ESTIMATION OF VENTILATION RATES IN MECHANICALLY VENTILATED BUILDINGS

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Summary

It is useful to know ventilation rates in order to evaluate indoor air quality (IAQ) and ventilation efficiency for mechanically ventilated buildings. A strong limitation of the current models in the literature is either they pay little attention on individual sites or they are too complicated for practical use. This paper develops a new method for accurately quantifying ventilation from field measured carbon dioxide (CO_2) concentrations for individual sites. The proposed method determined ventilation rates using maximum likelihood estimation (MLE). The experimental data were used to validate the developed model. Experiment was conducted in a school office by measuring indoor CO_2 concentrations and pressure differences between the return air vent and room. Estimated ventilation rates were verified by CO_2 equilibrium analysis and measured pressure differences. Excellent results have been obtained. At least 0.998 R^2 values (coefficient of determination) were obtained for fitting measured CO_2 concentrations when conducting MLE for estimating ventilation rates, and the corresponding residual plots showed no pattern and trend. Furthermore, ventilation rates obtained from MLE also showed great consistencies with the results from the CO_2 equilibrium analysis in the experiments. The model is simple and effective.

Keywords: Space air change rate prediction, Maximum likelihood estimation, Mechanically-ventilated building

1 Introduction

It is useful to know ventilation rates in order to evaluate indoor air quality (IAQ). Many works, for instance Nabinger et al. [1], Wong and Mui [2] and Miller et al. [3] etc., contributed to use indoor CO_2 concentration to evaluate IAQ and ventilation rates. Despite extensive studies, there is sparse information available regarding the use of field measured CO_2 concentrations to estimate ventilation rates (i.e. space air change rates) for a particular space, such as office room, in commercial buildings. In this paper, we develop a new method to estimate space air change rates for an individual space in commercial buildings using field measured CO_2 concentrations by applying MLE [4].

2 Methodology

The method discussed in this paper focuses on spaces with nearly constant air change rates and well-mixed indoor air. But the method can be easily adapted for time-varying ventilation systems. Furthermore, we split the working (i.e. occupied) period of a working day into *occupied working period* when staff is present and *unoccupied working period* when staff has left for home with the 'on' ventilation system. The space air change rate for an *unoccupied working period* is relatively easier to estimate as the CO_2 generation rate is zero. For a well-mixed and mechanically-ventilated space, space air change rate can be solved by MLE as:

$$\sum_n (1-\exp(-\alpha_1 n\Delta t))\left[d_n-(C(0)-\alpha_0)\exp(-\alpha_1 n\Delta t)-\alpha_0\right]=0 \tag{1}$$

$$\sum_n n\exp(-\alpha_1 n\Delta t)\left[d_n-(C(0)-\alpha_0)\exp(-\alpha_1 n\Delta t)-\alpha_0\right]=0 \tag{2}$$

where $\{d_n\}$ is a set of samples for indoor CO2 concentrations, α_1 the space air change rate, α_0 supply CO_2 concentration, $C(0)$ initial indoor CO_2 concentration, Δt time step of the measurement, and n sample number. Solving these two equations, Eqs. (1) and (2), for the *unoccupied working period* of a working day simultaneously allows for the estimation of the space air change rate (i.e. α_1) and supply CO_2 concentration (i.e. α_0) for a working day. In this study, the residuals of the model fit were also examined.

3 Experimental Data

The field measurement was set up in an office (27.45 x 2.93) m^3 in a school building. In addition to indoor CO_2 concentrations, the pressure differences between the return air vent and room were also measured. Fig. 1 shows the office's layout as well as the measurement location.

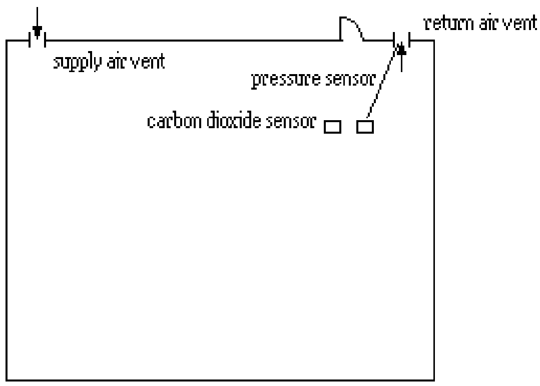

Fig. 1 The layout of the office

4 Results and discussion

There was no direct measurement available for airflow rate due to technical difficulties. Therefore, we need an extra equilibrium analysis [1] as a supplement tool to analyze results. Fortunately, on one day, one person was present in the office for a long time which allowed reaching near-equilibrium. Table 1 shows the estimated space air change rate results from the equilibrium analysis and MLE . Their residuals by applying the mass balance of CO_2 concentrations [1] to fit estimated CO_2 concentrations based on estimated space air change rates and supply p CO_2 concentrations to measured ones were presented in Fig. 2, showing no trend and pattern. In addition, all fittings between estimated and measured CO_2 concentrations were found to have at least 0.998 coefficient of determination (R^2). In summary, the space air change rates estimated from MLE are accurate.

