行政院國家科學委員會專題研究計畫　期中進度報告

自然通風建築中不同粒徑顆粒物質室內/室外/人體暴露之關係(1/3)

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計畫主持人： 廖中明

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摘要

本研究以一簡易室內空氣品質模式，結合戶外量測資料探討台灣地區 PM (Particulate matter)損失機制於誘導式自然通風住宅室內/外(Indoor/Outdoor , I/O)關係。選擇之自然通風建築型態為邊牆開口一般型(sidewall openings ， SP)及屋頂與邊牆皆開口之太子樓型(covered ridge with sidewall openings , CRSP)建築。考量 PM 移除機制包含通風夾帶移除及建築物表面之 PM 沉降，並採開口有效性評估自然通風量。由台灣環保署資料預測 SP 及 CRSP 型建築型態 PM_{10} 之 I/O 比值範圍分別為 0.15 – 0.24 及 0.20 – 0.32。研究結果可說明誘導式自然通風空間中 PM I/O 比值與周圍環境 PM 分佈及建築物開口設計、風速及風入射角度有密切的關係。

關鍵詞：顆粒物質，自然通風，開口有效性，室內/室外比值。

Abstract

We applied a simple size-dependent indoor air quality model to characterize PM10 indoor-outdoor relationships for wind-induced naturally ventilated residences in Taiwan region. The natural ventilation rate was quantified by the opening effectiveness for sidewall opening (SP) and covered ridge with sidewall opening (CRSP) type homes. The predicted PM10 mass indoor/outdoor (I/O) ratios were 0.15 – 0.24 and 0.20 – 0.32, respectively, for SP and CRSP type homes. Results demonstrate that PM10 I/O ratios for a wind-induced natural ventilated airspace depend strongly on the ambient PM size distributions, building openings design (e.g. height to length ratio of openings and roof slope), wind speed, wind angle of incidence.

Keywords: Particulate matter; Natural ventilation; Opening effectiveness; Indoor-outdoor ratios

Introduction

Outdoor PM attributable to the indoor air in urban/suburban residence houses has been the most serious indoor air pollution in Taiwan region (Li and Lin, 2002). The relationship between exposure to airborne PM and resulting health effects is the subject of an ever-increasing number of studies. Guo et al. (1999) revealed that PM10 was positively associated with the prevalence of asthma in middle-school students in Taiwan. Hwang and Chen (2002) demonstrated that rates of daily clinic visits were associated with current-day concentrations of PM10 in Taiwan region.

In the indoor environment, the removal of entrained outdoor PMs occurs through ventilation and deposition. Natural ventilation is widely used in Taiwan region with the advantages of saving energy, expense, and installation time in that dwelling houses are controlled by natural convection to remove excessive heat and moisture. The mechanism of natural ventilation depends on wind effects, thermal buoyancy and the combination of both wind and buoyancy forces. Wind speed and wind direction are the dominant factors for wind-induced effects (Miguel et al., 2001). The characteristics of openings affect natural ventilation efficiency with the arrangement, location, and control of ventilation openings to achieve a desired ventilation rate and good distribution of ventilation air through the buildings.

In this study we attempt to understand the PM10 I/O relationships focusing on the building operational characteristics of a wind-induced naturally ventilated airspace and the size-dependent effects on indoor PM10 levels. We employed an opening effectiveness model to quantify the wind-induced natural ventilation for sidewall openings (SP) and covered ridge with sidewall openings (CRSP) that are commonly employed in Taiwan region. We predicted the size-dependent I/O ratios of PM10 mass for urban and suburban naturally ventilated homes and compared our results with empirical evidence. There are uncertainties in the measurements; thus, we also performed uncertainty analysis for the proposed model.

Materials and Methods

Modeling PM I/O ratio for a naturally ventilated airspace

Thatcher and Layton (1995), Abt et al. (2000), and Riley et al. (2002) have developed rigorous indoor air quality models for studying the PM I/O relationships and size-dependent removal mechanisms in a residence, in which the model employed by them applied also to our study. Combining the physical processes controlling the gain and loss rates, the deposition (including Brownian and turbulent diffusive deposition and gravitational sedimentation), and air exchange, yields a dynamic equation that describes the concentration profile of PM I/O relationships in a wind-induced naturally ventilated airspace.

