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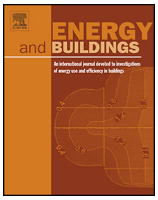

A method of assessing the energy cost saving from using an effective door closer

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ABSTRACT

Door closers are widely used for doors in commercial buildings, not only for safety purposes but also for reducing the airflow through door openings. This study aimed to develop a method for quickly assessing, in the design phase, the heating and cooling energy cost saving from using an effective door closer. The method developed in this study consists of a stop angle model, airflow model, and energy cost calculation. This investigation also conducted experimental measurements in a full-scale test facility to validate the models. This study then used the proposed method to assess the heating and cooling energy cost saving from using an effective door closer in the cities of Minneapolis, Boston, San Francisco, and Phoenix. It was found that, under a greater indoor–outdoor pressure differential, using an effective door closer would save more energy cost. When using a closer with a larger size, the energy cost lost would decrease, but a large closing torque may significantly reduce ease of use and accessibility and potentially violate building codes related to the Americans with Disabilities Act (ADA). Furthermore, the energy cost saving from using an effective door closer in San Francisco would be lower than that in Minneapolis, Boston, and Phoenix.

1. Introduction

The building sector accounts for nearly 41% of the total primary energy consumption in the United States [1]. Therefore, energy saving in buildings has the potential to significantly reduce overall energy consumption. Air infiltration through the building envelope is considered to be among the most important factors in building energy saving [2–4]. The National Institute of Standards and Technology (NIST) has reported that annual heating and cooling energy costs could be reduced by 3–36% for different climate zones if the target air tightness level were achieved [5]. In commercial buildings where exterior doors are used frequently, airflow through door openings can cause a considerable increase in energy consumption. In strip malls with vestibules, for example, the total energy consumption is 5.61% lower than in similar malls without vestibules [6]. Therefore, building designers are paying more and more attention to the reduction of airflow through exterior door openings.

Door closers are widely used for doors in commercial buildings, not only for safety purposes but also for reducing the airflow through exterior door openings. Ease of use and accessibility are ongoing requisites for building designers and facilities management. The Americans with Disabilities Act (ADA) has set a maximum force for pushing or pulling open a door for accessibility reasons [7]. These requirements in turn limit the amount of force that can be applied by a door closer to close the door. When the indoor–outdoor pressure differential created by a ventilation system is relatively large, the door closer with low opening force set to accommodate ease of use may not be able to overcome the resistance and fully close the door. In this case, the door may remain open at the angle at which the force due to the pressure differential balances the closing force. Under such circumstances, the continuous airflow through the door opening could significantly increase the energy costs for heating and cooling.

During the design phase, designers must decide whether or not to use door closers in a building, and what kind of door closer to

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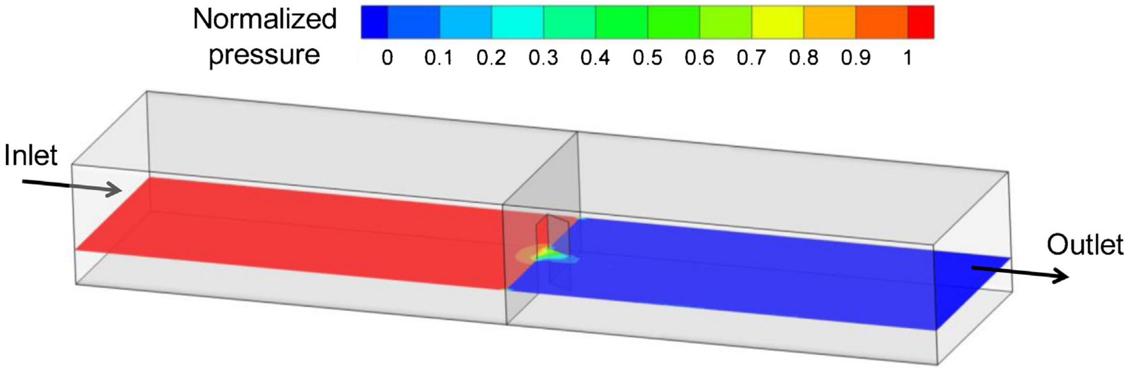

Fig. 1. Calculated normalized pressure distribution at a height of 1 m in the numerical wind tunnel test when the opening angle was 60° and inlet velocity was 1 m/s. The pressure was normalized by the pressure at the inlet.

use. This decision for an effective door closer should help achieve a balance among accessibility, security, and energy efficiency. From the perspective of energy efficiency, designers need to know the extent to which heating and cooling energy costs can be reduced by the use of an effective door closer. However, there is no simple method available for obtaining such information in the design phase. In fact, a literature search found very few scientific publications focusing on door closers. Several studies have investigated the design of door closers [8,9] and their effectiveness in improving fire safety [10,11], but these studies did not address the issue of energy efficiency. Therefore, the present study aimed to develop a method for quickly assessing, in the design phase, the heating and cooling energy cost saving from using an effective door closer.

