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Fuzzy logic-based advanced on–off control for thermal comfort in residential buildings

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HIGHLIGHTS

- Fuzzy logic-based advanced on–off control is proposed.
- An anticipative control mechanism is implemented by using fuzzy theory.
- Novel thermal analysis program including solar irradiation as a factor is developed.
- The proposed controller solves over-heating and under-heating thermal problems.
- Solar energy compensation method is applied to compensate for the solar energy.

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ABSTRACT

In this paper, an advanced on–off control method based on fuzzy logic is proposed for maintaining thermal comfort in residential buildings. Due to the time-lag of the control systems and the late building thermal response, an anticipative control mechanism is required to reduce energy loss and thermal discomfort. The proposed controller is implemented based on an on–off controller combined with a fuzzy algorithm. On–off control was chosen over other conventional control methods because of its structural simplicity. However, because conventional on–off control has a fixed operating range and a limited ability for improvements in control performance, fuzzy theory can be applied to overcome these limitations. Furthermore, a fuzzy-based solar energy compensation algorithm can be applied to the proposed controller to compensate for the energy gained from solar radiation according to the time of day. Simulations were conducted to compare the proposed controller with a conventional on–off controller under identical external conditions such as outdoor temperature and solar energy; these simulations were carried out by using a previously reported thermal analysis program that was modified to consider such external conditions. In addition, experiments were conducted in a residential building called Green Home Plus, in which hydronic radiant floor heating is used; in these experiments, the proposed system performed better than a system employing conventional on–off control methods.

1. Introduction

Radiant floor heating (RFH) systems have gradually increased in popularity because they have many advantages compared to convective heating (CH) systems. The advantages of RFH systems over CH systems are their low system temperatures, uniform temperature distributions, efficient use of space, elimination of the need to clean ducts, and noiseless operation [1]. In addition, RFH systems are not only more energy-efficient than CH systems, but also provide more comfortable indoor thermal environments [2].

Despite the many advantages of RFH systems, their thermal control systems tend to suffer from problems regarding late thermal response and management of thermal loads in well-insulated buildings [1]. First, late thermal response arises mainly from the thermal mass and structure characteristics of RFH systems. Different materials have different heat transfer characteristics such as thermal mass. Concrete, is widely used material for building construction, has a high thermal mass, increasing the delay between heat supply and indoor temperature response,

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and thereby resulting in overheating and additional heat loss. RHF systems also include components such as boilers, pumps, and pipe systems, which also introduce delay in the thermal response.

The other main thermal control problem of RHF systems occurs in well-insulated buildings; in this case, room temperature can vary greatly depending on changes in internal loads such as the number of occupants or appliances in use, the type and amount of lighting fixtures, and external loads such as solar irradiation. In particular, the room temperature depends on solar irradiation more than any other factor. Solar irradiation varies throughout the day of a day and can contribute a great deal of radiant energy, and thus it can result in overheating and thermal discomfort unless it is appropriately taken into consideration as an important factor in system control.

There have been many reports on the topic of thermal control of RFH systems, and both on–off and proportional-integral-derivative (PID) control methods have been widely implemented because they have simple structures [3–5]. However, conventional control methods do not sufficiently address the problem of late thermal response in RFH systems. Although a control system gives appropriate inputs to the building immediately depending on current condition, the building's thermal condition does not change immediately due to the characteristics of its thermal mass. Besides, control systems have time lag. Even if the controller is activated instantly, it takes some time to generate appropriate inputs.

To solve these problems, an anticipative algorithm has been researched [6–8]. Lee et al. [9,10] developed artificial neural network (ANN) models for anticipative control, which determines the proper on–off times for the circulation pump in a floor heating circuit that supplies heat to apartment rooms. However, they conducted this study using a simple test chamber, meaning that external factors such as sunlight could not be considered. Argiriou et al. [11,12] developed an ANN-based controller for application to RFH systems; it predicts outdoor temperature, solar radiation, indoor temperature, and supply temperature. However, due to the complex and multi module structure of ANN, the system has a high computational cost and lacks a knowledge representation, meaning that the knowledge of expert control designers cannot be incorporated in its controller's design. Furthermore, the explanation ability of ANN is low, meaning that the control designers cannot sufficiently explain why they designed an ANN in a particular way. Although some studies included the use of anticipative control to enhance the control performance of an RFH system compared with a conventional control, many issues remain to be addressed, including the problem of solar gain and optimization of heating time.

To the best of our knowledge, no fuzzy-based thermal control method has been proposed to determine proper on–off control for RFH systems, even though fuzzy logic does not require a complex learning process and allows the incorporation of expert knowledge, unlike ANN. Some studies have investigated the effects of solar radiation, but none have used a fuzzy-based solar energy compensation algorithm at the controller level by means of changing the weight of the output membership function. In addition,

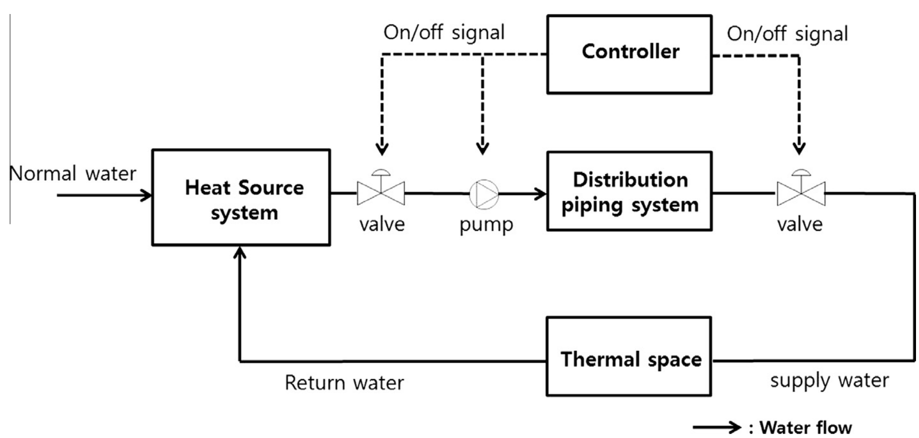

Fig. 1. Schematic diagram of water flow in hydronic radiant floor heating system.

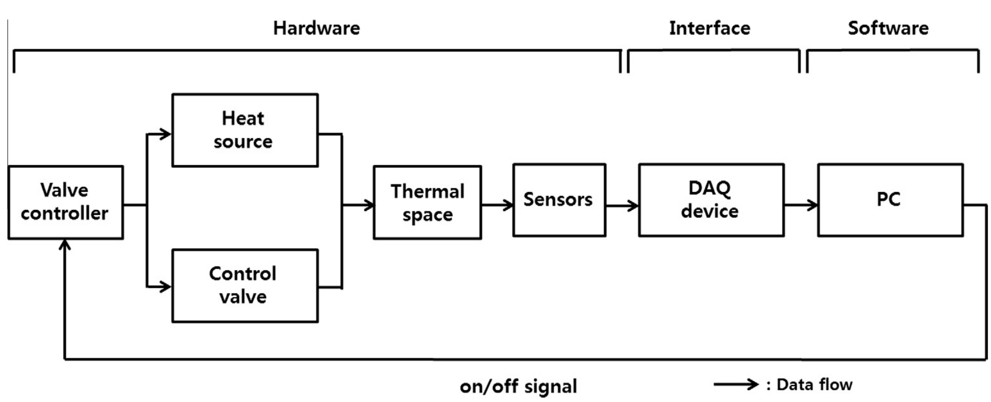

Fig. 2. Schematic diagram of data flow in a hydronic radiant floor heating system.