INFILTRATION AND VENTILATION MEASUREMENTS ON THREE ELECTRICALLY HEATED MULTIFAMILY BUILDINGS

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ABSTRACT

In recent years, increasing importance has been placed on energy efficiency in residential buildings. This has resulted in tighter buildings, which raises concerns about the amount of ventilation required to provide acceptable indoor air quality. Relatively few studies have been conducted on multifamily buildings, where the multiple zone interaction makes testing and analysis difficult. In order to address this problem, detailed testing of air flows, pressures, and temperatures was done at three electrically-heated multifamily buildings in the U.S. Pacific Northwest under heating season conditions. These were done in-situ using multizone tracer gas technology. Tests were short-term tests, with several fan tests performed each day for a test period of about a week. The average natural infiltration for each of the three buildings ranged from 0.14-0.22 air changes per hour (ACH), with individual units ranging from 0.075-0.31 ACH. Due to stack effect, units on lower floors experienced a higher percentage of outdoor air in the total unit flow. Interzone flows were found to be dominated by stack effects. With ventilation fans in all of the units on, the average outdoor air ventilation for the buildings increased to 0.38-0.47 ACH with individual units ranging from 0.31-0.54 ACH.

INTRODUCTION

Increasing importance has been placed on energy efficiency in residential buildings, including multifamily buildings. As these buildings become tighter, concerns are raised regarding the amount of ventilation air and whether it provides acceptable indoor air quality. Three multifamily buildings in the Pacific Northwest were tested under heating season conditions using a multizone, multigas tracer measurement system [1]. These were the first tests done *in-situ* on multizone buildings using tracer gas technology to determine airflows among zones. The purpose of the tests was to determine the variation in ventilation among units based on location relative to other units, differential tightness, and fan operation. The results of these tests give insight into how well buildings of the type tested meet minimum ventilation standards.

METHODS

The Multi-Tracer Measurement System used in this study injects a different tracer gas into each zone under study using mass flow controllers. The injection of tracer gases and the measurement of gas concentrations are controlled by computer, allowing for rapid measurement. Flows between all zones and the outside are then calculated from the measured tracer concentrations. Temperature and pressure measurements are also taken in each zone, and environmental weather data are collected to assist in the flow analysis.

Tracer gas concentrations were measured with a quadruple mass spectrometer, which has an absolute accuracy of about 1% of any given reading. Temperatures were measured in the center of each zone with thermocouples, and pressures were measured with transducers placed across walls, ceilings, and floors.

Designated ventilation fans were cycled on and off during the test period, with typical fan on-times of two hours. Tests with the designated fans on in all units were performed 2-3 times per day at the same times each day; tests were also performed with only individual fans running. Tests with all fans running provided the maximum infiltration, while individual fan tests are probably the most realistic cases.

Characteristics of the three multifamily buildings tested are given in Table 1.

Table 1. Site Characteristics

	Site A	Site B	Site C
Location	Portland, OR	Portland, OR	Issaquah, WA
Year Built	1992	1992	1992
Number of Stories	2	3	2/3
Number of Units Tested	6	6	5
Average Floor Area (m^2)	86.2	77.2	92.2
Average Volume (m^3)	213.7	183.1	218.4
Average Ceiling Height (m)	2.48	2.37	2.37
Foundation Type	Built over Garages	Slab-on-grade	Crawl Space
Entry to Units	Common Area	External Stairwell	External Stairwell
Heating Fuel	Electric	Electric	Electric
Heater System	Wall Heaters	Wall Heaters	Wall and Baseboard Heaters
Ventilation Fans	Range Hood, Dryer, Two Bath	Range Hood, Dryer, Laundry, Two Bath	Range Hood, Dryer, Laundry, Two Bath
Designated Fan Rating	$0.024m^3/sec$	$0.024m^3/sec$	$0.042m^3/sec$
Passive Ventilation	Slot Vents	Slot Vents	Slot Vents

RESULTS

Flows From Outdoors

Measured natural infiltration rates in every unit in each building are low, with a median unit air change rate of 0.15 ACH from outdoors for the three buildings. The highest air change rate in any unit with all fans off is 0.31 ACH and the lowest is 0.08 ACH. Natural infiltration is dominated by stack effect at all three buildings.

