Airflow Performance of Building Envelopes, Components, and Systems

Mark P. Modera
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Foreword

This publication, *Airflow Performance of Building Envelopes, Components, and Systems*, contains papers presented at the symposium of the same name, held in Dallas/Fort Worth Airport, TX on 10–11 October 1993. The symposium was sponsored by ASTM Committee E-6 on Performance of Buildings and its Subcommittee E06.41 on Infiltration Performance. Mark P. Modera, Lawrence Berkeley Laboratory, University of California, Berkeley, and Andrew K. Persily, National Institute of Standards and Technology (NIST), U.S. Department of Commerce, served as co-chairmen of the symposium and are editors of the resulting publication.

Contents

Overview

Airflow in buildings has been a topic of interest since people began to build shelters. One of the earliest issues was orientation with respect to the wind, including both augmentation and reduction of indoor air motion. The issues of interest expanded to include thermal buoyancy effects, as well as the provision of air for ventilation and combustion as building shells became more airtight. The issues of current interest encompass natural and mechanical ventilation systems, pressure control, control and dilution of air pollutants, control of the thermal environment (including distribution of ventilation air, heat and cooling), and control of airflow through leaks in the building envelope. As the numerous types of airflow in buildings have been studied over the years, the level of detail of the knowledge available and required relative to those types has continued to increase.

ASTM Subcommittee E06.41 (Infiltration Performances) began writing consensus standards on measurement techniques for air infiltration in 1975, focusing on measuring the airflow through building envelopes with tracer gases (current version: E 741-93, Test Method for Determining Air Change in a Single Zone by Means of Tracer Gas Dilution), and the air leakage characteristics of building envelopes (current version: E 779-87, Test Method for Determining Air Leakage Rate by Fan Pressurization). Since 1975, ASTM Subcommittee E06.41 has written a number of additional standards addressing more of the details associated with understanding airflow and air leakage in buildings (E 1186-87, Practice for Air Leakage Site Detection in Building Envelopes; E 1258-88, Test Method for Airflow Calibration of Fan Pressurization Devices; E 1465-92, Guide for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings; and E 1554-94, Test Method for Determining the External Air Leakage of Air Distribution Systems by Fan Pressurization).

In parallel with the efforts of E06.41, ASTM Subcommittee E06.51 (Component Performance of Windows, Curtain Walls, and Doors), has been addressing the airflow performance of various building components, starting with the performance of various building shell components in the laboratory (E 283-91, Test Method for Determining the Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors under Specified Pressure Differences Across the Specimen; and E 1424-91, Test Method for Determining the Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors under Specified Pressure and Temperature Differences Across the Specimen), and extending to the installed performance of those components (E 783-93, Test Method for Field Measurement of Air Leakage through Installed Exterior Windows and Doors).

To aid in the consensus standards process, as well as to provide concentrated documentation of progress in the area of building airflow and air leakage, ASTM Subcommittee E06.41 has sponsored a technical symposium (and subsequent Special Technical Publication) approximately once every five years. The first of these, Building Air Change Rate and Infiltration Measurements (*ASTM STP 719*), held in 1978, was focused principally on measurement techniques, with some limited data taken by researchers. The 1984 symposium, Measured Air Leakage of Buildings (*ASTM STP 904*) was focused on relatively large sets of field data. The third symposium, Air Change Rate and Airtightness in Buildings (*ASTM STP 1067*) was held in 1989 and was divided fairly evenly between analyses of measurement techniques and compilations of field measurement results.

The symposium that forms the basis of this book attempted to document current research efforts for and knowledge of airflow through the building envelope as a whole, a topic that has been the focus of the earlier symposia put together by ASTM Subcommittee E06.41, as well as to address the growing interest and concerns associated with airrflow through the various components that make up that building envelope (e.g., windows), and the systems that serve to distribute air (and heat or cooling) within a building. Like the 1989 symposium, this symposium was split between analyses of measurement techniques and summaries/analyses of field data, with somewhat more emphasis on the latter. This symposium served to bring together the expertise within at least two ASTM subcommittees: E06.41 and E06.51.

The symposium was divided into four sessions, each session focusing on a particular aspect of building airflow. These four sessions included, in order of presentation: (1) Air Movement, Ventilation, and Indoor Air Quality, (2) Window Air Leakage, (3) Envelope Heat and Mass Transfer, and (4) Envelope and Distribution System Leakage.