Tab. 1 Space air change rates estimated from equilibrium analysis and Maximum Likelihood Estimation (MLE) on 22.9.2008, 23.9.2008 and 24.9.2008

Date	Method	Space air change rate (α_1, ach)	Supply CO_2 concentration(α_0, ppm)	Pressure difference (Pa)[a]
22.9.2008	Equilibrium analysis	2.93	401[b]	58
	MLE	2.92	401[b]	56
23.9.2008	MLE	2.94	378[b]	56
24.9.2008	MLE	2.92	370[b]	55

[a] This is average pressure difference between the space and return air vent for the estimated period
[b] Supply CO_2 concentration estimated by MLE

5 Conclusions

A simple and efficient model based on MLE was developed to estimate space air change rates for an individual space in commercial buildings. The results were verified by experimental measurements. The residuals from experimental results showed no trend and pattern, and all fittings between estimated and measured were satisfactory with at least 0.998 coefficient of determination (R^2). It is worth mentioning that the proposed model is based on the assumption of a well-mixed ventilated space, this restriction is chosen for convenience but can easily be relaxed.

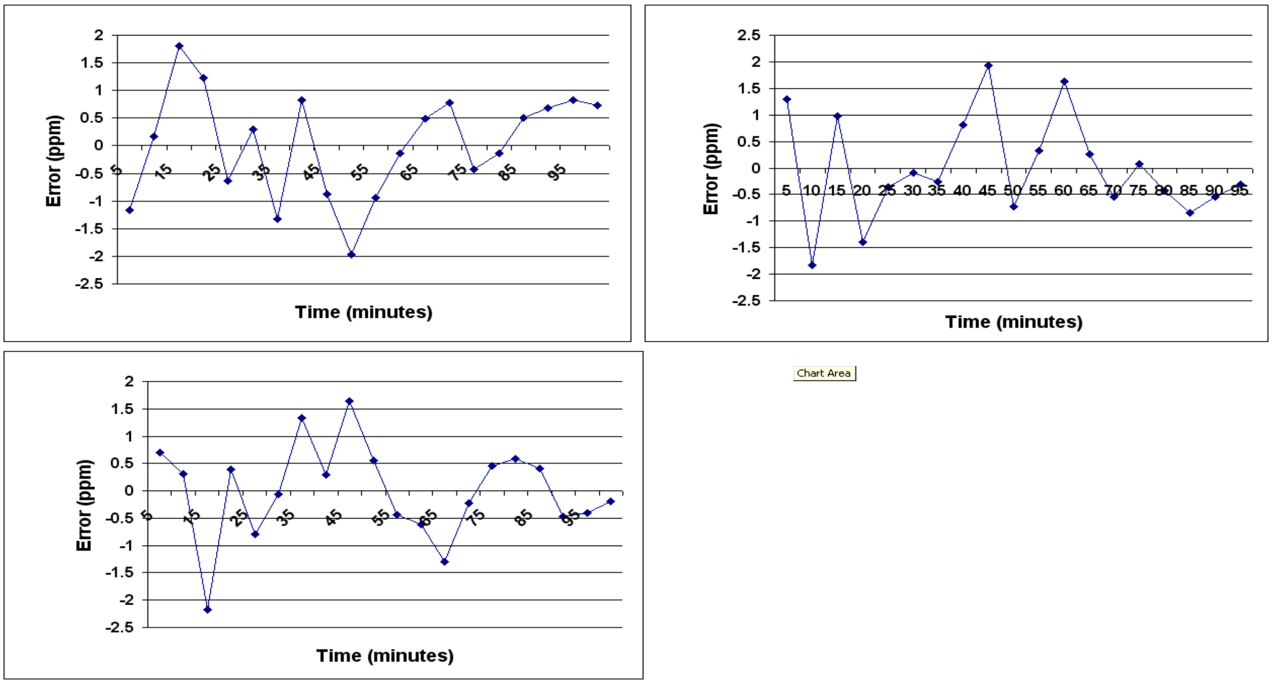

Fig. 2 Residuals from fittings : (a) 22.9.2008, (b) 23.9.2008 and (c) 24.9.2008

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