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Performance evaluation of artificial neural network-based variable control logic for double skin enveloped buildings during the heating season

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A B S T R A C T

This study describes integrated logic for an artificial neural network (ANN) to control heating devices on a continuous basis. Two ANN-based control logic systems and two conventional rule-based logic systems were developed to control a heating device and the openings of a double skin enveloped building. The ANN-based logic controls heating devices on a continuous basis according to the indoor temperature. The rule-based logic controls heating systems and openings at envelopes in two-position on/off operation. Control performance for the developed logic was numerically conducted using computer simulations for a small office space with double skin envelopes during the heating season.

Analysis results indicate that the ANN-based temperature control logic resulted in a more stable temperature near the center of the comfortable range with a reduced opening period of the internal envelope. The reduced number of on/off moments of the heating device and the openings in the ANN-based logic were predicted to save energy and prevent system degradation. The use of ANN-based logic would be effective for maintaining a stable thermal environment and for system operation. Rule-based logic can be effectively used to improve building energy efficiency. In this study, two ANN-based logic types were developed for heating devices controlled on a continuous basis and their performance was compared with those of rule-based on/off logic. Thus, in order to cover the limitation of this study, further study is warranted for examining the clear difference achieved by ANN-based vs. rule-based control, when they are applied to control heating output on a continuous basis.

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1. Introduction

The double skin envelope, which consists of internal and external building envelopes, cavity space, openings for ventilation, and shading devices, is a widespread type of building envelope that started being used in recent years. Besides its lightweight structural superiority, one advantage of double skin envelopes is effective control of the indoor environment.

A double skin envelope effectively controls energy flows between indoors and outdoors, and ensures a comfortable indoor visual and thermal environment with improved energy efficiency [1–7]. The control of opening conditions and the cavity space contribute to reduced heating load, cooling load and energy consumption in the thermal environment [8–14]. The application of combined controls affects the indoor thermal condition, which is a critical factor for the occupants' thermal comfort and building energy efficiency [1–3,15–21]. In particular, the thermal buffer zone between internal and external envelopes significantly reduces energy transfer and improves energy efficiency.

In order to examine the influence of thermal buffer zone on energy transfer, control strategies for the use of accumulated energy in a cavity space in winter have been investigated based on two major approaches, rule-based control and optimal control [1]. The rule-based control method employs an intuitively developed simple rule for controlling the openings and the shading device. For example, the openings of the internal surface will be opened when the cavity air temperature is higher than the indoor air temperature. Due to its simplicity, the rule-based control method has been

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Nomenclature

U	output [unitless]
U_{NEW}	U of the current cycle [unitless]
U_{OLD}	U of the previous cycle [unitless]
U_{TRN}	U for the new training dataset [unitless]
T_{NEW}	air temperature of the current cycle [°C]
T_{H}	set-point temperature for the heating system [°C]
E	difference between the air temperature and the set-point temperature [°C]
E_{OLD}	E of the previous cycle [°C]
ΔE	change in E from the previous cycle [°C]
ΔE_{OLD}	ΔE of the previous cycle [°C]
n_{i}	number of input neurons
n_{h}	number of hidden neurons
n_{o}	number of output neurons
n_{d}	number of datasets
$\mathrm{TEMP_{IN}}$	indoor air temperature
$\Delta\mathrm{TEMP_{IN}}$	indoor air temperature change from the preceding cycle
$\mathrm{TEMP_{CAV}}$	cavity air temperature
$\mathrm{TEMP_{OUT}}$	outdoor air temperature
$\mathrm{TEMP_{PR}}$	predicted air temperature
INPUT	input value for the input neuron
$\mathrm{INPUT_{ACT}}$	actual value of each thermal factor
$\mathrm{INPUT_{MAx}}$	maximum value of each thermal factor
$\mathrm{INPUT_{MIN}}$	minimum value of each thermal factor

widely applied for the thermal control of double skin-enveloped buildings.

However, the control strategy determined by the rule-based method was not an optimal solution because it was derived from an intuitive rule set by building managers or occupants. Therefore, better solutions should be created when a prudently developed optimal algorithm is applied.

The effect of an artificial neural network (ANN) has been investigated in terms of its applicability to thermal controls in double skin-enveloped buildings [22–24]. In these studies, the ANN, which is analogous to the human neural structure and learning process, has been successfully applied to non-linear systems or systems with unclear dynamics. Unlike mathematical models such as proportional-integral-derivative (PID) controllers or regression models, the self-tuning process conducted by ANN models results in accurate decisions when unusual disturbances, perturbations and any changes in building background conditions occur.

In other previous studies, ANN-based thermal control methods showed superiority over mathematical strategies in terms of improved thermal conditions with accurate controls and energy efficiency [25–33]. ANN models were developed to calculate the optimal start and stop times for heating systems to provide for energy-efficient system operation and a comfortable thermal environment [25,26].

A similar study was conducted for developing ANN models to predict the optimal end-of-setback moment of air-conditioning systems [27]. The ANN has been successfully applied to operate hydronic heating systems of solar buildings, and to control residential water heating systems and radiant floor heating systems with significant energy savings [28–32].

An ANN model incorporating fuzzy logic was developed to control a radiant heating system [33]. The ANN model was designed to predict the indoor temperature and the fuzzy controller used the predicted value as one of the inputs. The controller markedly reduced overshoots of indoor air temperature and energy consumption compared to proportional-integral (PI) controls.

In particular, various ANN-based optimal control logic methods were developed and tested for various conditions in order to examine the applicability of ANN on thermal controls in double skin enveloped-buildings [34]. Four ANN models were developed to predict future indoor temperatures for four different opening strategies of openings in envelopes. The control logic compared the predicted indoor temperature and determined the optimal opening strategy for reducing heating energy consumption. The ANN effectively contributed to control the openings and reduce heating energy. The superiority of ANN in terms of optimal control for thermal comfort and energy efficiency has been proved using a performance analysis with a simple rule-based method.

The operation of heating devices with two control options (on/off two-positions) was determined by the control logic. The heating device worked in both predictive and adaptive manners. However, the ANN logic used for the study assumed that heating devices were controlled by on/off-based controls, under which maximum or no heat was supplied to the indoor space.

Although the on/off-based control logics were effectively used for control in a double skin-enveloped building, they are not suitable for controlling heating devices on a continuous basis in modern buildings. Heating devices controlled on a continuous basis supply a certain amount of heat based on specific control algorithms that determine proper thermal output during a certain operation period. In this case, the heating devices produce linear or nonlinear output in order to keep the indoor temperature close to its set point.

Therefore, more advanced ANN control logic should be considered in order to control heating devices on a continuous basis and openings in an integrated manner. Also the control logic should achieve improved thermal control for double skin envelopes, which contain various elements for thermal energy transfer under diverse weather conditions.

In this study, four different types of control logic were developed and applied to control heating devices and openings in the envelopes of a double skin-enveloped building. In order to investigate the effect of ANN-based control logic on heating devices controlled on a continuous basis, the control performance of the four types of logic was examined in terms of thermal elements that are relevant to an indoor thermal environment.

The control performance of the ANN logic was compared with the control performance using rule-based logic, which employed separate control for heating devices and openings in the envelopes, since analysis results in various previous studies are based on conventional rule-based logic that controls heating devices and openings simultaneously.

2. Development of control logics

For integrated control of the heating device and openings in the envelopes of a double-skin-enveloped building, four types of control logic were developed using the different ANN application levels. The developed logic was designed to keep the indoor temperature within a comfortable range based on the integrated control of the heating device and openings.

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