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Evaluation of the control performance of hydronic radiant heating systems based on the emulation using hardware-in-the-loop simulation

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ABSTRACT

This study presents an emulation method to evaluate the control performance of a hydronic radiant heating system. Since heat output in the system is dependent on the pressure loss and flow rate in the hydronic network, the interaction between thermal and hydronic models needs to be considered in the evaluation of the control performance. For this reason, many studies apply an integrated simulation to the evaluation; however, the analysis of the hydronic network sometimes leads to unreliable results due to the improper initial values for algebraic loops or the lack of modeling information on the hydronic components. In order to deal with this problem, this study suggests an emulation method, where the hydronic network is replaced by real hardware and the building physics is analyzed by a simulation. In the emulation, the pressure loss and flow rate in the hydronic network were represented by replacing the real pipe with equivalent hydraulic resistance. In addition, by using real control systems that connect the hydronic network and building simulation, the interaction between building physics and hydronic network could be considered in the evaluation. Based on the proposed emulation method, the performance of several control strategies was evaluated in terms of the accuracy and the rise time. The result shows that the individual control needs to be combined with hydronic balancing for more accurate control. Hydronic control devices such as a flow limit valve and a pressure differential control valve also proved to be helpful to the improvement of the control performance.

1. Introduction

The hydronic radiant heating system is widely used in residential buildings due to its high thermal comfort level, energy saving potential, and clean and quiet operation [1–3]. As it uses hot water as a heating medium, it is controlled by modulating the temperature and/or flow rate of hot water, or the heat flux from the heat source [4]. Previous studies show that it is practical to apply water flow rate control combined with water temperature control to the hydronic radiant heating system for multi-zone buildings [5,6]. Thus, the condition of pressure loss and flow rate in a hydronic network should be considered in the control performance analysis of a hydronic radiant heating system. In addition, it should be noted that the control performance is considerably affected by hydronic components such as manifolds, embedded pipe, circulation pump, balancing valves, control valves and so on.

Therefore, many studies argue that the control performance should be analyzed with an integrated simulation [7–11] or co-simulation [12] that interconnects the different physical domains. This approach makes it possible to consider the interaction between building-side physics (room air temperature, heat output from the floor surface, and so on) and system-side physics (water flow rate, water temperature, pressure, and so on) in a building with hydronic networks. These studies investigated the trend of building simulations and laid an emphasis on the necessity of the integrated or coupled simulation. It is thought that these studies also presented the direction for the simulation of combined heat and fluid flow in a building and system context. However, there have been few studies on the integrated simulation method to analyze the coupled hydronic-thermal physics in hydronic radiant heating systems.

Gamberi et al. [13] developed a hydraulic-thermal approach to simulate the dynamic behavior of water flow rates, water temperatures, and room air temperatures in a building with radiator heating system. Thermal quantities of a heating system were determined by applying the result of a hydronic system simulation. Although the effects of the hydronic network on thermal output (water and air temperature) were taken into account, the change of flow rate or pressure in the hydronic network due to the on/off of the control valve, which is caused by the change of room air

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