Flows from outdoors increase significantly when ventilation fans in all of the units are operating. At Sites A and B the designated ventilation fans are rated 0.024 m^3/sec at 25 Pa backpressure, and in Site C the designated fans are rated at 0.042 m^3/sec at 25 Pa backpressure. In Sites A and B, running all of the designated fans in all units provides a median unit flow from outdoors of 0.37 ACH with a median increase of about 0.22 ACH. When all of the designated fans in Site C operate, the median unit flow from outdoors is 0.49 ACH with a median increase of 0.36 ACH.

Running a single designated fan substantially increases the flow from outdoors into the unit in which the fan is operating, though not by as much as when all fans operate. This occurs because running all fans depressurizes all units about equally, whereas running a single fan depressurizes only that unit, and some of the additional flow through that unit is from other units. The median increase in flow from outdoors due to running a single fan in Sites A and B is 0.18 ACH, and in Site C the median increase is 0.30 ACH.

In Sites A and B, running a range hood fan in a single unit increases the flow through the unit by a very large amount. These fans are rated at 0.090 m^3/sec at 25 Pa backpressure. In Site A, running the range hood fans in two units simultaneously results in flows from outdoors of about 0.9 ACH through each unit. Running a single range hood fan at Site B causes a flow from outdoors through the unit of about 0.6 ACH. Flow through other units does not increase substantially even under these conditions. This finding is supported by the pressure measurements. Indoor-outdoor pressure differences in the units with range hood fans operating are 4 to 5 Pa in Site A and 2.5 to 3.0 Pa in Site B, while the other units are typically depressurized by less than 1 Pa at the same time.

Interzone Flows

The largest flows between zones in these buildings are flows from lower units to the units directly above, and are due to stack effect. Interzone flows due to stack effect lessen the percentage of the total flow through upper units that comes from outdoors. Assuming that air from other units is more polluted than outside air, this diminishes the overall air quality in those units.

There is some vertical flow from first floor units to third floor units. One reason for this is that some of the flow from first floor units to second floor units continues up to the third floor, rather than exiting the building at the second floor. Another method by which these bypass flows occur is by air entering the first floor ceiling cavity, going to an interior wall cavity, and emerging in the third floor unit. There is very little horizontal flow between units.

The consequence of these flow patterns is that units on the lowest floor typically get nearly all of their air from outdoors. Higher units get much less of their flow from outdoors, with a single-unit minimum in these three buildings of about 64% from outdoors with all fans off. The median percentage of flow from outdoors for units above the first floor is about 70%.

Interzone flows do not increase substantially when all fans operate. However, when a fan in a single unit operates, flows to that unit from other units increase. This may bring in more pollutants from other units, further reducing the air quality of the unit in which the fan is operating. This effect is most severe in mid-story units because they get less airflow from outdoors than other units. On a percentage basis, higher-floor units get significantly more flow from outdoors with all fans on, with a median of about 86% and a minimum of about

76%. The bottom-floor units still typically get almost all of their flow from outdoors with all fans on.

Measured Flow Rates vs. ASHRAE Standard 62

Based on natural infiltration alone, flow rates in all units are seriously below ASHRAE Standard 62 minimum ventilation levels of 0.35 ACH. Interzone flows do not contribute to the ventilation rates because they may carry pollutants from elsewhere in the building, and polluted air is not considered to be acceptable ventilation. Even when the designated ventilation fans are operating in all of the units, many of the units in Sites A and B fall below the Standard 62 levels. This is partially the result of fans not supplying their rated output due to excessive hydraulic resistance in the duct systems. Only three of the 0.024 m^3/sec fans provide their rated output. The other nine provide from 0.011-0.021 m^3/sec, with a median of about 0.018 m^3/sec. Running fans in all units in Site C does provide sufficient levels of ventilation based on Standard 62. None of the fans in Site C delivers its rated output of 0.042 m^3/sec. The measured fan flows at Site C range from 0.030-0.038 m^3/sec, with a median of 0.032 m^3/sec. In all three buildings, fan operation in a single unit is not as effective at improving ventilation rates for the whole building, and also increases the potential for carrying pollutants between units.

Since it is unlikely that residents in all units will operate their fans simultaneously, fans should be installed and operated continuously without resident control. These fans should be silent and be of sufficient size to guarantee acceptable ventilation. The fans should also be manufactured to better deliver their rated flow. Note that partially due to preliminary results of this study, current utility specifications require continuous operation of 0.038 m^3/sec or larger fans.

