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Building and Environment 40 (2005) 701–718
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

An attic-interior infiltration and interzone transport model of a house

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Received 16 July 2002; accepted 29 June 2004

Abstract

A detailed model is developed for predicting the ventilation rates of the indoor, conditioned zone of a house and the attic zone. The complete set of algorithms is presented in a form for direct incorporation in a two zone ventilation model. One of the important predictions from this model is the leakage flow rate between the indoor and attic zones. Ventilation rates are predicted from a steady state mass flow rate balance for each zone where all individual flow rates through leakage sites are based on a power law expression for flow rate versus pressure difference. The envelope leakage includes distributed leakage associated with background leakage, localized leakage associated with vents and flues, and active fan ventilation. The predicted ventilation rates agree quite well with field measurements of ventilation rates in houses and attics with different leakage configurations, without the use of any empirically adjusted parameters or constants.

Keywords: Attic; House; Infiltration; Ventilation; Wind; Buoyancy; Tracer gas

1. Introduction

Ventilation is generally classified as passive (relying only on natural driving forces of wind and indoor–outdoor temperature difference) or active (operation of an exhaust fan). For the indoor, conditioned zone, ventilation is used to remove indoor air contaminants such as volatile organic compounds, radon gas, and excess moisture. For unconditioned zones such as attics, ventilation is used to control excessive temperatures and moisture accumulation. A detailed description of previous studies of attic ventilation is given by Walker and Forest [1].

Since ventilation plays such a large role in controlling the interior environment of a house, it is important that simple and reliable models be developed to predict ventilation rates based on meteorological conditions and characteristics of the leakage area of the building envelope. Ventilation models by the authors and other co-workers have considered a single indoor zone with distributed leakage [2,3]. Single zone models have been extended to include localized leakage associated with large openings such as, vents and furnace flues [4]. In these models, the individual mass flow rate through each leakage site is calculated based on the pressure difference acting at the leakage site and the flow characteristic of the leakage site. This pressure difference is a combination of the actions of wind and indoor–outdoor temperature difference. The superposition of these two pressure differences is discussed by Walker and Wilson [5]. For the attic zone, Forest and Walker [6] describe a ventilation model based on the same approach taken by Walker and Wilson [4], which includes background leakage of the attic envelope and localized leaks associated with roof vents. A simplified version of this attic ventilation model is presented in Walker et al. [7] for use as a diagnostic tool.

The present work was undertaken to develop a two zone model to predict ventilation rates in a given zone as well as the mass flow rate between the zones. Our focus

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0360-1323/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2004.08.002

here is on the attic zone. The inter-zonal house-to-attic leakage flow rate is important since this flow convects both heat and moisture into the attic zone. The two zone ventilation model developed here falls between extremely complex multi-zone models such as, Feustal and Raynor-Hoosen [8] which require a great deal of input data that is difficult to determine and simple single zone ventilation models. The predictions of zone ventilation rates and the inter-zonal flow rate are compared with measurements of these rates at the Alberta Home Heating Test Facility over several years of testing and for houses with different leakage configurations. The predicted rates will be shown to agree quite well with measured values without recourse to empirically adjusted parameters or constants.

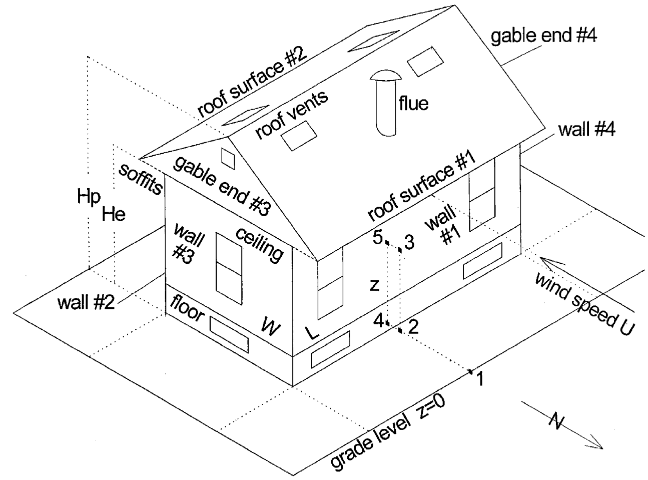

Fig. 1. Schematic of house showing reference numbers for wall and roof surfaces and reference numbers for points on the building envelope where pressures are calculated.

2. Attic-interior two zone ventilation model

In order to develop a model for predicting attic ventilation rates, the house that is being modeled is divided into two zones: a single interior zone that is conditioned to some constant temperature, and an attic zone that is not conditioned. Both zones are included in the ventilation model since one of the important predictions from the model is the inter-zonal leakage flow rate; this leakage air flow can convect moisture into the attic space where condensation occurs during periods of cold weather. One of the important features of our ventilation model is the combination of distributed leakage area with site-specific, localized leaks such as, attic vents, soffits, combustion air inlets, and furnace flues. Walker and Wilson [4] have shown how including a single localized leak (in their case a furnace flue) can have a significant effect on calculated ventilation rates in a model with distributed leaks.

We consider a residential building that has a rectangular plan form as shown in Fig. 1. The plan form is restricted to rectangular shapes where the longest side is no more than about three times the shorter side because wall pressure coefficients used in calculating wind pressures (see Section 2b) have been taken from data sets that are restricted to these simple shapes. The attic is restricted to having two pitched surfaces with gable ends. This restriction is set by the availability of measured data for roof pressure coefficients rather than any real "typical" roof construction. More complex building shapes can be incorporated in the model if data on surface pressure coefficients exists. The air in the two zones is assumed to be well-mixed implying that air has uniform properties within each zone although these will be different in the two zones. The interior zone is assumed to be at a constant, specified temperature while the attic air temperature is dependent on meteorological conditions including solar gain, ventilation rate, and attic insulation level. In our comparison of measured and predicted attic ventilation rates given in Section 3, we used the measured attic air temperatures rather than values predicted by an attic thermal model. An attic thermal model is beyond the scope of this paper. In connection with the assumption of well-mixed zones, it is further assumed that there are no vertical temperature gradients either inside each zone or outdoors. Measurements performed in our test houses by Dale and Ackerman [9] have shown that this is a good assumption because all the change in temperature in indoor air occurs in thin boundary layers on the walls, the floor and the ceiling that are about 5% or less of the total room volume. Furthermore, it is assumed that the density and viscosity of air depend only on temperature.

The building envelope leakage is divided into three categories: *distributed* leakage which includes all small cracks, holes, and imperfections in the envelope, *localized* leakage sites such as, furnace flues and attic vents, and *active* leakage sites with fans. Fans are included using a fan pressure-flow performance curve so that if large natural pressures due to wind and stack effect occur at the fan location then the fan flow will change. The distributed leakage area is assumed to be spread uniformly over each wall and roof surface with the flow characteristics independent of the flow direction. The general mass flow rate equation for each localized leak is assumed to be

$$\dot{m} = \rho C \Delta P^n, \tag{1}$$

where $\dot{m}$ is mass flow rate (kg/s), ρ is the density of air (kg/m^3), C is the leakage flow coefficient (m^3/(sPa^n)), ΔP is the pressure difference across the leak (Pa), and n is the flow exponent. The value of n varies from 1.0 for laminar flow to 0.5 for turbulent orifice flow. Values of C and n are obtained from separate measurements of