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Evaluation of Five Simple Ventilation Systems Suitable for Houses without Forced-Air Heating*

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INTRODUCTION

ADEQUATE VENTILATION IS essential in houses to ensure acceptable indoor air quality and to control condensation. In Canada, this means that not only does the ventilation rate for the whole house meet the recommended value but also all individual rooms in the house receive their recommended ventilation rates, as specified in the Canadian standard CAN/CSA-F326-M91 "Residential Mechanical Ventilation Systems" [1]. Those requirements have already been adopted into the 1993 Ontario Building Code [2] and the 1995 National Building Code of Canada [3].

The new ventilation performance standards present tremendous challenges for house builders to meet the ventilation air distribution requirements without installing a complete, fully-ducted, forced-air heating, and ventilation system. They may also make it difficult for alternative heating systems, such as electric baseboards and hydronic systems, to comply with the new building codes. Work has been carried out by others, such as the Canada Mortgage and Housing Corporation and the Ontario New Home Warranty Program, to develop designs that will satisfy the CSA F326 requirements for houses with forced-air heating systems. The project described in this paper examined simplified ventilation system designs

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suitable for houses that do not have the ducted air delivery system of forced-air heating.

THE VENTILATION SYSTEMS

Five ventilation systems were considered in this project [4]. Four were exhaust-only systems and one was a balanced system. Two exhaust-only systems used either only typical local exhaust fans in the kitchen and bathrooms, one without any inlet vents (Configuration A) and one with deliberate inlet vents distributed among the bedrooms and the main floor living areas. (Configuration B). The other two exhaust-only systems combined or included a partially distributed centralized exhaust (PDE) system on the second floor with pick-up grilles in each bedroom in addition to the kitchen and bathroom fans, one without any inlet vent (Configuration C) and one with a single centralized inlet vent (Configuration D). For each of these exhaust-only approaches without inlet vents, make-up air was provided either through one or more deliberate passive inlet vents or by air leakage through accidental openings in the exterior building envelope. The balanced system (Configuration E) used the kitchen and bathroom fans for its exhaust side and a minimal ducted supply (MDS) system for its supply side. The minimal ducted supply system was sized to provide only ventilation air requirements (5L/s to all rooms except 10 L/s to the master bedroom and the basement [5]), not the larger flow rates required in a forced-air heating system to meet thermal loads.

EXPERIMENTAL APPROACH

These various ventilation system designs were tested experimentally by installing them in the NRC/IRC two-storey research house. This house was built using conventional modern Canadian wood-frame construction methods in 1989, and included a full-depth poured concrete basement. The air distribution performance of each system was measured, using both single and multiple tracer gas decay techniques, for the full range of typical Canadian weather conditions during a late autumn to late spring combined heating/shoulder season in Ottawa. The existing electric forced-air heating system originally installed in the research house provided two reference cases for useful comparison with the various test ventilation systems: the house with all windows, doors, and vents closed and both with (Configuration G) and without (Configuration F) the furnace fan operating continuously to circulate the leakage air within the house interior.

For the single tracer gas tests, either SF₆ or N₂O tracer gas was dosed into the whole house and mixed to a uniform concentration before the doors to

the bedrooms, bathrooms, and basement were closed and the test ventilation system operation was started. For the multiple tracer gas tests, SF₆ was dosed into the sealed master bedroom and N₂O was dosed into the rest of the house. The two gases were mixed within their respective zones to uniform concentrations before unsealing the master bedroom door, closing the doors to the other bedrooms, bathrooms, and the basement and starting the operation of the test ventilation system. The concentrations of either or both tracer gases in each room were monitored continuously during the entire mixing and decay periods using an absorptive infrared analyzer (N₂O) and a gas chromatograph (SF₆) and were recorded by a computerized data acquisition system. The flow rates through all the mechanical ventilation components, (fans and ducts) were continuously monitored during each test to ensure consistent mechanical ventilation conditions were maintained.

TEST RESULTS

The concentration decay data measured in each room for the single tracer gas tests were fitted with an exponential curve to determine their apparent local air change rates, which in turn were multiplied by room volumes to calculate the apparent fresh air supply flow rates for each room. For each ventilation system configuration, averages of these measured flow rates for each room were calculated, and are listed, along with their ranges expressed as percentages of the room requirements, in Tables 1 and 2 for rooms on the second floor and in the basement, and for rooms on the ground floor, respectively.