Blower Door Test Results

Blower door tests confirm that these buildings are tight compared with typical single-family homes. Individual building results are unit averages except for the flow exponent, which is the unit median. With slot vents open, the average flow rate across buildings at 50 Pa is about 6.5 ACH, which is below the measured rates found in many previous studies of single-family homes in the region. The average of the median calculated flow exponents from each building under these conditions is about 0.65.

Comparison Of LBL And AIM-2 Model Results To Measured Data

The LBL [2] and AIM-2 [3] models were run using the on-site weather conditions, and applied to each building using a height of one story and the average unit ELAs, volumes, and temperatures. Both models are highly dependent on unknown and difficult to measure factors such as leakage distributions. Measurements of neutral levels suggest that the standard assumption of half of the leakage equally distributed between the floor and ceiling does not apply in these buildings. Instead, more than half of the leakage is in the floor and ceiling, with the major share of this amount in the ceiling.

With the standard assumption of half of the leakage equally distributed between the ceiling and floor, the LBL model has a mean absolute percentage error across buildings of 41% relative to measured data. When a modification to the wind portion of the LBL model is made, the mean absolute percentage error drops to about 37%. The AIM-2 model has a mean absolute percentage error of about 24%.

Comparisons of the measured results to model predictions show that they are inconsistent in their abilities to accurately predict flow rates. At Site A the LBL model overpredicts the infiltration by 46%, while the AIM-2 model overpredicts by only 1%. At Site B the LBL model is closer, overpredicting the infiltration by only 4% while the AIM-2 model underpredicts by 31%. At Site C both models overpredict the infiltration, by 73% for the LBL model and by 39% for the AIM-2 model.

Assuming an extreme case of airtight walls and 75% of the leakage in the ceiling, the LBL model has a mean absolute percentage error of about 21% for the three buildings relative to the measured data. Since wind has no effect on the infiltration of a building with airtight walls, the modified wind model has no impact on the results. The AIM-2 model has a mean absolute percentage error of 25% with these leakage distribution assumptions. The LBL model overpredicts at Sites A and C and underpredicts at Site B. The AIM-2 model overpredicts at Site C and underpredicts at Sites A and B.

As was found in a study on several single-family homes [4], the LBL model always predicts a higher infiltration rate than does the AIM-2 model. In that study it was determined that this was partially because the LBL model extrapolates from 4 Pa to the actual pressure range using an exponent of 0.5 instead of the actual measured flow exponent.

DISCUSSION

This study has shown that for newer multifamily buildings in the Pacific Northwest, measured natural infiltration rates are low, with a median unit air change rate of 0.15 ACH from outdoors. When ventilation fans in all units are operating, flows from outdoors increase significantly. Running all of the designated fans at Sites A and B increases the median unit flow from outdoors to 0.37 ACH, and running all designated fans at Site C increases the median unit flow from outdoors to 0.49 ACH.

The largest flows among zones in these buildings are flows from lower units to the units directly above, and are due to the stack effect. The consequence of these flow patterns is that units on the lowest floor typically get nearly all their air from outdoors, and higher units get much less of their airflow from outdoors.

Based on natural infiltration alone, flow rates in all units are well below the ASHRAE Standard 62 minimum ventilation levels of 0.35 ACH. To meet this standard, fans should be operated continuously without resident control.

REFERENCES

1. Sherman, M H and Dickerhoff, D J. 1989. A multigas tracer system for multizone air flow measurement, *Proceedings of the ASHRAE/DOE/BTECC/CIBSE Thermal Performance of the Exterior Envelopes of Buildings Conference* (Orlando, FL). Atlanta: American Society of Heating, Refrigeration, and Air-conditioning Engineers, Inc.

2. Sherman, M H and Grimsrud, D T. 1980. *Measurement of Infiltration Using Fan Pressurization and Weather Data.* Report LBL-10852, Lawrence Berkeley Laboratory, Berkeley, California.

3. Walker, I S and Wilson, D J. 1990. The Alberta Air Infiltration Model. University of Alberta, Department of Mechanical Engineering, Edmonton, Alberta. Technical Report 71.

4. Palmiter, L and Bond, T. 1994. Modeled and Measured Infiltration: Phase II: A Detailed Case Study of Three Homes. Electric Power Research Institute, Palo Alto, California. EPRI Report TR-102511.

KEYWORDS

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