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Load characteristics and operation strategies of building integrated with multi-story double skin facade

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ABSTRACT

This study measured an actual behavior of a multi-story double skin facade (DSF) in South Korea. The verification of simulation model was made against measured data, and a case study was conducted based on the verified model. Seasonal load characteristics of the DSF building were examined in comparison with the single skin facade (SSF) building, and seasonal operation strategies of the DSF were proposed.

The DSF building resulted in 15.8% and 7.2% reductions in heating and cooling energy consumption respectively, compared to the SSF building. In the proposed model of heating seasons, heated air in the cavity was introduced to an outdoor air (OA) mixing box of a HVAC system. In the proposed model of cooling seasons, air in the cavity was flowed into an indoor space through inner layer openings for natural ventilation, and outdoor air supply in a AHU was controlled based on the amount of the natural ventilation. These seasonal proposed models resulted in 28.2% and 2.3% reductions in heating and cooling energy consumption respectively, compared to the DSF model to which operation strategies were not applied.

1. Introduction

1.1. Background and purpose

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

The DSF in heating seasons has a low *U*-value so that a loss of an indoor heating energy is decreased and a cavity heated by solar radiation has a positive influence on a heating load. The DSF in cooling seasons has an effect of shutting off solar radiation compared to the SSF, whereas greenhouse effect of the cavity has a negative influence on a cooling load [1]. In addition, the DSF shows different thermal characteristics depending on target region, weather, climate, and operation. As mentioned thus far, the DSF is sensitive to change in surrounding environment, and such sensitivity is directly linked to the energy consumption. Table 1 shows various case studies on DSFs. Even though many studies have been conducted regarding the DSFs in many regions, some of those relied on simulation without measurement and verification [2–8]. Furthermore, in the aspect of the cooling and heating load, some studies drew the negative conclusions on the DSFs in comparison with the SSFs [2,3,15,16]. Such limitations to the studies on the DSF and diverse conclusions on the energy consumption rather aggravate uncertainty about the feasibility of the DSF.

Against this background, the purpose of this study is to examine seasonal load characteristics of multi-story DSF building compared to the SSF building, and propose seasonal operation strategies. To this effect, field measurement was conducted and a case study was carried out based on a validated simulation model to examine the feasibility of the multi-story DSF.

1.2. Methods

The research proceeded in the order of measurement, verification of the simulation model, comparison between SSF and DSF, and suggestion of seasonal operation strategies as shown in Fig. 1. The weather data were obtained from the weather station installed on the rooftop of the target building. The temperature and wind velocity data were obtained through the thermocouples and multi-point anemometers installed in the cavity. EnergyPlus 6.0, with which the airflow network algorithm of AIRNET [17] is combined, was used as a simulation program. The wind pressure coefficient value, which has a crucial effect on the ventilation performance, was calculated [18] via atmospheric boundary layer simulation using CFD

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Table 1
Literature review of DSF.

	Year	Experiment		Simulation	Energy demand		Region
		Temp.	Air flow		Heating	Cooling	
Gratia [2,3]	2004 and 2007			○	P	N	Belgium
Wong [4]	2005			○		P	Singapore
Hensen [5]	2002			○		P	Czech
Ballestini [6]	2005			○	P		Italy
Høseggen [7]	2008			○	P		Norway
Hashemi [8]	2010	○		○	P	P	Iran
Hamza [9]	2008	○		○		P	Egypt
Kim [10,11]	2009 and 2011	○		○	P		Korea
Haase [12]	2009	○		○		P	Hong Kong
Stec and Saassen [13,14]	2003 and 2005	○	○	○	P	P	Netherlands
Saelens [15,16]	2002 and 2003	○	○	○	P or N	N	Belgium

P: positive; N: negative

and was then inputted into the EnergyPlus simulation model at 30° intervals. Subsequently, the calibration and verification of the simulation model were carried out using the experimental data. Based on the validated DSF model, seasonal load characteristics and operation strategies for the multi-story DSF were analyzed.

