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A virtual thermostat for local temperature control

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ABSTRACT

Conventional HVAC thermostats use a single temperature sensor at one fixed location in a controlled space to control the temperature of the whole space. However, in most applications only a small zone in the controlled space need to be controlled (for example where the people are located). Heating and cooling of the unnecessary zones lead to extra energy consumption that can be saved if only the required zones are controlled. Such a control system requires knowledge of the temperature distribution in the whole zone at all times. In this work, we have used computational fluid dynamics (CFD) to determine the distributive temperature inside the controlled space at all times and turn the HVAC system ON and OFF based on the temperature of the desired zone in the space. In this case, since the distributive temperature is not directly measured, and it is only calculated, the control system is referred to as a virtual thermostat for local temperature control. In this study, we have determined the energy savings by comparing the energy consumption of a thermostat controlled system with a locally controlled one. Several cases with different heat losses, and different inlet air velocities and directions are studied. Energy savings of more than 22% is realized for the cases studied here.

1. Introduction

Indoor environment, where most people spend 80–90% of their time, has a significant effect on human health and work quality. The purpose of most heating, ventilation, and air conditioner (HVAC) systems is to provide thermal comfort and a suitable indoor air quality with minimized energy consumption. A large portion of today's energy consumption goes to indoor thermal control. Therefore, a small improvement in its energy consumption may result in a significant global energy savings.

A thermostat is usually used to control the heating and cooling of a space. Almost all thermostats use a single point temperature sensor located at a certain location in the control space to control the temperature of the whole space. Generally, there is no control on the air temperature at locations away from the temperature sensor. This lack of temperature control affects the energy efficiency of a HVAC system by unnecessarily heating/cooling of a zone. Therefore, the location of the thermostat sensor influences not only the energy consumption of the system but also the thermal comfort of the occupants of the space. Another drawback of a single point sensor is its disability of keeping a desired level of thermal comfort with low energy consumption.

The objective of the present study is to determine the potential energy savings by using the temperature around a person to control an HVAC system as compared to that of a conventional thermostat located at a fixed location on a wall in the controlled space. The energy saving in this study represents the energy which can be saved by switching from a conventional control to a local control. This energy saving does not represent the entire energy saving of HVAC system.

To conduct this study a computational fluid dynamics (CFD) method is used to simulate the transient flow and temperature field of an indoor space, which has an HVAC system and a person standing in the middle of the space. CFD has been used by several investigators to study the performance of HVAC systems. For example, Murakami et al. [1] developed a 3D-CFD simulation model of a human (just rectangular box) in the middle of a semi-enclose space to choose between two different HVAC systems. CFD has also been integrated with building simulation to provide specialists with information related to poor indoor environments and potential consequences during building design stages. For instance, Bartak et al. [2] studied and validated the possible outcomes of a room with several surface temperatures, and inlet/outlet air position configuration. CFD has also been integrated with other energy software packages to provide complementary information about energy performance of buildings. For instance, Zhai et al. [3–5] used CFD to study the cooling load of a large indoor auto-racing complex for two different cooling methods. Beausoleil-Morrison

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[6] introduced adaptive conflation controller with two possible control schemes to support coupling of CFD with ESP-r programs. He examined the controller with HVAC system case and showed how the adaptive conflation controller can simulate realistic operation condition. Kim et al. [7] introduced a technique for coupling a building envelope model to a CFD to improve energy efficient and thermal human comfort. Chen et al. [8] studied temperature and velocity distribution of UFAD and conventional air distribution (CAD) with variable air volume (VAV) by comparing CFD results with experimental data. The results show a reasonable agreement between numerical and experimental data. The maximum temperature error was about 10% and 25% for velocity. Lin et al. [9] studies the effect of air supply location on the performance of displacement ventilation (DV) system based on indoor air quality and thermal comfort. The study has been conducted using CFD and the results show that the air supplier should be closer to the space center to provide more uniform thermal condition. Stavrakakis et al. [10,11] presented a computational method to optimize thermal comfort of naturally ventilated building by improving the design of the windows. The method is based on utilizing CFD results to train Radial Basis Function Artificial Neural Network (RBF-ANN), which is used to optimize the design of the windows. The optimized design has been verified with CFD results, which showed good agreement. Zhou and Haghighat [12,13] developed and implemented an optimization scheme for a ventilation system to improve comfort, indoor air quality, and energy consumption of office buildings. The scheme utilizes CFD in combination with genetic algorithm and artificial neural network. The improved ventilation system showed better comfort level, higher ventilating efficiency, and lower energy consumption in comparison with the tested conditions. References [14–18] show other applications of using CFD on ventilation system design.

