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Numerical optimization on thermal performance characteristics of interior walls based on air-conditioning intermittent running

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ABSTRACT

When the air-conditioning runs intermittently, there may be the large temperature differences of the indoor air in two adjacent rooms due to the air-conditioning different running behaviors. Under this condition, a lot of the cold quantity was lost through interior walls and then the large cooling load was formed by interior walls. Aimed to this, six typically-employed interior walls were built to compare their thermal performance characteristics under air-conditioning intermittent running. The heat transfer model was built by the finite volume method and verified by the experimental data. The numerical results showed that the air-conditioning running behavior in the adjacent room had an observable influence on temperature response rates and heat flow values in inner surfaces. Compared with the solid brick walls, the daily cooling load formed by interior walls can be reduced by 26.1% for the foamed concrete wall and 12.7% for the hollow brick wall, respectively. When the temperature environment in the adjacent room was beneficial to improving the thermal response rate of the interior wall, the thin wall was the reasonable choice and whereas, the thick wall was the reasonable one.

1. Introduction

Thermal insulation performance of building envelopes is the main factor affecting the building energy consumption and indoor comfortable level [1,2]. Under the air-conditioning continuous running, indoor air temperatures are considered to be the same. Under this condition, the thermal performance of the interior wall is usually ignored in present energy-saving design standards [3–5]. However, the air-conditioning intermittent running is widely applied in the building daily management due to the daily habit of occupants, especially for the summer hot and winter cold zone in China [6], and thereby, there may be the large temperature differences of the indoor air in two adjacent rooms due to the air-conditioning different running behaviors. Therefore, a lot of the cold quantity was lost through interior walls and then the large cooling load was formed by interior walls due to the different air-conditioning running behaviors. It indicates that the thermal performance of the interior wall should be valued, due to its affecting on the energy consumption noteworthily.

Meng [6] investigated the air-conditioning running habits in the different climate zones of China and put forward the typical air-conditioning intermittent running models suitable for the thermal environment requirement. Based on the proposed air-conditioning intermittent running models, the energy conservation optimization of envelops have been done [7,8]. Meng et al. [7] built five typical wall insulation configurations with the same heat transfer coefficients and analyzed the influence of wall insulation configurations on temperatures and heat flows in inner surfaces. Their results showed that the interior insulation was more suitable for wall insulation configuration under the air-conditioning intermittent running. Compared with the air-conditioning continuous running, the daily

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cooling load formed by walls was reduced by 44∼55% under air-conditioning intermittent running and the interior insulation wall had the highest energy-saving ratio, which was up to 52∼65%. The experimental research of Zhang et al. [8] showed the interior thermal insulation wall had the smallest heat flow value, which was less 35–86% than the exterior thermal insulation wall and the sandwich thermal insulation wall under the air-conditioning intermittent running. The similar results were obtained by Yuan et al. [9].

Hou et al. [10] analyzed the effect of the insulation materials filling on the thermal performance of sintered hollow bricks under the air-conditioning intermittent running and their results showed filling the expanded polystyrene (EPS) in internal air cavities of sintered hollow brick had the optimum effect, while filling EPS in external air cavities had the least effect. Zhou et al. [11] experimentally studied the thermal performance differences of building envelopes under the multiple heating running conditions and found that the exterior insulation wall had the highest rate of surface temperature variation and achieved the best thermal comfort under the heating continuous running, while the interior insulation wall had the highest rate of temperature variation and obtained the best thermal comfort under heating intermittent conditions.

Tsilingiris [12–14] numerically analyzed the effect of the wall insulation configurations on the wall dynamic thermal response rate under the step variation of indoor air temperature and showed that the interior thermal insulation layer was in favor of improving the wall thermal response rate. However, air temperature variation case was built on a theoretical assumption by ignoring the effect of indoor furniture and occupants in the research of Tsilingiris. Barrios et al. [15] researched the energy saving effect of the roof insulation configurations and found the insulation layer located close to inner surface was more suitable for the heating intermittent running.

In addition, Li et al. [16] experimentally researched the heat storage and release processes of building envelopes integrated with phase change material (PCM) under four typical heating intermittent running summarized by questionnaires in China [6]. Their results showed that the average values of inner surface heat flow for the PCM wall was lower 18.48% than that for the reference wall under four heating intermittent running models.

For air-conditioning intermittent running strategies, Xu et al. [17] analyzed the air-conditioning intermittent running behaviors and their effect on building energy consumption in Hong Kong. Their research showed that most of respondents were willing to switch off lighting and the small power equipment and that up to 11% of annual air-conditioning energy consumption could be saved for the office rooms with no decrement of the thermal comfort level for occupants. Cho and Zaheer-uddin [18] explored a predictive control strategy as a means of improving the energy efficiency of the intermittently heated radiant floor heating systems and their results showed that the application of the predictive control strategy could save 10∼20% of energy during the cold winter months, compared with the “on-off” control or PI control of the air-conditioning intermittent running. However, the research of Kim et al. [19] showed that the simple “on-off” intermittent control could obtain the higher energy-saving ratio.

Xu et al. [20] proposed a predictive control strategy for the intermittent heating in office buildings by predicting the warm-up time on each working day. Their results showed the warm-up time was significantly longer on a Monday than on other working days and increased as outside temperatures decreased. The warm-up time was shorter for an energy efficient building than that for an ordinary building, and the colder the weather, the greater the difference. And the energy saving rate of intermittent heating systems can be as much as 20% in a typical week compared with continuous heating. Budaiwi and Abdou [21] researched the HVAC system running strategies to reduce building energy consumption with the intermittent occupancy in mosques, which were under the hot-humid climatic conditions in the eastern region of Saudi Arabia. Their results showed that the annual cooling energy was reduced by up to 23% by applying the suitable HVAC running strategies and 30% by applying the appropriate running zoning. In addition, Fraisse et al. [22–24] analyzed the relationships among the pre-heating time, the thermal comfort level and the energy consumption under the intermittent heating system, and Hazyuk et al. [25,26] proposed the optimal temperature control strategy of intermittently heated buildings.

Meanwhile, Wang et al. [27] built a validated dynamic thermal model based on the thermal-electrical analogy to compare convective and radiant heating systems for the intermittent space heating and four typical space heating systems were studied, namely all-air, radiator, in-slab floor heating and lightweight floor heating systems. The results showed the convective heating systems were more comfortable and more energy efficient for the intermittent running than the radiant heating systems. The intermittent heating was no longer suitable for the cold weather due to the long preheat time and the high heating load. And the performance gap between radiant and convective heating systems would be enlarged under the colder conditions. Among the four heating systems, the convective heating system was the most suitable one for intermittent heating, and floor heating was the most unsuitable one.

Based on the above review, there has been not any published paper about the thermal performance of interior wall under the air-conditioning intermittent running, although the cooling load formed by interior walls may have the high proportion due to the low thermal insulation performance and the large area of interior walls. In the energy conservation standards of China [3–6], the thermal properties of interior walls only between the heating room and the non-heating room are required in the present standards of the cold zone and the severe cold zone, while they are not required in other climate zones in China. So it is worthy of studying on the thermal performance optimization of interior walls under the air-conditioning intermittent running. Based on these, six interior walls were built by considering two thicknesses of 210 mm and 110 mm, and the heat transfer model was built by the finite volume method and verified by the experimental data. And the effect of air-conditioning intermittent running model, wall configurations and thicknesses was numerically analyzed on temperatures and heat flows in inner surfaces under air-conditioning intermittent running.