The method developed in this study consists of (1) a model for determining the stop angle at which the pressure differential force balances the closing force produced by a door closer, (2) a model for calculating the airflow rate through a door opening that accounts for various influencing factors, and (3) energy calculation with the use of the two models. This study also conducted experimental measurements in a full-scale test facility to validate the two models. This investigation then used the proposed method to assess the heating and cooling energy cost saving from using an effective door closer in different climate zones.

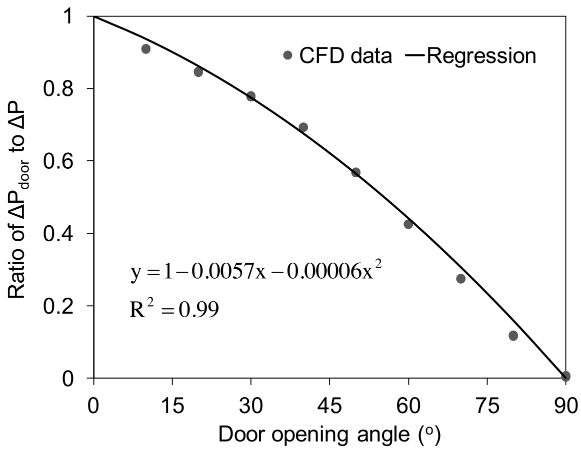

Fig. 2. Relationship between the ratio of ΔP_{door} to ΔP and the door opening angle.

2. Methods

As discussed above, an ineffective door closer or closer with low opening force to accommodate ease of use may not be able to overcome the force on the door due to the indoor–outdoor pressure differential. In this case, a door may remain open at a certain angle, which could result in a significant increase in heating and cooling energy costs. This study first developed a model for determining the stop angle, θ^*, at which the pressure differential force balances the closing force produced by a door closer, as described in Section 2.1. Next, the stop angle was used to calculate the airflow rate through the door opening. This investigation then developed an airflow model for calculating the flow rate through a door opening that accounts for various influencing factors, as described in Section 2.2. The final step was to calculate the effect of the airflow rate through the door opening on heating and cooling energy costs. The energy cost calculation method is described in Section 2.3.

2.1. Stop angle model

The stop angle is the angle at which the door remains open when the pressure differential force balances the closing force produced by a door closer. Note that the force on the door due to the indoor–outdoor pressure differential depends on the opening angle. When the door is fully closed, this pressure force is equal to the indoor–outdoor pressure differential multiplied by the area of the door. When the door is opened to a certain degree, the pressure force on the door is smaller than the product of the pressure differential and the door area because of the drop in pressure. To correlate the pressure force on the door and the indoor–outdoor pressure differential, this study conducted numerical wind tunnel tests using computational fluid dynamics (CFD) and created a database. Fig. 1 shows the configuration of the wind tunnel with a partially opened door that was used in the numerical tests. The wind tunnel had dimensions of 25 m in length, 6 m in width, and 3.5 m in height. The door was 2 m high and 0.9 m wide. The case setup was the same as that in a previous study by Yang et al. [12]. There were 45 cases with different door opening angles (10–90°) and inlet air velocities (0.2–1 m/s). This study employed the RNG k-ε turbulence model to calculate the pressure distribution across the door opening, as shown in Fig. 1. The CFD model was validated by experimental data measured by Yang et al. [12]. The pressure differentials between the two sides of the door, ΔP_{door}, and the corresponding indoor–outdoor pressure differentials, ΔP, for the 45 cases were recorded to create a database.

Fig. 2 shows the ratio of ΔP_{door} to ΔP as a function of door opening angle. It can be seen that, for a given door opening angle, the five data points with different inlet velocities (0.2, 0.4, 0.6, 0.8, and 1 m/s) collapse to a single point. Therefore, the ratio of ΔP_{door} to ΔP is independent of the inlet velocity. However, the ratio of ΔP_{door} to ΔP decreases with the increase in door opening angle. Through