The first symposium session, Air Movement, Ventilation, and Indoor Air Quality, was chaired by Andy Persily, and included five papers. The major focus of this session was building airflows under more complex circumstances, in particular larger buildings with multiple zones, and pollutant entry from soil gases. The Palmiter et al. paper provided one of the few published sets of simultaneous measurements of airflow through all pathways in a multifamily building. The Dols and Persily paper compared and contrasted ventilation measurement results obtained for a large office building with several different techniques, whereas the Shaw and Reardon paper reports on changes in the airtightness of six office buildings over a period of about 20 years. The Kozik et al. and Williamson et al. papers explored two aspects of soil gas entry and dilution in the field, the Kozik paper focusing on the impacts of duct leakage and resulting house pressurization/depressurization on radon entry and dilution, and the Williamson paper focusing on whether or not slab flooring provides an effective barrier to soil-gas entry.

The Window Air Leakage session, chaired by Mark Modera, was comprised of four papers addressing the airtightness of window systems. The papers in this session focused on the various issues associated with understanding how windows will leak in the field as opposed to under ideal conditions in a laboratory. The first of the Kehrli papers described the relatively recently-approved ASTM standard for window air leakage, E 1424, which includes the impacts of temperature differentials in laboratory measurements of window air leakage. The second Kehrli paper was a simulation-based analysis of the energy implications of window air leakage for several window products placed in four different building designs in various U.S. climates. The Louis and Nelson paper outlined an approach for quantifying window perimeter leakage, which is not accounted for in current ASTM standards. The Proskiw paper addressed the issue of perimeter leakage for the particular case of residential construction, including cost data for various types of rough opening seals.

The third session, Envelope Heat and Mass Transfer, was chaired by William Brown, and consisted of four papers. In particular, two of the papers addressed airflow and moisture in the envelopes of manufactured housing, and two papers addressed the interactions between conduction heat flows and airflows in the building envelope. The Tenwolde et al. paper addressed the impacts of airflow on moisture accumulation in the walls of manufactured homes, and the Burch paper addressed the same problem for the roof cavities of those structures by means of computer simulation. The Claridge et al. and Jones et al. papers dealt with the important issue of how airflow through building walls interacts with fourier conduction within those walls.

The final session, Envelope and Distribution System Leakage, was chaired by David Saum. This session contained three papers analyzing measurement techniques, and one paper focusing on field measurement results. The Levin et al. paper presented comparisons of various air leakage standards, focusing on the impacts of different test pressures and variations in flow exponents. The Proskiw paper presented field data on variations in whole building airtightness over a three-year period. The Sherman and Palmiter paper presented an error analysis of various single-zone fan pressurization measurement protocols and analysis procedures. The Modera paper compared and contrasted the performance of two alternative techniques for measuring duct system leakage that were recently incorporated into a new ASTM test method (E 1554).

As was the case with earlier ASTM symposia on building airflow, the papers presented and published herein serve both to enlighten us on the progress that has been made in our understanding of building airflows, as well as to point out where that understanding is lacking. This is true both for our ability to predict those flows and their impacts by means of computer modeling, as well as for our ability to standardize measurement techniques that can provide accurate airflow characterization data in a minimum amount of time. This symposium represents a small step forward in our continuing quests to improve our understanding of building airflow, and to use that understanding to provide the building community with standards that can provide accurate data as cost-effectively as possible.

The publication of this book was made possible by the efforts of a large number of individuals. We, as the editors and organizers of this symposium, would like to thank all of those individuals, starting with the authors, who provided the substance upon which this book is based. We would also like to thank the ASTM editorial and conference organization staff who took on the thankless task of assuring that the symposium and the publication of this book actually came to pass. Finally, we would also like to thank the session chairmen for their efforts.

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Air Movement, Ventilation, and Indoor Air Quality

Larry Palmiter,[1] Jonathan Heller,[1] and Max Sherman[2]

Measured Airflows in a Multifamily Building

REFERENCE: Palmiter, L., Heller, J., and Sherman, M., "**Measured Airflows in a Multifamily Building,**" *Airflow Performance of Building Envelopes, Components, and Systems, ASTM STP 1255,* Mark P. Modera and Andrew K. Persily, Eds., American Society for Testing and Materials, Philadelphia, 1995, pp. 7–22.

ABSTRACT: A method has been developed to measure real-time airflow in multifamily buildings. This method uses a multi-tracer measurement system (MTMS) and simultaneous measurements of pressure, temperature, and environmental conditions. These measurements are evaluated along with the results of blower door and flowhood fan tests to develop a complete picture of the airflow patterns in multifamily buildings due to temperature differences, wind, and mechanical ventilation.

Six units in an unoccupied three-story multifamily building in Portland, Oregon were tested for a period of eight days during February and March 1992 using this method. The apartments were equipped with timer-controlled ventilation fans that were set to come on at regular two-hour intervals throughout the test period, enabling a thorough evaluation of the effect of various fan conditions on the flow of air from the outside as well as between units.

