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VENTILATION EFFECTIVENESS AND ADPI MEASUREMENTS OF THREE SUPPLY/RETURN AIR CONFIGURATIONS

Francis J, Offermann
Indoor Environmental Engineering , San Francisco, CA, USA

Dan Int-Hout
Krueger Division of Phillips Industries, Tuscon, AZ, USA

Abstract

The two purposes of a building ventilation system are (1) to remove indoor contaminants and (2) to provide thermal comfort. Ventilation effectiveness is measured using tracer gas techniques and age distribution theory to compare the actual delivery rates of outside air at specific locations to those projected for the case of perfect mixing. ADPI is a thermal comfort parameter which compares the effective draft temperature as determined by dry bulb temperatures and air speeds to acceptability criteria established by ASHRAE. Three different supply/return configurations were evaluated for a recirculating constant volume system in a steady heating mode under standard conditions for an office space. Ventilation effectiveness ranged from 0.57 to 0.76 at points in the occupied zone. ADPI measurements ranged from 81 to 94 %. Short circuiting of supply air to the return air inlet was evident in tests of each configuration. More research is required to characterize the performance of existing systems and develop more effective ventilation strategies.

Introduction

Ventilation systems in the United States are designed to recirculate air at rates of 4 to 10 air changes per hour in order to satisfy internal cooling loads and provide acceptable thermal comfort. The flow rate of outside air required to remove indoor contaminants is often set at recommended minimums as a result of energy considerations. These recommendations follow from tests and calculations which are based on perfect mixing of indoor contaminants and outside air. The recommended minimum flow rate of outside air for an office space ranges from 2.5 to 10 l/s · person (1) which for an occupant density of 7 occupants/100 m^2 translates into ~ 0.2 to 0.8 air changes per hour or between 5 and 25 % of the total air circulation rate. While this relatively high rate of air circulation to outside air flow suggests that the delivered outside air should be well mixed with the indoor air the few tests conducted to date (3,4,5) indicate that the actual delivery rates of outside air to points in the occupied zone may be substantially less than those projected assuming perfect mixing. The effectivness of a ventilation system to deliver outside air to the occupied zone of a building is effected by a number of variables including the configuration of the supply/return air circuits, the rates of air circulation and outside air flow, the mode of operation (e.g. cooling, heating), and the presence of interior partitions. In this paper we compare measurements of ventilation effectiveness and thermal comfort for three supply/return configurations of a recirculating constant volume system in a steady heating mode under recommended minimum ventilation rates for an office space (1).

Ventilation Measurements

Nominal Ventilation Rate. The nominal ventilation rate or air exchange rate is defined as the rate at which outside air is delivered to the building divided by the volume of the indoor air space. The nominal ventilation rate is the most frequently cited building ventilation parameter and is commonly used in terms of air changes per hour (h^{-1}). The nominal ventilation rate may be computed directly from measurements of the volumetric flow rate of outside air entering the building and dividing by the volume of the indoor air space. In buildings where all of the outside air enters through the outside air inlet of the ventilation system the outside air flow rate is measured using routine air velocity scans across the face of the air inlets. Other potentially significant sources of ventilation such as duct leakage and infiltration are not detected with this technique. Using either tracer gas decay or constant injection techniques the nominal ventilation rate may be computed from the exponential rate constant in the latter part of the test or the inverse of the average age of air in the exhaust air stream. The nominal ventilation rate, N, may also be computed from the steady state indoor tracer concentration, C_{ss}, at the end of a constant injection test:

$$N = Q/V = Q_T/(C_{ss} \cdot V) \qquad (1)$$

where: Q = the total flow rate of outside air to the building.
V = the volume of the indoor air space.
Q_T = the volumetric flow rate of pure tracer.

Local Ventilation Rates. While the nominal ventilation rate provides information regarding the total amount of outside air entering the building it provides no information regarding the distribution of outside air within the building. Tracer gas techniques have been employed to measure local ventilation rates which reflect the actual delivery rates of outside air to specific indoor locations . These techniques follow from concepts developed in chemical reactor engineering as applied to building ventilation systems using age distribution theory (5). Local ventilation rates as reported from a tracer gas decay test are calculated as the recipricals of the local ages of air, A_i :

$$n_i = \frac{C_i(0)}{\int C_i(t)\,dt} = \frac{1}{A_i} \qquad (2)$$

where: n_i = the local ventilation rate at location i (h^{-1})
$C_i(t)$ = the tracer concentration at location i at time t.
$C_i(0)$ = the perfectly mixed initial concentration

For a constant tracer injection test this same equation may be used provided the concentrations are transformed by subtracting the measured concentration data from the final steady state indoor concentration.

