PERFORMANCE APPRAISAL OF A VENTILATION SYSTEM – A COMPARISON OF TWO METHODS

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ABSTRACT

The performance of a ventilation system, particularly that which is incorporated in centralised air-conditioning system, can be evaluated in several ways. The "ventilation efficiency and ventilation effectiveness" and "air exchange efficiency" are two of the most commonly employed methods in ventilation analysis. This paper deals with the determination of ventilation parameters such as ventilation efficiency, ventilation effectiveness, age-of-air, air change rate and air exchange efficiency and a comparison is made between the two different methods of ventilation analysis to determine the significance with which each method is capable of assessing the ventilation performance. Tracer gas analysis, using sulfur hexafluoride, is employed for ventilation measurements.

KEYWORDS

Ventilation efficiency; Ventilation effectiveness; Air change rate; Age of air; Air exchange efficiency; Tracer gas analysis

INTRODUCTION

A detailed investigation of the quality of indoor air in a building encompasses the performance evaluation of the ventilation system (Zweers *et al.*, 1990). Several methods of ventilation analysis exist and central to all methods is the determination of certain key ventilation parameters which is expected to give a better understanding of the provision and transportation of fresh air to the occupied zones to achieve good dilution. The "ventilation efficiency and ventilation effectiveness" and the "air exchange efficiency" methods are investigated in this paper through a case study.

METHODS OF VENTILATION ANALYSIS

Ventilation efficiency and ventilation effectiveness

Before proceeding with the theory of these two parameters, it is pertinent to point out that a clear distinction between the two in terms of their definitions is not to be found in the literature and that several researchers have used ventilation efficiency and ventilation effectiveness quite synonymously. A common interpretation for both the ventilation efficiency and the ventilation effectiveness is implicit from the definition offered in the ventilation standard by ASHRAE (ASHRAE, 1989), in which they are both defined as the fraction of the outdoor air delivered to the space that reaches the occupied zone. An attempt has been made to explore the possibility of a different interpretation of these two parameters within the framework of definition provided by ASHRAE (Sekhar *et al.*, 1994).

A stratification model for ventilation effectiveness for a forced ventilation system is one in which a fraction, S, of the supply air may pass directly to the return inlet without mixing with the air at the occupant level. The ventilation effectiveness depends on the location of the supply outlet, the return inlet and the design and performance of the supply diffuser. In a typical system with supply outlet and the return inlet in the ceiling, it is possible for some supply air to flow directly from the supply to the return, bypassing the occupied zone of the room. The entire exhaust could be taken from the return air or some air may also be exhausted directly from the room.

The ventilation efficiency is defined as :

$$\eta_v = [V_o - V_{oe}] / V_o \qquad (1)$$

where V_o = amount of fresh air at the intake point, V_{oe} = amount of unused air that is exhausted. V_o and V_{oe} can be expressed in terms of the stratification factor, S, and the recirculation factor, R, which after corresponding substitutions in equation (1) yields the following expression for ventilation effectiveness:

$$E_v = [1 - S] / [1 - RS] \qquad (2)$$

Equation (2) defines the effectiveness with which the fresh air is circulated to the occupied space in terms of a stratification factor S and the recirculation factor R. If there is no exhaust flow, R = 1 and E_v = 100%. If both stratified flow and recirculation occurs, fresh air can pass through the system without ever being used to dilute contaminants at the occupant level, which ventilation loss also represents an energy loss.

Air exchange efficiency

Before determining the air exchange efficiency, it is important to determine the air change per hour (ACH). In a concentration decay method, the ACH is defined as the slope of the tracer gas concentration decay curve.

$$ACH = [\ln C(0) - \ln C(\tau)] / \tau \qquad (3)$$

where C(0) = initial concentration [time = 0] (m^3/m^3), $C(\tau)$ = final concentration [time = τ] (m^3/m^3), τ = total measurement period (h).

The concept of air exchange efficiency involves the determination of the age-of-air in a room, which is a measure of the length of time that the air has spent in the room. The local-mean age-of-air, essentially, refers to the age-of-air of a localised spot in a room and the room-average age-of-air, is a number that quantifies the performance of a ventilation system by taking into account both the quantity of ventilation air supplied to the room and the efficiency with which it is distributed around the room. The room-average age-of-air is measured in the extract air duct. The efficiency with which the ventilation system exchanges the room air with outside air can be calculated by dividing the local-mean age-of-air in the extract by twice the room-average age-of-air. For simplicity, the mathematical details in the calculation of age-of-air and air-exchange efficiency involving computations of the area under the tracer gas concentration curve during the discrete time intervals are excluded from this paper.

