.

2. Parametric study

2.1. Simulation model description

Chapter 2 describes the parametric study conducted based on a verification model. The hourly weather data of Seoul [16] was used for the parametric study, unlike the verification model which was based on measurement of weather data in Yongin. This weather data were generated using the ISO Test Reference Year (TRY) method [17]. The cavity depth is 78 cm and the area of the floor plan of the adjacent conditioned zone is 180 m^2 (15 m × 12 m). The material properties of window glazing are shown in Table 1. Low-e glazing was applied to the three sides at 28% of the window wall ratio, excluding the south side where the DSF was installed. A blind was operated at a fixed 45° if the outdoor air temperature was higher than 25 °C. Internal heat gain density was set to 11 W/m^2 and 10.7 W/m^2 for lighting and equipment, respectively [18]. An electric heat pump of packaged direct expansion was installed at each story and operated from 08:00 to 18:00 at the setpoint temperature of 21 °C (heating seasons from November to March) and 26 °C (cooling seasons from April to October). Fan electric energy in the air handling unit (AHU), equal for all cases, was not considered in the parametric study. In this respect, the electric energy of the cooling and heating coils was assumed to be air-conditioning energy consumption. Occupant density was set at 0.1 person/m^2 while outdoor air supply for one person was set at 28.8 m^3/h [19]. With respect to the operation of the upper and lower vents of the cavity, they were closed in the heating season and opened during the cooling seasons. They were closed except building operation time to prevent invasion for security and ignore the effect of a night ventilation. The inner layer openings that could be manually opened remained closed.

2.2. Window glazing types

In the studies related to DSF that have been conducted thus far [1,3–11], the window composition of the DSF included single glazing for the outer layer and double glazing (clear, low-e, solar control, etc.) for the inner layer. This is in accordance with the suggestion made by the BBRI [12]. Therefore, in a parametric study, the outer layer and inner layer were set as single glazing and double glazing respectively, and an air gap inside the double glazing was fixed at 12 mm. As the window glazing types of one layer among three layers change, the other two layers stay the same as the existing windows. This is important for investigating the effect of thermal properties of various glazing on heating and cooling energy consumption. The windows data are taken from open data set in EnergyPlus [20]. For glass in the outer layer, 20 data items were considered, and 27 data items were considered for the outside and inside surfaces of the inner layer, including the existing data of Table 1. Regarding the inner layer, it was possible to configure the double glazed low-e by applying low-e or reversed low-e on the outside and inside surfaces of the inner layer, respectively.

Fig. 3 shows a parametric study of window glazing types. The variation of energy consumption, when the window glazing type of the outside surface of the inner layer changes was the largest (−3.4% to +18.8%) while that when the window glazing type of the inside surface of the inner layer changes was the smallest (−1.1% to +4.7%), compared to the initial window glazing type. This implies the significance of window glazing types in the outside surface of the inner layer in terms of heat transfer between a cavity and the adjacent conditioned zones. The optimal glazing types in each location are Clear 3 mm, Low-e Spectrally Selective Clear 6 mm, and Low-e Spectrally Selective Clear 3 mm (Reverse) in the outer layer, outside surface of the inner layer, and the inside surface of the inner layer, respectively.

2.3. Cavity depth

The size of the upper and lower openings of the cavity changes according to the changes of the cavity depth. To this end, the coordinates of all the points on the southern facade of the DSF were set as variables for the parametric study and optimization (Fig. 4.)