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Thermal comparison between ceiling diffusers and fabric ductwork diffusers for green buildings

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ABSTRACT

Continuously increasing energy standards have driven the need for increasing the efficiency of buildings. Most enhancements to building efficiency have been a result of changes to the heating/cooling systems, improvements in construction materials, or building design code improvements. These approaches neglect the way in which air is dispersed into individual rooms or in a building – i.e., the ducting system. This opens up the possibility of significant energy savings by making ductwork systems lighter and better insulating while ensuring cost effectiveness.

The current study explores this idea by comparing the performance of conventional ductwork with recent advancements in fabric-based ductwork. We focus on the transient behavior of an on/off control system, as well as the steady state behavior of the two ductwork systems. Transient, fully three dimensional validated computational (CFD) simulations are performed to determine flow patterns and thermal evolution in rooms containing either conventional or fabric ductwork. This analysis is used to construct metrics on efficiency. A number of different flow rates are examined to determine the performance over a range of operating conditions. Transient finite volume simulations consisted of over 13 million degrees of freedom for over 10,000 time steps. The simulations utilized HPC (High Performance Computing) for the large scale analysis.

The results conclusively show that fabric ducting systems are superior to the conventional systems in terms of efficiency. Observations from the data show that fabric ducting systems heat the room faster, more uniformly, and more efficiently. The increase in performance demonstrates the potential benefits of moving away from conventional systems to fabric systems for the construction of green buildings: particularly in conjunction with adaptive control systems.

1. Introduction

The design of efficient building systems is necessary for meeting increasing energy standards. This trend pushes designers to create green buildings. Numerous strategies are available for increasing the energy efficiency of buildings: energy collection systems such as solar power cells can decrease the energy load in the building [1], solar water heating systems can preheat water to cover a large fraction of the heating demand [2], and materials such as aerogels and phase change materials (PCMs) can help increase the thermal resistance of building envelope components [3,4]. Control and supervision of heating ventilation and air conditioning (HVAC) systems can optimize the task of efficiently moving the energy through the building [5,6]. In addition, architectural design can create spaces that are both aesthetically pleasing and energy efficient [7]. Each of these approaches have aided in decreasing the amount of energy needed to operate green buildings.

Most energy saving systems used in green buildings have neglected a significant component of HVAC systems, the ductwork system. Conventional ductwork systems comprised of sheet metal ductwork and diffusers have a number of features that can adversely affect their performance. The conduction of heat through the sheet metal leads to a loss in energy as the air is dispersed in the building. Coatings can be added to the ductwork to make them less conductive, but the coatings lead to additional costs in the system. Moreover, the ductwork is heavy, and needs extra parts for support. Most importantly, the non-homogeneous nature of the airflow generated by diffusers leads to non-uniformities in heating/cooling causing discomfort. Finally, placement of conventional diffusers becomes a significant design decision in the effort to minimize local hot/cold spots and unpleasant drafts within the space.

Recent advances in ductwork technology has shown promise towards enhancing building efficiency. Fig. 1(b) shows a ventilation system where an *insulating fabric* ductwork has been used to transport air to desired locations within the building, thus limiting

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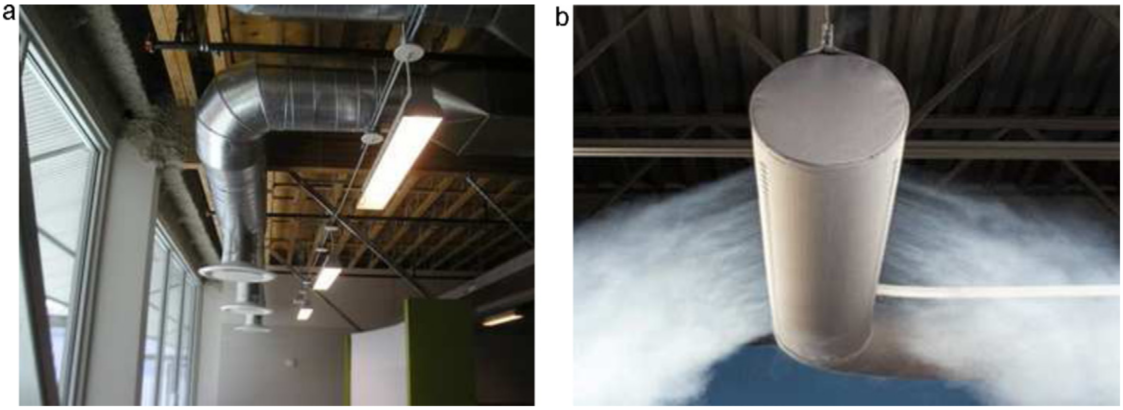