THE CASE STUDY

The portion of the institutional building studied consists of a drawing room, a common room, two conference rooms and eight individual office rooms. The building cannot be considered to be air tight as all the rooms are essentially perimeter rooms and have openable windows. Moreover, the access to all the rooms is from the corridor and the doors leading to the corridor on either side of the building are quite frequently operated resulting in them being kept open for substantial periods during the normal operating hours of the Air Handling Unit (AHU).

INSTRUMENTATION

The tracer gas investigations were performed with a multigas monitor and a multiple doser and sampler, capable of continuous real-time measurements in a building. The multigas monitor can be operated in either the monitoring or the ventilation mode with similar sampling cycles and sampling intervals for both modes. The sampling interval is typically about 12 minutes and the indoor pollutants measured include carbon dioxide, carbon monoxide, sulfur hexafluoride, total volatile organic compounds (methane equivalents) and water vapour.

RESULTS AND DISCUSSION

The various field data and the derived ventilation parameters are presented and discussed here.

Air change rate, fresh air quantities and air exchange efficiency

The results of tracer gas analysis is obtained in the form of a concentration decay profile on a semi-logarithmic plot, which then leads to the determination of the ACH. The values of ACH together with the corresponding computed values of fresh air quantities are presented in Table 1.

Table 1. ACH and fresh air quantities

Location	**Volume (m^3)**	**ACH**	**Fresh air quantity (Ls^{-1})**
Space 1	540	2.6	390
Space 2	45	2.3	29
Zone A	1380	2.44	935

In Table 1, Zone A represents the entire occupied zone, consisting of several spaces (such as Space 1, Space 2 etc.), which is served by one AHU. The ACH of 2.44 is, thus, indicative of a system-wide exchange rate and consequently, the computed fresh air quantity of 935 Ls^{-1} (V_o) represents the total amount of fresh air that is to be distributed to the various spaces. This fresh air is actually made up of design intake at the AHU and the inevitable infiltration at several possible locations, such as visible crack openings in the windows and doors in the office spaces.

The values of the age of air and the air exchange efficiency are presented in Table 2.

Table 2. Age of air and air exchange efficiency values

Location	Local age of air (hr)	Room average age of air (hr)	Air exchange efficiency (%)
Space 1	0.2525	0.4249	29.7
Space 2	0.2483	0.4511	27.5

Low values of air exchange efficiency suggest that the fresh air is not delivered to the occupant zone in the most efficient manner. An air exchange efficiency of 50% is indicative of a perfectly mixed system and any downward deviation from this value would imply some sort of short-circuiting.

Ventilation efficiency and ventilation effectiveness

A stratification factor of 0.16 and a recirculation factor of 0.87 is obtained for the present case study in which the values of the ventilation efficiency and the ventilation effectiveness are essentially the same and are both equal to 0.98.

It is apparent that a proper evaluation of the ventilation performance makes it necessary to determine both the parameters since effective dilution of indoor pollutants largely depends upon the amount of outside air provided. In the present case study, it is observed that despite fairly reduced fresh air quantities at the fresh air intake point in the AHU, a significant proportion of the outside air that reaches the internal zones is through infiltration.

CONCLUSION

A comparison of two methods of ventilation analysis is presented in this paper. It is seen that the ventilation efficiency and ventilation effectiveness method provides a limited understanding of the performance of the ventilation system while the air exchange efficiency method provides a more detailed performance assessment in the form of the quantity of fresh air supplied to the occupied zones and the efficiency with which the ventilation system exchanges the space air with outside air.

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REFERENCES

ASHRAE (1989). ASHRAE Standard 62- 1989, Ventilation for acceptable indoor air quality, *American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA.*

Sekhar, S.C., K.W.Tham, M.A.Haque and S.E.Lee, (1994). An assessment of ventilation in air-conditioned buildings in Singapore. In : *Proceedings of 12th International Conference - Clean Air '94.* Perth, Western Australia.

Zweers, T., P.Skov, O.Valbjorn and L.Molhave, (1990). The effect of ventilation and air pollution on perceived indoor air quality in five town halls. *Energy and Buildings*, 14, pp 175-181.