The average ventilation rate from natural driving forces alone (wind and stack effects) was about 40 m^3/h per unit, or 0.22 air changes per hour (ACH). The average ventilation rate during the periods with all ventilation fans running was 75 m^3/h (0.41 ACH). There was also a significant amount of inter-apartment airflow, which was dominated by flow from lower units to the unit directly above from temperature-driven stack effects. Operating all exhaust fans together had little effect on the interzone flows; however, operation of a single exhaust fan significantly increased the interzone flow to that apartment from all adjacent units. The percentage of total airflow that was outdoor air was found to be lower for higher units than for lower units.

KEYWORDS: infiltration, tracer gas techniques, multifamily buildings, indoor air quality, ventilation, multizone airflow

Measurement of airflow in residential buildings is important for obtaining information about heating and cooling requirements, humidity levels, and indoor air quality. With increasing emphasis on energy efficiency, new building standards are mandating tighter buildings with lower infiltration levels. This raises the question of whether the fresh air necessary to maintain a healthy indoor environment is being provided. In the case of multifamily buildings where the air flowing between units carries smoke, dust, biocontaminants, and other pollutants, this question is especially difficult to answer. Air infiltration should only be counted as ventilation when it comes directly into the living space from outdoors without passing through another already polluted environment.

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Single-family buildings have been extensively tested, and many methods have been developed to measure airflow in buildings which can be treated as a single zone. Less extensive testing has been done in multifamily buildings where the interzonal nature of airflows complicates the analysis. Most studies of interzonal flows in multifamily buildings have yielded only average results. This paper presents the results of real-time multizone flow measurements made using a multiple tracer gas technique at a multifamily building in Portland, Oregon. The intent of this paper is not to fully analyze the flow data from this test case, but simply to use the case as an example of the type of data which can be collected by this method. The multizone tracer gas measurement system used for this test is described in the next section, followed by an explanation of the experimental instrumentation and procedures used at the test site. The test site and environmental conditions during the test period are discussed in later sections. A summary of the measured data is provided, along with a brief summary and discussion of the findings. The conclusion draws out some of the interesting aspects of the airflow in this building which were discovered during testing. A brief description of the physical characteristics of the test site is given in Table 1.

Multi-Tracer Measurement System

The multi-tracer measurement system (MTMS) used in this study was developed at Lawrence Berkeley Laboratory. A different tracer gas is injected into each zone under study using mass flow controllers. The injection of tracer gases and the measurement of gas concentrations are controlled from a personal computer. This allows for rapid measurement of

TABLE 1—*Physical characteristics of testing site.*

Building Characteristics	
Location	Portland, Oregon
Year built	1992
Energy efficiency	Built to Utility Super Good Cents specifications
Number of stories	3
Number of units in building	21
Number of units tested	6
Foundation	Slab on grade
Entry to units	Outside recessed stairwell
Arrangement of Test Units	
Two stacks of three units, mirror images. All apartments have south and north facing walls. The test units are in the center of a long row of apartment units, with double fire walls on both sides.	
Unit Characteristics	
Average floor area	77 m^2 (829 ft^2)
Average volume	183 m^3 (6462.6 ft^3)
Ceiling height (not including cathedral ceilings)	2.3 m (7.54 ft)
Mechanical Equipment	
Automatic exhaust system	Timer-controlled laundry fan
Makeup air	Operable inlet ports in window sashes
Other ventilation fans	Two bath fans, range hood fan
Heating system	Electric resistance wall heaters
Test Period	
12:00 noon, February 22, 1992 to 12:00 noon, March 1, 1992	

all tracer gases in all zones. Flows between all zones and the outside can then be calculated from the measures of tracer concentrations. At the same time that the concentrations are being measured, temperature and pressure measurements are taken in each zone, and environmental weather data are collected to assist in the flow analysis.

The most demanding aspect of the MTMS is the accurate measurement of tracer gas concentrations. This is accomplished with a residual gas analyzer quadrupole mass spectrometer. Air is selected for analysis from the various zones by a manifold and pumped into a vacuum chamber which houses the spectrometer. The air is ionized, and the resulting positive ions are separated by their charge-to-mass ratio by a variable electric field. The electric field is controlled to select out mass particles which correspond to the various tracer gases being measured. The ions corresponding to the desired tracer gas are then directed at an electron multiplier for detection.

The spectrometer has an absolute accuracy of about 1% of any given reading; however, at the working pressures, electronic noise produces errors of about ±20 parts per billion (ppb). Most tracer gases can be calibrated to ±1% down to 2 parts per million (ppm) where the noise dominates the uncertainty. Typically, tracer gas concentrations of about 20 to 50 ppm are used in each zone in multifamily buildings so that the flow of air to neighboring zones can be accurately measured. Reference *1* provides a more detailed description of the MTMS.