The multiple tracer gas tests were originally intended to provide some indication of the interzonal airflows between the master bedroom, the rest-of-the-house (as a single zone), and the outdoors. Attempts to use multiple tracer gas interzonal air flow calculation techniques [6] were unsuccessful, even for Configuration G where the furnace fan operation provided well-mixed concentrations throughout the rest-of-the-house as a single zone (the best case). However, the decay of the SF₆ dosed only in the master bedroom did provide some useful estimates of the total air change rate within the master bedroom (including outside air and interior air flowing from other rooms into the master bedroom). The averages of the supply flow rates calculated from these total air change rates for each ventilation system configuration are also listed in Table 1 as second entries in the Master Bedroom column.

Also listed in Tables 1 and 2 are the individual rooms' ventilation rates required by the CSA F326 standard. The single tracer gas tests' results indicate that the local exhaust system both without and with deliberate passive inlet vents (Configurations A and B) do not provide adequate ventilation for the

Table 1. Average measured ventilation rates in second floor rooms.

Average Ventilation Rates in Habitable Rooms* on Second Floor and Basement Levels												
Config ID	Master Bedroom (10 L/s)**		Bedroom 2 (5 L/s)**		Bedroom 3 (5 L/s)**		2nd Floor Bath (5 L/s)**		Basement Area (10 L/s)**		Utility Room (5 L/s)**	
	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]
A	3.6 4.5 [†]	23-47 41-48 [†]	1.47	16-46	1.02	15-26	2.06	35-45	13.36	110-155	7.15	110-178
B	6.77 8.0 [†]	38-140 54-121 [†]	3.61	26-176	3.6	24-115	3.45	51-93	10.21	72-148	4.85	67-139
C [†]	6.06 12.1 [†]	49-74 118-125 [†]	2.72	43-69	2.18	33-60	2.33	39-56	13.88	104-183	7.79	99-213
D [†]	7.42 12.6 [†]	64-84 118-136 [†]	3.26	58-74	3.12	25-73	3.24	55-75	9.97	71-160	44.85	72-142
E [‡]	9.81 11.96 [†]	94-104 113-133 [†]	4.5	86-106	4.24	80-98	2.61	46-58	15.26	134-184	7.96	128-226
F	0.89 4.0 [†]	2-20 27-51 [†]	0.37	2-17	0.32	2-13	0.39	2-11	6.80	41-129	3.25	42-111
G	3.14 34.1 [†]	17-47 200-402 [†]	1.28	15-38	0.99	11-29	0.75	8-22	4.64	24-68	2.56	24-70

*Habitable rooms do not include hallways or storage closets (CSA F326 standard).

**Room ventilation rate requirements shown in parentheses, verified by measurement where applicable as indicated below.

[†]Second entries for master bedroom are results from multiple tracer gas tests' SF6 decay curve fits indicating total airflow into MBR zone.

[†]Bedroom, bathroom, and kitchen exhausts measured and verified for PDE tests (Configurations C and D).

[‡]Supply rates to all rooms and all exhaust rates measured and verified for MDS tests (Configuration E).

Table 2. Average measured ventilation rates in first floor rooms.

Config ID	Average Ventilation Rates in Habitable Rooms* on Ground Floor									
	Kitchen (5 L/s)**		Dining Room (5 L/s)**		Living Room (5 L/s)**		Family Room (5 L/s)**		Powder Room (5 L/s)**	
	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]	Ave. [L/s]	Range [%]
A	5.20	87-130	5.47	98-137	5.46	92-137	5.21	88-131	0.70	11-18
B	10.1	145-319	11.7	181-352	9.85	136-278	9.33	128-277	1.22	17-36
C†	5.88	99-147	6.16	107-151	6.12	103-143	5.77	100-133	0.79	13-19
D†	7.98	127-201	8.27	133-206	7.14	94-214	6.65	83-199	0.98	14-26
E‡	4.80	84-108	4.87	84-110	5.26	93-128	4.97	87-123	0.80	13-18
F	1.81	19-76	1.84	20-78	1.99	21-83	1.86	19-76	0.32	3-10
G	1.37	16-40	1.37	17-39	1.47	18-44	1.36	17-41	0.19	2-5

*Habitable rooms do not include hallways or storage closets (CSA F326 standard).

**Room ventilation rate requirements shown in parentheses.

†Bedroom, bathroom, and kitchen exhausts measured and verified for PDE tests (Configurations C and D).

