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Application of control logic for optimum indoor thermal environment in buildings with double skin envelope systems

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ABSTRACT

This study proposes an effective thermal control method for thermally comfortable and energy-efficient environments in buildings with double skin envelopes. Four rule-based control logics and an artificial neural network (ANN)-based control logic were developed for the integrated control of openings and cooling systems in summer. Using numerical computer simulations, the performance of the proposed control logics was comparatively tested in terms of thermal performance and energy efficiency.

Analysis results imply that the more detailed rules of thermal control logic were effective to maintain the indoor temperature conditions within comfortable ranges. The ANN-based predictive and adaptive control logic presented its potential as an advanced temperature control method with an increased temperature comfort period, decreased standard deviation of temperature from the center of the comfortable range, and decreased number and ratio of overshoots and undershoots out of the comfort range. The additional rules embedded for control logic or ANN applications yielded a more comfortable temperature environment in an integrated manner according to the properly designed operations of envelope openings and the cooling system. However, logics with additional rules and ANN models consumed more energy for space cooling. Therefore, the rule-based controls with advanced logics or an ANN model are required in case occupant comfort is a primary factor to be satisfied. In other cases, the simple rule-based logic is effectively applied.

1. Introduction

Curtain wall structures covered with glazing materials have been effectively applied to high-rise commercial buildings due to the advantages of reducing the structural loads of buildings. Despite these advantages, buildings with curtain wall structures present weak insulation levels of envelopes and difficulty controlling the penetration of solar irradiance into the indoor space from outdoors. Accordingly, the weakness of envelopes in terms of the thermal environment and energy consumption results in increasing heating and cooling loads due to the inappropriate heat transfer between outdoor and indoor environments.

In order to reduce such inappropriate heat transfer, double skin envelopes have been applied to buildings with curtain wall structures. The double skin envelope, which is composed of internal and external envelopes, openings for air inlets and outlets in each envelope, a cavity between the internal and external envelopes, and shading devices, helps reduce heating and cooling loads and energy consumption [1–7].

The cavity space between internal and external envelopes primarily contributes to reducing the load and energy consumption, since the space functions as a thermal buffer zone for controlling the amount of energy transfer between indoor and outdoor environments. Appropriate controls of air inlets and outlets installed at the internal and external envelopes also work effectively to reduce thermal loads and energy consumption.

The double skin envelope can be strengthened when the relevant components for controlling the amount of energy transfer between the indoor and outdoor environments are properly installed and operated. For example, the opening conditions of internal and external envelopes effectively determine the amount of convective heat transfer (*i.e.*, ventilation) between indoor and outdoor environments.

The indoor temperature condition, which is one of the most important factors in determining the thermal comfort of

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Nomenclature

$TEMP_{IN}$	indoor air temperature
$\Delta TEMP_{IN}$	indoor air temperature change from the preceding control cycle
$TEMP_{OUT}$	outdoor air temperature
$TEMP_{CAV}$	cavity air temperature
$TEMP_{PR}$	indoor air temperature predicted by ANN model
$COOLING_{PRE}$	operating condition of the cooling system in the previous control cycle
$COOLING_{CUR}$	operating condition of the cooling system in the current control cycle
$INPUT_{ACT}$	actual input value
$INPUT_{MAX}$	maximum input value
$INPUT_{MIN}$	minimum input value
N_d	number of training data sets
N_i	number of input neurons
N_h	number of hidden neurons
N_o	number of output neurons

occupants, is closely related to the opening conditions at the envelopes. For proper operation of the openings, diverse rule-based strategies have been studied and applied [8–10]. These control strategies employ simple rules for controlling the openings of the envelopes. For example, the openings at the external envelope are always closed and those at the internal envelope are open when the cavity temperature is over 28 °C in winter. Due to their simplicity, rule-based control strategies have been most widely applied to the control algorithms. A specific rule for operating the openings controls the amount of heat transfer by conduction, ventilation, and solar radiation.