Methodology and Data Analysis

Different tracer gases were injected into each of six zones using six separate mass flow controllers. Each apartment unit was treated as a separate zone. Mass flow was measured to within 1% accuracy. The gases used in this analysis were helium, sulfur hexafluoride (SF_6), and four types of refrigerants: F12, F13B1, F22, and F116.

In this study, the constant injection method was used whereby the tracers are injected into the zones at a constant rate throughout the test period. Tracer gases were transported to each zone via tubing from the MTMS and injected at three different locations in each zone through a manifold arrangement. Each injection point was attached to an oscillating fan which ran continuously during the test period. These fans served to disperse the tracer into the zone and to improve mixing. The air was sampled from four different locations in each zone and gathered together in a manifold to provide a single air sample to the measurement equipment. Sampling at multiple locations also helps to reduce errors associated with incomplete mixing.

In addition to taking concentration measurements in each of the apartment units, outdoor air was sampled well away from the building at four-minute intervals. This allowed for the measurement of any background levels of the tracer gases in the environment. The MTMS is temperature and pressure sensitive, so a calibration chamber was set up outside and the MTMS was recalibrated throughout the test period using as a baseline the background level of helium in the atmosphere. The calibration chamber consisted of a 6 m (20 ft) length of pipe with a fan located on the downstream end, continuously pulling air through the pipe. Every three hours, helium and one of the other tracer gases were injected into the upstream end of the pipe at a known flow rate, and the concentrations were measured at the other end. The helium reading was then adjusted for the background level and used to calculate the flow rate through the pipe. The reading for the other tracer could then be recalibrated. This resulted in a new calibration for each gas approximately every 18 h. The mean calibration for each tracer gas over the duration of the test period was used to correct the concentration measurements. The relative error in the flow calibrations (standard deviation divided by the mean) was calculated for each gas using all of the calibrations derived during the test period. This error ranged from 2% to 9% for the six gases. The average relative error of all gases together was about 7%. The propagation of error through the multizone matrix equations is very complex, a detailed discussion of which is beyond the scope of this paper. In general, errors in the concentration determination will lead to comparable errors in the calculated flows.

Reference 2 contains a detailed accounting of multizone flow theory and calculations.

Temperatures and Pressures

Temperature readings were taken in each apartment continuously during the testing period. The temperatures were measured with thermocouple wires running from the center of each zone to a personal computer. Temperatures in every zone were recorded each time that any zone was sampled.

Pressure transducers were installed across all of the interior walls between zones, from the top zones to the attic, and at the floor of the ground floor zones to the outside. This allows for a calculation of total stack and wind pressures. These measured pressures can then be used with flow data from the MTMS to help evaluate irregularities in the data.

Data Analysis

The concentration readings were converted to flows using a matrix deconvolution program developed by the primary author. The time series concentrations were filtered using Savitsky-Golay filters [3] to estimate a smoothed concentration and its derivative at each time step. These filters are equivalent to fitting a quadratic by least squares to each successive group of nine points and calculating the predicted central value and its derivative. The flows were then calculated by inverting the matrix equations, resulting in 36 interzone flows at 4-min intervals. The flows to and from outdoors were calculated from flow balances on each zone. The flows were then averaged to 15-min data.

An integral number of days was chosen for this analysis, starting some time after the initial setup to allow for equilibration of the site and instrumentation, and ending before any significant interference from other testing began. We used eight complete days of data: from noon on February 22 to noon on March 1, 1992. For this analysis, the 15-min data were averaged by time-of-day to produce a single average daily profile. This procedure maximizes the signal-to-noise ratio for studying the effects of periodically operated fans.

Test Building Description

Building

The tests were done in a multifamily building in the vicinity of Portland, Oregon, immediately after the building was constructed, but before occupancy. The test period was a full eight days in February and March 1992. The building is three stories high and contains 21 apartment units. All of the apartments have exterior entrances accessed by recessed stairwells. The building is of standard wood frame construction, with a slab-on-grade foundation. The north wall of the ground floor units is buried about 1 m below grade. The floor of every unit has about 4 cm of lightweight concrete and carpeting.

Only six units in the building were tested. These constituted two stacks of three units, accessed by a single exterior stairwell in the center of the building. The units are separated from the rest of the building on both sides by double fire walls. It was assumed for the purpose of this testing that negligible airflow occurs across these fire walls. Therefore, for airflow evaluation and all other references in the remainder of this paper, the six test units