‡Supply rates to all rooms and all exhaust rates measured and verified for MDS tests (Configuration E).

bedrooms but either satisfy (A) or exceed (B) the ventilation requirements for the ground floor and basement rooms. The partially distributed exhaust system (Configurations C and D) similarly fail to provide adequate ventilation for the bedrooms but either meet or exceed the requirements for the ground floor and basement rooms. The minimal ducted supply system comes the closest to meeting consistently the ventilation requirements for each room.

The total of the average supply flow rates for most ventilation system configurations tested failed to sum to the total of the directly measured mechanical exhaust flow rates for those configurations (65 L/s for A, B and E; 70 L/s for C and D). This suggests that the multiple zone single tracer gas decay analysis technique used here may not be completely valid for the conditions of these tests. It is useful to compare the multiple tracer gas tests' results for SF₆ decay in the master bedroom with the corresponding results from the single tracer gas tests' results. The MTG results suggest that the local exhaust system indeed failed to provide adequate air flow to the master bedroom either with or without deliberate vents. The MTG results also suggest that the PDE and the MDS systems both provide adequate ventilation air flow to the MBR, in accord with the direct flow rate measurements through the mechanical ventilation components.

CONCLUSIONS

The results of the experiments on the local exhaust-only strategy led to the following conclusions.

- The kitchen and bathroom fans alone do not meet the overall house air change criterion, despite their total measured exhaust being equal to the whole house ventilation requirement, nor do they provide adequate air distribution to the various individual rooms.
- With make-up air provided only by air leakage, the ground floor storey's rooms are adequately ventilated, the basement rooms are overventilated, but the critical bedroom areas are underventilated.
- When supplemented by deliberate passive inlet vents distributed in the second storey bedrooms and in the main floor rooms, the house overall was overventilated, with the ground floor rooms substantially overventilated receiving virtually all the incoming outdoor air supply, the basement rooms adequately ventilated, while the closed bedrooms still received less ventilation air than recommended by the standard.

Despite the overall excess ventilation with deliberate passive inlet vents open, closed bedrooms still received too little ventilation air.

For the critical bedrooms on the second floor, these two test cases could

be characterized as a centralized single-point exhaust system with distributed passive supply either via accidental leaks or via deliberate purpose-provided inlet vents. The distributed passive vents did not serve successfully as air inlets in the second storey bedrooms, but instead served as exfiltration sites and, matched by the deliberate openings in the lower envelope, helped to increase the overall air change rate for the house, primarily driven by stack effect.

The experiments on the partially distributed exhaust system produced more encouraging results.

- Both with and without deliberate make-up air venting, this strategy provided better air distribution to the critical closed bedrooms on the second floor.
- With only accidental air leakage as the make-up air supply, not quite enough outdoor air was provided to the bedrooms to fully comply with the new standards, despite sufficient measured exhaust from each bedroom. For the same conditions, the ground floor rooms were adequately supplied with outdoor air, and the basement rooms were somewhat overventilated.
- With a single centralized passive inlet opening, however, the bedrooms were better ventilated, the basement rooms were adequately ventilated, and the ground floor rooms experienced modest overventilation.

For the second storey, this system could be characterized as a distributed mechanical exhaust with a single centralized passive supply. This strategy was judged as suitable for further development. By providing only one passive inlet, relatively centralized with regard to building height and probably near the neutral pressure level, this arrangement was not so susceptible to stack effect dominance as was the distributed passive venting arrangement of the local exhaust fan strategy above. However, the influence of the passive vents in both the local exhaust system and the PDE system seems to have lowered the house's neutral pressure level, which was reflected in the decreased air supply (by leakage) into the basement room.

The experiments on the minimal ducted supply system balanced with the local exhaust fans confirmed that this mechanical supply strategy successfully provided adequate outdoor air supply and good air distribution to all the rooms in the house. Since it was a balanced approach, the background leakage of air contributed to but did not dominate the interior air flow patterns in these tests. This was demonstrated by modest excess ventilation in the basement rooms.

The single tracer gas technique used in this research seemed to be an effective method for determining the amount of fresh air supplied to each room in the house. However, it tends to underestimate the ventilation rate

somewhat in rooms where the majority of inflow is from other rooms in the house. The multiple tracer gas technique, while unable to quantitatively identify all the interzonal flow rates among all the rooms, was useful to complement the single tracer gas measurements of fresh air supply rates with measurements of the total air supply rates to the master bedroom as an illustrative example. The verification of these methods was made possible by the direct measurement of flow rates through each ventilation system component for all the tests.

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