Comparative Analysis of the Artificial Intelligence Theories for Heating System Controls of Double Skin Facade Building

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Abstract

This study aimed at developing artificial-intelligence-(AI)-theory-based optimal control algorithms for improving heating energy efficiency of double skin façade (DSF) building. One conventional rule and three AI algorithms, artificial neural network (ANN), fuzzy logic (FL), and adaptive neuro fuzzy inference systems (ANFIS), were used to operate the heating system and the openings at building envelopes. Developing AI algorithms and performance tests were conducted by MATLAB and TRNSYS software. The analysis results revealed that the ANN-based algorithm showed the best method among the other algorithms, potential to be the most energy-efficient and stable strategy.

Keywords: Artificial Intelligence; Heating System Controls; Double Skin Facade Building

Introduction

In recent years, 'energy saving' has become one of the primary aims of energy policy in many countries. In Korea, energy consumption in building sector is about 30% of national total energy, especially, over 60% of total energy in Seoul where the rapid urbanization progressed. To reduce the building energy consumption effectively, envelope planning should be conducted by blocking and absorbing solar radiation.

Along with demands for energy savings in building and adaptive building components have led to increasing attention towards the Double Skin Facade (DSF) system. The architectural trend of DSF which is the representative passive envelope technology having an advantage of building energy savings and advanced building environmental quality has been increased [1].

A lot of previous researches on DSF system has been conducted from a variety of perspectives, such as energy consumption in DSF building [2-4], performance of DSF applied building with PV [5], ventilation performance [6–8], and thermal elements (including PCM) in the cavity [9]. Although there were many detailed studies on DSF system, the efforts for suggesting the optimal operation and energy optimization of DSF have not relatively been satisfied.

Therefore, this study aims at developing a control logic using artificial intelligence theories to propose the optimal operation of DSF building and suggest basic data for developing more comfortable and energy efficient algorithm. Among the various AI theories, artificial neural network (ANN), fuzzy logic (FL), and adaptive neuro fuzzy inference system (ANFIS) which are the representative model applied to building controls were compared to find best solution [10-11].

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Development of control algorithm

AI-theory-based algorithms were developed for the integrative control of the heating system and the surface opening. Four different algorithms were developed by AI theory, opening at envelopes was controlled by ANN and heating system was controlled by conventional rule, ANN, FL, and ANFIS respectively (See Table 1). Each control algorithm models were developed by a numerical computer simulation method incorporating the matrix laboratory (MATLAB).

Also, each control algorithms are developed by separate parts, heating system control and opening system control. Fig. 1, Fig. 2, and Fig, 3 shows Algorithm I, [Algorithm II & Algorithm IV], and Algorithm III, respectively.

Table 1. Four Algorithms with Different Theories.

Algorithms	Theories	
	Heating system	Opening at envelopes
Algorithm I	Rule	ANN
Algorithm II	ANN	ANN
Algorithm III	FL	ANN
Algorithm IV	ANFIS	ANN

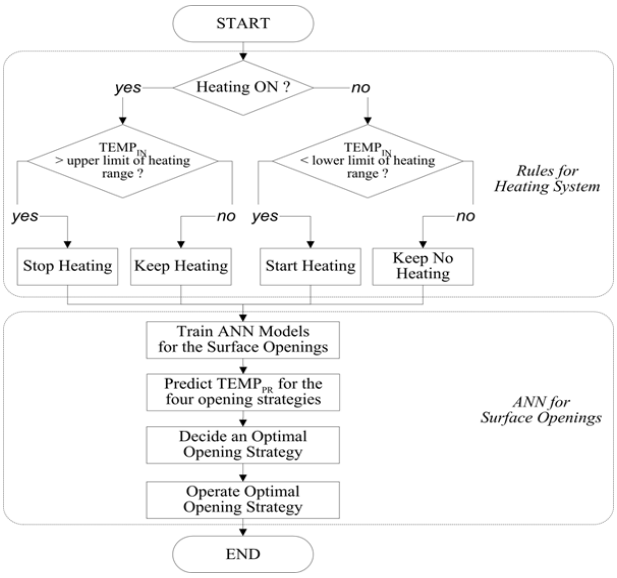

Fig.1. Flow of Algorithm I.

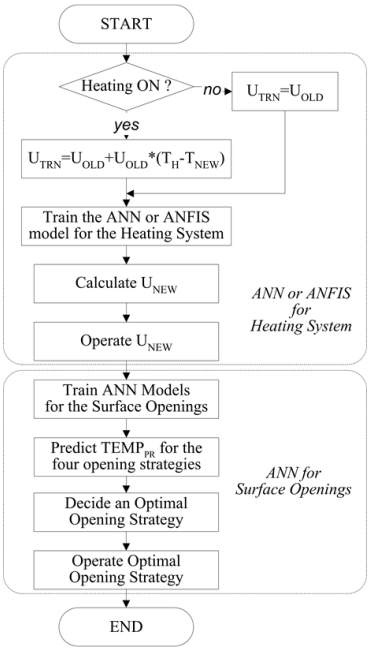

Fig.2. Flow of Algorithms II and IV.

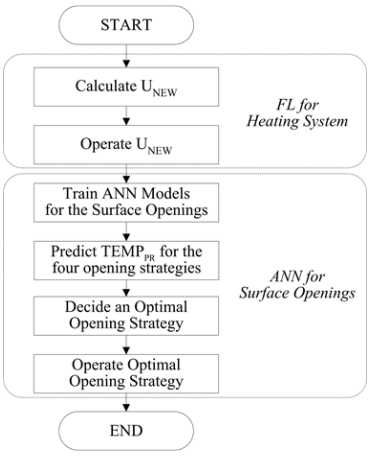

Fig.3. Flow of Algorithm III.

