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Passive energy management through increased thermal capacitance

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ABSTRACT

This paper investigates the potential of using passive energy management through increased thermal capacitance (ITC) on the building cooling load by circulating water through a piping system located in the building walls or ceiling and then through a water storage tank. The cooling load obtained from the application of the ITC on the building walls and the ceiling is compared with the cooling load of a reference building without ITC. The reference building, which is located in Atlanta, GA, as well as the building with the ITC are simulated using a transient building simulation software, TRNSYS, for the month of May. Several parameters that affect the performance of the proposed ITC are also analyzed, including the tank size, the mass flow rate of the working fluid, and initial working fluid temperature. In addition, the effect of the window-to-wall ratio was analyzed for the ITC case in the walls. It was found that as the window-to-wall ratio increases the amount of potential of the ITC to reduce the cooling load decreases. In general, results indicate that the application of ITC reduces the cooling load, with an application on the ceiling being the best scenario.

1. Introduction

Energy consumption in the world is increasing at a drastic rate. According to United States Energy Information Agency (EIA), the world's energy consumption is expected to increase 56% by the year 2040 [1]. Also according to the EIA, commercial and residential buildings consume about 40% of the energy consumption in the US [2] with about 48% of the energy used in buildings being for heating and cooling [3]. Radiant heating and cooling is identified as one of the technologies that can effectively reduce energy consumptions in buildings [4,5]. Studies of radiant cooling and heating have been conducted by several authors, such as Miriel et al. [6], Vangtook et al. [7], Wang et al. [8], Venko et al. [9], Zhao et al. [10], Yang et al. [11], and Stetiu [12] among others. Miriel et al. [6] presented results for radiant heating and cooling experiment in a water ceiling panel in western France. Simulation models that allowed for yearlong simulations were developed for TRNSYS [13] and verified by experimental data. They determined that the ceiling needed to be maintained at 17 °C to prevent condensation from the radiant ceiling due to high humidity. Vangtook et al. [7] presented results for using pipes with water for cooling in residential buildings in Thailand. They concluded that thermal comfort could be maintained with a cooling tower keeping the water temperature at 10 °C to prevent condensation. Venko et al. [9] presented results on enhanced heat transfer for an active cooling wall in commercial buildings. In this study, an active wall was used in combination with fresh air supplied from a diffuser mounted at the top of the wall. The study determined that the forced convection from the diffuser provided superior heat transfer from the active wall when compared to the heat transfer due solely to natural convection. Zhao et al. [10] presented results of radiant floor cooling in a large building. The radiant floor cooling of a large building was found to provide better thermal comfort and required 20–30% less energy than a conventional forced air system. Yang et al. [11] presented results using a radiant cooled ceiling with a heat exchanger and conventional window air conditioner. A radiant cooling system was shown to reduce operating time and also reduce energy consumption by 13–19%. Stetiu [12] presented a study on the peak power savings using radiant cooling in commercial buildings in the US. A radiant cooling system was shown to produce save 30% on energy consumption and reduce the peak power by 27%. The savings were found to be climate-dependent.

In contrast with radiant cooling or heating, the research presented in this study explores the potential of using passive energy management through increased thermal capacitance (ITC) aimed at reducing the building thermal load. The proposed concept is similar to the concept of radiant floor heating and cooling, popular in the US [13], to control the cooling and heating load in a building. The main difference is that the radiant heating and cooling system is aimed at increasing the comfort level of the occupants while

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0378-7788/

Fig. 1. Reference building model in TRNSYS.

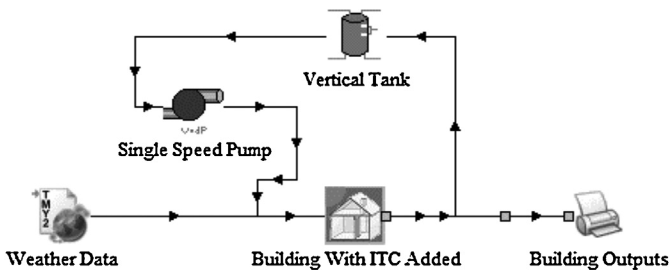

Fig. 2. Schematic of the TRNSYS model with ITC on the walls or ceiling.