Although diverse strategies employing specific rules have been introduced for the control of the thermal environment in buildings with double skin envelopes, they have two major limitations. Primarily, the criterion and algorithm for deciding the opening conditions of the air inlets and outlets of the envelopes is determined intuitively by building mangers or occupants. The cavity temperature or the amount of solar radiation are used as determinants, but other thermal factors such as indoor and outdoor temperature are not employed in the control logic.

Secondly, the existing rule-based control methods cannot control the openings and the thermal control systems in an integrated manner. The air inlets and outlets of the envelopes are controlled independently without any interactions with the heating or cooling systems. The respective criterion for controlling openings and thermal control systems is cavity temperature and indoor temperature.

Therefore, new methods that can synthetically consider the related thermal factors and system components need to be developed to optimize thermal controls and energy efficiency. This study proposes an effective thermal control method for greater thermal and energy efficient environments in buildings with double skin envelopes. Several rule-based control logics and artificial neural network (ANN)-based control logic were developed for the control of openings and cooling systems in summer. The performance of the proposed control logics was compared in terms of thermal performance and energy efficiency.

The developed control logics commonly considered the cavity temperature and indoor temperature in the control algorithm to determine the operation of the air inlets and outlets as well as the cooling system. The ANN-based logic additionally used outdoor temperature and the opening conditions of the envelope in the algorithm. Considering relevant components in the algorithm, the logic was expected to provide a more comfortable thermal environment.

The proposed logics were designed to operate the openings of envelopes and the cooling system in an integrated manner, in which the operating conditions of the cooling system affect the decision for the opening conditions of the envelopes. Due to the contribution of the integrated method, energy could be consumed more efficiently for thermal control in buildings.

2. Development of control logics for indoor temperature

The temperature control logics considered in this study were developed in two categories. The first one was a rule-based control logic, which employs specific rules to control the openings and the cooling system. Four different logics were organized with diverse rules. The second one was an ANN-based logic that uses the predictive and adaptive controls of the opening and cooling systems.

2.1. Rule-based control logics

The algorithms and descriptions of the different assumptions and features of each algorithm used for the rule-based control logics are shown in Figs. 1–4 and Table 1. The developed rule-based control logics synthetically employed the indoor and cavity temperatures as well as the operating conditions of the cooling system in the algorithm in order to determine the operation of the air inlets, outlets, and cooling system.

The first rule-based logic, which is shown in Fig. 1, employs the current operating condition (ON or OFF) of a cooling system, indoor temperature, and cavity temperature as determinants. Based on these determinants, the operation of the cooling system and the openings of internal and external envelopes are determined. For

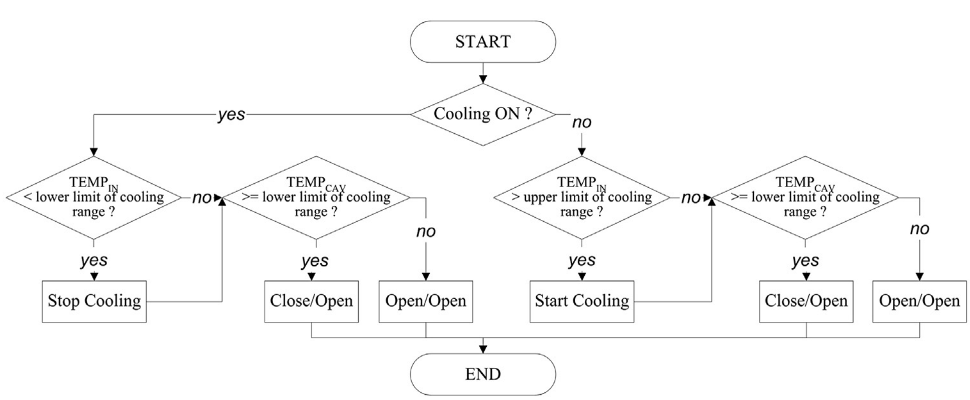

Fig. 1. Algorithm of rule-based control logic (1).