Fig. 4 and Fig. 5 shows developed ANN models for opening control heating system control. For optimally operating surface openings, four ANN models were developed for predicting the future indoor temperature (TEMPPR). Six inputs of ANN model for opening control at DSF were considered, such as, indoor temperature, difference between indoor and outdoor temperature, outdoor temperature, cavity temperature, and opening conditions of internal surface and external surface.

Each ANN model calculates the TEMPPR for the four opening cases: (i) the openings on both surfaces are closed; (ii) the internal openings are closed and the external openings are open; (iii) the internal openings are open and the external openings are closed; and (iv) the openings on both surfaces are open.

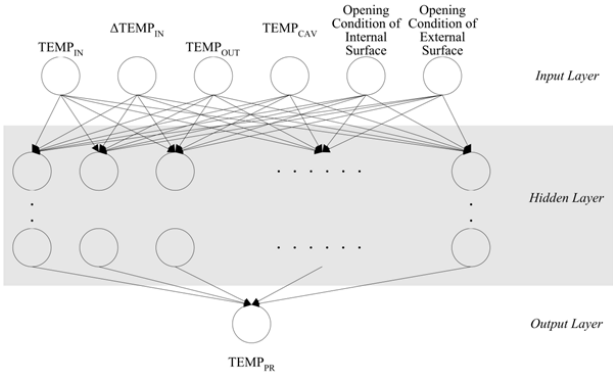

Fig.4. ANN Model for Openings at DSF.

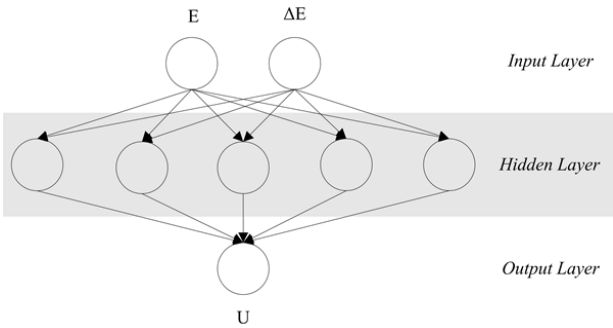

Fig.5. ANN Model for Heating System.

Performance tests

The performances of the four algorithms were comparatively tested to investigate the algorithms' influence on building energy by transient systems simulation (TRNSYS) software. A one-story test building with a double skin was modeled for the numerical simulation (See Fig. 6).

Conditions of simulation were as followings; assumed that a test module located in Seoul and simulated in winter season, from November 1st to February 28th. Two occupants, two computers, and lighting equipment with 5 W/m^2. Heat insulation property of each outer wall, roof, floor, internal window, and external window is 2.78 m^{2}K/W, 5.0078 m^{2}K/W, 2.4478 m^{2}K/W, 0.7778 m^{2}K/W,

0.1878 m^2K/W, respectively. Air change ratio per hour (ACH) was 0.7 and the capacity of radiant heating system was 7,172 kJ/hr.

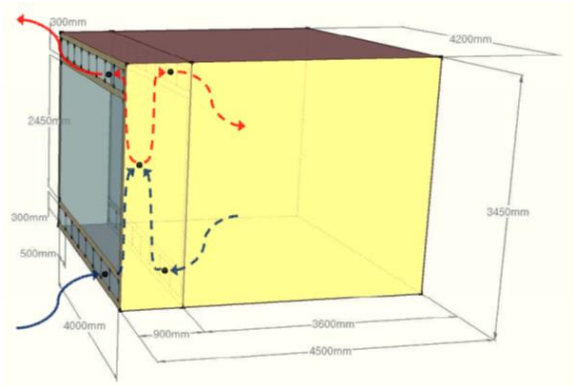

Fig.6. A Test Module with Double Skin Facade.

Result of performance tests

The result of performance tests on four control algorithms shows that the AI-theory-based algorithms presented the possibility of consuming more energy for space heating (See Table 2). Compared to rule-based heating system control, the AI algorithms supplied a greater amount of heat to the indoor space. The increase amounts were 3.97%, 8.42%, and 11.48%. This has a connection to the fact that the AI-based heating system control methods keep the indoor temperature higher than that of the rule-based method. Similarly, the average heating system operating ratio (U) was greater when the four AI theories were applied.

In addition, the ANN and FL models reduced the number of on/off operations of the heating system compared to the rule-based method, about 14,864 and 222, respectively. It means that the stability of the system operation and reduced on/off moments could be operated for a long time.

Table 2. Heating System Operation.

Analysis components	Algorithms			
	I	II	III	IV
Amount of heat supply [kWh]	1537.28	1598.31	1666.68	1713.85
Average operating ratio	0.214	0.222	0.231	0.238
Standard deviation of operating ratio	0.168	0.033	0.048	0.082
Number of on/off	15046	182	14824	34032

Conclusion

This study aimed at developing AI-theory-based optimal control strategies for heating energy efficiency of double skin facade building. For this, one conventional rule-based algorithm and three AI-based algorithms were developed, including ANN, FL, and ANFIS. Results of comparative analysis on four algorithms are summarized below.

(1) The quantity of heat was conditioned slightly higher than conventional rule when the AI theories were applied to the control algorithm, due to the variable control of the heating system using the calculated operation ratio (U).

(2) In addition, the ANN-based algorithm significantly reduced the on/off moments, meaning the stability of the system operation. The reduced number of on/off operations can in the long run reduce the system degradation caused by the iterative and frequent turning on/off system.

Acknowledgement

This study was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (Ministry of Science, ICT and Future Planning) (No. 20160268).

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