Ventilation Effectiveness. Ventilation effectiveness or efficiency is a relative performance parameter which compares the actual delivery rates of outside air to the indoor space to those projected for the reference case of perfect mixing. Since for the case of perfect mixing the ventilation rate is the same everywhere and equal to the nominal ventilation rate, Q/V, the local ventilation effectiveness is calculated as the ratio of the local ventilation rate to the nominal ventilation rate. Ventilation effectivenesses may vary from much less than one for a short circuiting air flow pattern to much greater than one for a plug flow pattern.

Experimental

Room. The room used for these tests, depicted in Figure 1, is a 46.4 m^2 unoccupied office suite with a ceiling height of 2.85 m, and a net air space volume (less partitions and furnishings) of 127.8 m^3. The constuction is typical of office spaces in the United States. The floor is a light concrete slab covered with carpet, the ceiling and walls are constucted of gypsum board, and the walls are partially finished with wood paneling. A suspended ceiling of acoustic tiles forms a return air plenum for the ventilation system and supports the supply air diffusers and flourescent light fixtures. Office furnishings consisted of four desks and four chairs. A floor to suspended ceiling wall partition seperated a portion of the room. The windows were not operable and the doors were taped shut for the tests.

Ventilation System. The ventilation system serving this office suite is a recirculating constant volume, gas heated, freon cooled, roof top unit. An outside air inlet is connected to the return air duct. There is no ducted exhaust outlet, a configuration popular with this type of light commercial equipment. For our tests we used a 3000 watt fixed output electric heater in place of the thermostatically controlled gas-fired heater so as to avoid modulations in the supply temperature. We divorced the system from two occupied adjacent office suites and throttled the fan discharge to establish a total air circulation rate of 135 $l\ s^{-1}$(2.9 $l\ s^{-1} m^{-2}$). We attached a 3.1 m length of 10.2 cm diameter PVC pipe to the outside air inlet in order to mix the tracer gas in the outside air stream. Three different supply/return configurations were evaluated as depicted in Figure 1. The first configuration tested was that of the existing system, a ceiling diffuser supply and a ceiling plenum return. The supply air was delivered to the room through four 61 x 61 cm four-way diffusers mounted in the suspended ceiling. The return air circuit consisted of a single high wall outlet exhausting air from the ceiling plenum space created by the suspended ceiling. Room air entered the ceiling plenum through a single 61 x 61 cm perforated exhaust grill installed in the suspended ceiling. The second configuration consisted of an open ceiling supply and a low wall point exhaust. We disconnected the supply ducts from the four diffusers and allowed the air to exit the ceiling plenum through the four open spaces left after removing the diffusers. The return air circuit was modified to take air from a single point in the corner of the room at a height of 28 cm above the floor. The third configuration was a high wall supply jet directed at a high wall point exhaust. We closed off three of the four supply ducts and used the remaining one as a 20 cm high wall supply jet. The return air was moved to a point on the wall under the suspended ceiling directly across from the supply jet.

Experimental Protocol. Ventilation effectiveness was measured using a constant injection tracer gas technique. Sulfur hexaflouride gas was injected upstream in the PVC pipe attatched to the outside air inlet at a constant rate of 180 cc/min. A pump and manifold system was used to sequentialy collect 20 cc syringe samples of air from the outside air inlet, the supply air outlet, SA, the return air inlet, RA, and five different room locations, S1-S5, at a height of 109 cm above the floor (seated breathing height). Seven samples were collected at different times from each location during the experiment which lasted untill the tracer gas concentration in the room was equal to the concentration in the supply air stream (typically 3-4 hours). The samples were analyzed for tracer concentration using a gas chromatograph with an electron capture detector. The nominal ventilation rates reported here were calculated using the steady state indoor concentration data as described in equation (1). The local ventilation rates are computed from equation (2) using transformed data. The integral in equation (2) was evaluated numerically assuming an exponential change in concentration between data points. Following the tracer gas measurements the researchers entered the test room and simultaneously measured one-minute time averaged air temperatures and air speeds at 15, 61, 107, and 168 cm above the floor each of the four indoor locations labeled S1-S4. ADPI was computed using an acceptable draft temperature range of -1.7 to 1.1 °C (2). We conducted a total of five tests of ventilation effectiveness: Tests H1 and H2 were repeat tests of the existing ceiling supply/return configuration, Tests H3 and H4 were repeat tests of the ceiling supply/floor return configuration, and Test H5 was a single test of the high wall supply/ return configuration. ADPI measurements were obtained once for each configuration.