Fig. 1. Example of (a) a conventional and (b) a fabric ductwork systems.

energy loss to non-desirable areas and eliminating the need for a coating to make the ductwork less conductive. Furthermore, the fabric weighs much less than conventional sheet metal ductwork, removing the need for extra parts for support and further reducing costs. Along the length of the ducting, a series of strategically placed holes disperses the air uniformly throughout the desired space.[1]

In addition to the general benefits of fabric ducting, fabric ducting aims toward producing uniform and low-draft air supply in the desired space. Recent technology trends such as stratum ventilation (SV) and personal ventilation (PV) strive to create such a personalized local climate for medium and small room sizes. Personal ventilation provides a tailored environment for each individual, for each individual has their own sensitivity to air movement or air quality [8]. In personal ventilation, an individual trying to increase the air quality can be strongly affected by a turbulent jet provided by the PV system [9]. Similarly, stratum ventilation creates a layer of fresh air within the breathing zone of the occupants [10]. The attention to the breathing zone in SV systems provides better indoor air quality, but can still suffer from the effects of uncomfortable drafts from turbulent jets. Fabric ducting can be naturally incorporated into the PV and SV systems to provide the necessary uniform quality airflow required by the occupants without the negative effects of turbulent high-draft jets.

The positive aspects of fabric systems directly improve upon the drawbacks of conventional sheet metal diffuser systems. Currently, limited data is available to evaluate either type of system with respect to air coverage and thermal performance. The present work consists of numerical simulations that directly compare conventional ceiling diffuser systems and fabric systems to quantify the increase in performance of the fabric systems in both the initial transient period and steady state operating conditions. Three dimensional, full-scale, time-varying realistic simulations have been performed to allow for direct comparisons. The simulations show the time evolution of the temperature field within the rooms. The simulations provide qualitative observations that can aid in future design decisions, in addition to quantitative data that provide a direct measure of the performance and comfort level of the room through time.

2. Problem definition

The problem the present work seeks to address is to compare fabric-based ductwork to conventional sheet-metal ductwork quantitatively based on measures of efficiency. The physical space being studied represents an individual office space or a bed room. The simulations performed represent a room that has been unattended during the night, which is typical for an office space. At a given time in the morning the heating system is turned on in anticipation for another working day. Metrics for efficiency (and comfort) include mean and standard deviation of both air speed and temperature, the amount of power absorbed by the room, the Air Distribution Performance Index (ADPI), and the energy used and time taken to heat the room to an average temperature of 290.94 K.

The simulations are performed in a 2.43 m × 2.43 m × 2.43 m [8 ft × 8 ft × 8 ft] domain, which is a typical configuration in office spaces. The air outlet is placed on the ceiling for a *worst case scenario* in which the return air outlet is near the inlet. The outlet was offset 0.61 m [2 ft] in the x-direction, and has dimensions of 0.30 m × 0.30 m [1 ft × 1 ft]. The inlet for the diffuser is placed on the ceiling in the center of the domain (Fig. 2 (a),(b)), and the inlet for the fabric ductwork is placed on the side wall (Fig. 2(c),(d)).

For the fabric ductwork system, the air flow travels through the ducting tube until the air reaches the edge of the domain in the z-direction where another wall is encountered. The air is forced through 7 pairs of 2.54 cm [1 in] diameter holes spaced 0.30 m [1 ft] apart. The tube's center is 2.13 m [7 ft] above the floor. In the case of the conventional system, the diffuser inlet is 15.24 cm [6 in] in diameter. The bottom of the diffuser is 55.88 cm [22 in] long in both the x and z directions, and protrudes downward 15.24 cm [6 in] into the domain.

The flow patterns and thermal evolution in each room are simulated for different flow rates (shown in Table 3) to quantify performance and efficiency. The flow rates correspond to multiples of ASHRAE's minimum required flow rate for an office space. The room and the walls are heated from an initial temperature of 288.67 K [60 F] by an inlet air supply at 299.56 K [80 F]. The walls are maintained at the initial temperature of the room.

3. Simulation methodology

3.1. Basic equations

The basic equations describing the thermo-fluid phenomena are the Navier–Stokes equations, conservation of mass, and conservation of energy. Variables used in subsequent developments

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[1] The number and size of holes placed in each desired room affects the power and static pressure required by the fan to a small extent. However, in multi-room buildings the fan power used will depend more on the major and minor losses of the ducting system that reaches the individual space rather than the specific air distribution mechanism within an individual room.