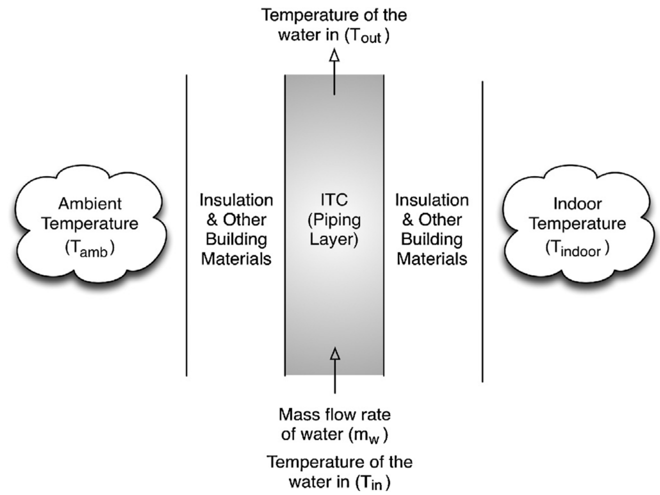

Fig. 3. Schematic of piping layer in building.

the proposed system aims to reduce the energy required to satisfy the thermal load of the building. This study investigates the potential of using passive energy management through ITC on the building cooling load by circulating water through a piping system located in the building walls or ceiling. A comparison between the cooling load for a reference building and that obtained when ITC is implemented in either the walls or ceiling is performed for the month of May. Then the effect of varying several parameters on the performance of the proposed ITC is also analyzed. These parameters include the tank size, the mass flow rate of the working fluid, and initial working fluid temperature. In addition, the effect of the window-to-wall ratio is analyzed on the performance of the ITC implementation on the walls is investigated.

2. Description of the simulation environment

To establish the benefits of using ITC, it is first necessary to create a reference building model to use as a baseline for comparisons. Both, the reference building and the building with ITC are modeled in TRNSYS [14,15], which is a simulation program primarily used in the fields of thermal energy engineering and building simulation. Fig. 1 shows the dynamic model generated in TRNSYS for the reference building. This model along with the input weather data is used to estimate the cooling and heating loads of the reference building. The building icon is called Type 56 Multizone Building that can model thermal behavior of a building. Typical meteorological Year 2(TMY2) weather data was used in the simulation. TMY2 weather data is a collection of solar radiation and other meteorological elements for various locations in the United States based upon weather over multiple years [16]. During the simulation, TRNSYS calculates the heating and cooling loads (i.e. the energy required for cooling) for the building model.

The effect of ITC was determined by modifying the reference building to include proposed ITC in either the walls or the ceiling. Fig. 2 illustrates the dynamic model of a building with the ITC added in either the walls or the ceiling. For this case, a piping system was inserted into the walls or into the ceiling to increase the thermal capacitance of these surfaces. A schematic of the wall with the piping system is shown in Fig. 3. This figure illustrates how the piping system is placed between the outer and inner material of the wall. The working fluid can either add or remove energy to the zone depending on working fluid, ambient, and zone temperatures. Adding or removing energy from the zone through increased thermal capacitance (due to the liquid in the pipes and in the storage tank) can reduce the amount of heating or cooling required, respectively. To establish the merit of this idea, a system presented in Fig. 2 has been implemented using an integrated model for thermo-active building elements (e.g. walls and ceilings) in TRNSYS [15]. This thermo-activated building element model is an integrated add-on feature available in Type 56 Multizone Building and is composed of a fluid piping system into a building construction element. The mean fluid temperature in a pipe loop is calculated based on the thermal resistance between the fluid and the pipe shell. The interior and exterior wall surface temperatures are calculated based on the effect of conduction between pipes and building construction material using a two-dimensional conduction analysis. Along with this thermo-activated building, the proposed model also consists of a single speed pump and a vertical tank connected to the building with the purpose of circulating water through the walls or the ceiling. The pump component in the TRNSYS simulation was used to control the working fluid flow rate for the entire system as well as to transmit information such as water temperature and flow rate to the building component. The mathematical model of the different components used in the model can be found in Ref. [15]. The building component calculates the water temperature change through the pipes in the walls and then conveys this data to the tank. A thermally insulated vertical tank with a single inlet and a single outlet was selected as the water storage tank. The insulated tank was placed outside of the building and exposed to ambient weather conditions.

3. Results

This section presents the results obtained using the models described in Section 2. Initially, a reference building was simulated to determine the cooling load. Next, the same reference building with ITC added to the walls and then to the ceiling was simulated to investigate the potential benefits from passive energy management through ITC.

3.1. Reference building

To establish the potential merit of ITC without introducing additional complexities due to architectural details, a very simple reference building was assumed for this investigation. Thus, at the beginning of this study, the hypothetical reference building is chosen to be a rectangular room with a surface area of 14 m × 14 m, wall height of 3.048 m, and a flat roof. No windows were used initially such as to allow the most piping possible to be used in the walls. The model for this initial reference building was simulated using the weather data for Atlanta, GA [16], during the month of May. The thermal set points were 21 °C and 24 °C for heating and