Results and Conclusions

The nominal ventilation rates ranged from 1.25 h^{-1} for tests H1 and H2 to 1.38 h^{-1} for test H5. The nominal ventilation rates were not determinable from measurements of the flow rate into the outside air inlet since the steady state tracer gas concentrations in the supply air and room were approximately 80% of the concentrations in the outside air inlet suggesting 20% leakage of outside air into the return ducts. The local ventilation rates ranged from more than 2 h^{-1} for a point in the supply air duct to 1.05 to 0.77 h^{-1} for points in the occupied zone (S1-S4). The ventilation effectiveness as determined from the average of the four local ventilation rates measured in the occupied zone ranged from 0.57 for test H5 to 0.76 for test H3. ADPI measurements ranged from 81 to 94 %.

Table 1: Ventilation and ADPI measurements for three supply/return configurations of a constant volume system (@ 33% outside air) in a steady heating mode.

Test Configuration	H1 1	H2 1	H3 2	H4 2	H5 3
Location		Local Ventilation Rates (h^{-1})			
SA	2.79	1.91	1.68	2.02	1.45
RA	1.83	1.43	1.16	1.27	0.87
S1	0.90	0.80	0.93	0.82	0.81
S2	0.87	0.82	0.92	1.00	0.79
S3	1.05	0.84	1.05	1.04	0.79
S4	0.83	0.86	0.94	0.96	0.77
S5	1.18	0.88	1.18	1.25	0.80
Occupant Zone avg.(S1-S4)	0.91	0.83	0.96	0.96	0.79
Nominal Rates Q/V (h^{-1})	1.25	1.25	1.26	1.32	1.38
Ventilation Effectiveness	0.73	0.66	0.76	0.73	0.57
Temp. Diff. (°C) SA-Room avg	8	13	8	8	9
ADPI (%) Measurements	-	81	94	-	88

The local ventilation rates measured for three configurations of an office ventilation system were between 57 and 76 % of those projected from the nominal ventilation rate which presumes perfect mixing of outdoor air with indoor air.

Short circuiting of supply air to the return air inlet is apparent in each of the configurations tested. Much more research needs to be done to determine the ventilation effectiveness of existing designs so that ventilation engineers may knowledgeably compensate for ventilation ineffectiveness. Such research also holds forth the promise of developing more effective ventilation strategies.

References

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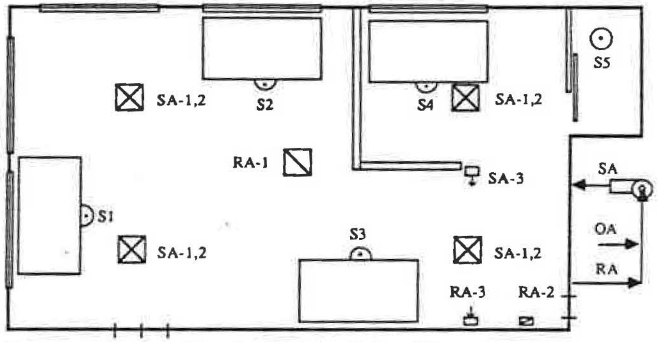
Figure Captions

Figure 1. Floor plan of office space depicting locations of measurement locations and supply and return air ducts.



Measurement locations: SA outlet, RA inlet, S1-5 at 109 cm above the floor.

HVAC Configuration:	1	2	3
Supply air:	4 ceiling diffusers	4 ceiling openings	1 high wall jet
Return air:	1 ceiling panel	1 low wall point	1 high wall point