One of the thermal comfort parameters is a zone temperature, which requires an HVAC system to operate in a specific range of temperatures. ASHRAE Standard 55–2010 provides standards for the thermal comfort range. This paper mainly focuses on the air temperature control and its objective is to develop a methodology to control the air temperature around people in a closed space. This is different than controlling the temperature based on a thermostat set on a wall in a controlled space, which can be away from the people occupying the controlled space. Since it is not possible to have thermostats everywhere in a space, here we are introducing a virtual temperature measurement method using computational fluid dynamics (CFD). In this method an average temperature around the person is estimated and based on this estimation the HVAC system is controlled by turning the air inlet ON and OFF. The tested model is a person inside a room which has a ventilation system. To show the advantage of using local temperature control over conventional thermostat, the two control systems are compared by controlling the air inlet velocity based on the average temperature at specified locations in the room. One of the specified locations is a zone around the person and the other one is a small zone around the conventional thermostat. The results are compared based on energy saving and how good the control system keeps the average temperature around the person in a preferred temperature range. All the systems have been tested for an hour of operation. In this study, thirteen parametric cases have been considered to cover important aspects of HVAC control system. For example, different inlet velocities to cover two ventilation mixing mechanism (displacement and mixing ventilation); different inlet air directions to demonstrate the effect of the position of a person in the controlled space with respect to the inlet; and different wall thicknesses to show the effect of heating/cooling loads.

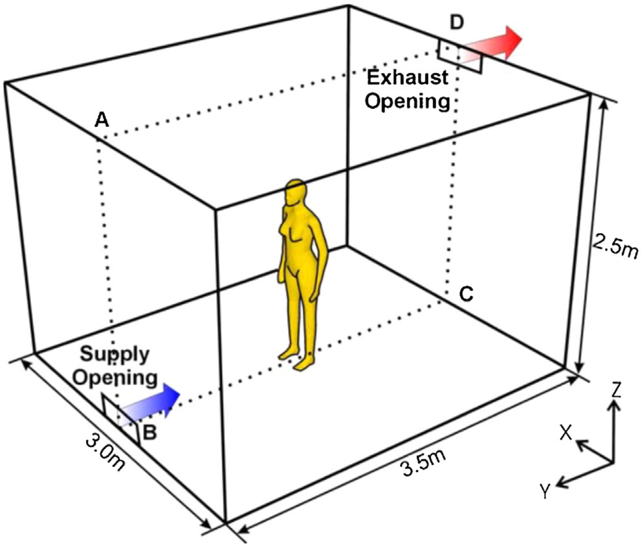

Fig. 1. CFD benchmarking – Nielson et al.'s tests [19].

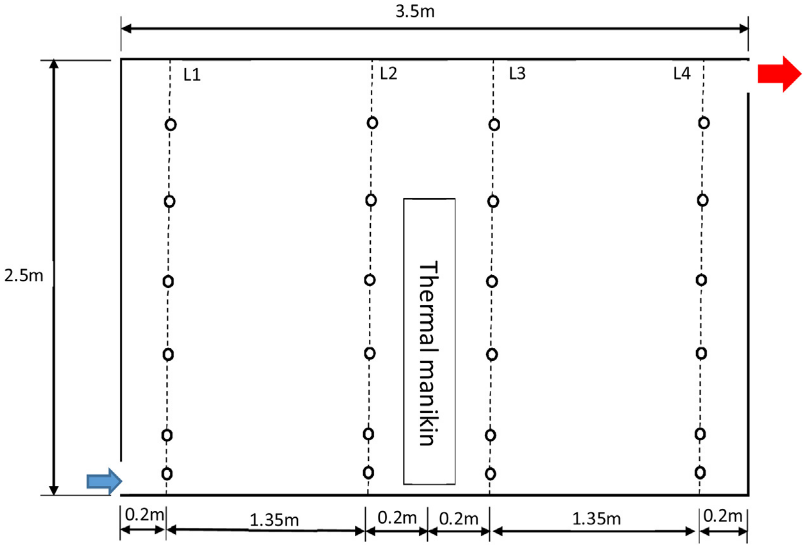

Fig. 2. Locations of the temperature and velocity measurements[19]. ^{a}The figure is not for scale.