2. Airflow network method

In the airflow network method, a building and its HVAC system components are represented by a network of nodes. The connection between one node and the other is expressed as a linkage through which the airflow passes, and this linkage takes components such as fans, ducts, pipes, cracks, doors, and windows into account. The assumption is made that there is a nonlinear relationship between the flow and the pressure difference across two connected nodes. In the process of calculation, the airflow occurred by pressure difference, and the law of conservation of mass is applied in each node. Assuming that the fluid is an incompressible, Newtonian and steady state, the fluid flow through component i is based on Bernoulli's equation, as Eq. (1).

$$\Delta P_i = \left(p_1 + \frac{\rho v_1^2}{2}\right) - \left(p_2 + \frac{\rho v_2^2}{2}\right) + \rho g(z_1 - z_2) \quad (1)$$

where ΔP_i is the total pressure difference crossing component i [Pa], $p_{1,2}$ are the inlet and outlet static pressures [Pa], $v_{1,2}$ are the velocities of the inlet and outlet [m/s], $z_{1,2}$ are the elevation of the inlet and outlet [m], ρ is the density of the fluid flowing through the component [kg/m^3], and g is the acceleration of gravity [m/s^2].

By combining the related terms, the above equation can be simplified and extended to the multi zone building. The total pressure P is defined as the sum of the static and dynamic pressures, and it is $P = p + (pv^2/2)$ in Eq. (1). The third term in Eq. (1) represents the stack effect, and it is referred to as P_s. Assuming the two consecutive nodes are called n and m, and adding wind pressure term P_w to this, the pressure difference of all the consecutive nodes can be expressed by Eq. (2).

$$\Delta P = P_n - P_m + P_s + P_w \quad (2)$$

where ΔP is the pressure difference between the two consecutive nodes [Pa], $P_{n,m}$ are the total pressures at nodes n and m [Pa], P_s is the pressure difference due to the density and height differences [Pa], and P_w is the wind pressure due to the wind [Pa]. According to the linkage, $\Delta P = P_n - P_m + P_s$ is applied to the flow between the interior zones, and $\Delta P = P_w - P_m + P_s$ is applied to the zones connected with the exterior.

The velocity at any level z is given by $(z) = \sqrt{2(p_1(z) - p_2(z))/\rho}$, and a flow through opening can be expressed by Eq. (3). A flow of one way to three ways can be simulated on airflow network method, depending on the number of neutral planes of the opening.

$$\dot{m} = C_d \theta \int_{z_1}^{z_2} \rho v(z) W \quad dz \quad (3)$$

where $\dot{m}$ is the mass flow rate through the component [kg/s], C_d is the discharge coefficient of opening, θ is the area reduction factor, $z_{1,2}$ are the top and bottom elevation of area where air flow occurs [m], ρ is the air density [kg/m^3], v is the airflow velocity [m/s], and W is the opening width [m].

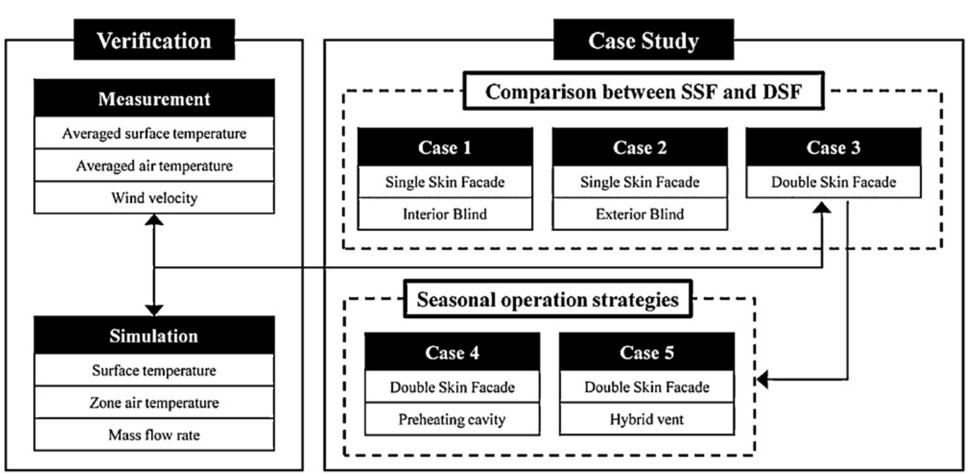

Fig. 1. Research process.