Followed by the principle of mass balance under an isothermal condition in that resuspension, coagulation of particles, and phase change processes are neglected, the dynamic equation varying with particle size range k and time t are given by

$$\frac{dC_I(k,t)}{dt} = -(\lambda_n + \lambda_d(k))C_I(k,t) + \lambda_n C_o(k,t),\ k = 1, 2, \Lambda\ , N-1 \quad (1)$$

where $C_I(k,t)$ is the time-dependent indoor PM concentration in the kth size range (kg m^{-3}); $C_o(k,t)$ is the time-dependent outdoor PM concentration in the kth size range (kg m^{-3}); λ_n is the air exchange rate of natural ventilation through open windows and doors (h^{-1}) in which $\lambda_n = Q_n/V$, Q_n is the natural ventilation rate (m^3 h^{-1}); V is the air volume (m^3); $\lambda_d(k)$ is the deposition rate of indoor PM due to Brownian and turbulent diffusive deposition and gravitational sedimentation in the kth size range (h^{-1}); k is the size range number; and N is assigned to be the end point number for a kth size range, d_k and d_{k+1} .

The particles are divided into geometrically equal sized bins in the size range of interest. The PM concentration is assumed to be a constant aerodynamic equivalent diameter (AED) within each bin size. The end points, d_k and d_{k+1} , of the kth bin size are considered to be equal to the geometric mean of the end points of the bin size as,

$$d_k = d_{\min} + \frac{(d_{\max} - d_{\min})(k-1)}{N-1},\ k = 1, 2, \Lambda\ , N \quad (2)$$

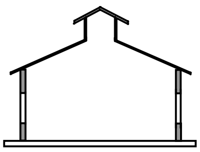
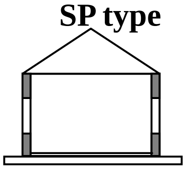
where particles smaller than d_{min} (the minimum diameter) are considered to be the finest, and d_{max} is the largest particle size of interest.

Applying a time average to Eq. (1) whereas neglecting the change of PM mass within the building and assuming that C_o and C_I are not correlated in time with Q_n or $\lambda_d(k)$ yields

$$\frac{C_I(k)}{C_O(k)} = \frac{\lambda_n}{\lambda_n + \lambda_d(k)} \quad (3)$$

where $C_I(k)/C_O(k)$ is the size-specific, time-averaged PM I/O concentration ratio. Eq. (3) indicates that I/O concentration ratios ≤ 0.5 for $\lambda_d(k) >> \lambda_n$ and I/O ratios ≥ 0.5 for $\lambda_d(k) << \lambda_n$.

Table 1. Configuration parameters used to determine opening effectiveness for SP and CRSP type buildings

Building type	Volume V (m^3)	Height to length ratio (h_0/l_0)	Roof slope angle (θ)
CRSP type 	256	2/3	23.5°
SP type 	256	1/3	30°

Opening effectiveness model

The natural ventilation rate (Q_n) depends on the effect of wind moving through openings. ASHRAE (1997) suggests an empirical expression to predict the flow through a sidewall opening as a function of wind speed and opening effectiveness as: $Q_n = EAV_w$, where E is the opening effectiveness (dimensionless), A is the area of inlet opening (m^2), and V_w is the wind velocity (m s^{-1}). The traditional Buckingham Pi theorem is commonly used to derive an empirical relationship between opening effectiveness and variables in terms of dimensionless parameters. The dimensionless parameters selected in the present study include: (i) the Reynolds number (Re) defined by the opening length, air density, air velocity, and absolute air viscosity; (ii) the ratio between opening height and opening length (h_0/l_0); (iii) the incidence angle of wind flow (ϕ); and (iv) the slope of roof (θ). Detailed algorithm for developing the opening effectiveness model can be found in Yu et al. (2002). The expressions of opening effectiveness for the SP and CRSP type buildings, E_{SP} and E_{CRSP}, respectively, can be obtained as follows (Yu et al., 2002),

$$E_{SP} = 7.44 \times (0.2\,\mathrm{Re})^{-0.3495} \times (4h_0/l_0)^{0.1029} \times (\sin\phi)^{0.7524} \times (\sin\theta)^{-0.1486}$$
$$E_{CRSP} = 33.81 \times (0.4\,\mathrm{Re})^{-0.3940} \times (3.2h_0/l_0)^{0.101} \times (\sin\phi)^{0.8799} \times (\sin\theta)^{1.0388} \quad (4)$$

Table 1 gives the configuration parameters used in the present study for determining opening effectiveness for the SP and the CRSP type buildings located at north, central and south Taiwan region in that monthly-averaged data of wind speed and wind direction were obtained from Taiwan EPA.

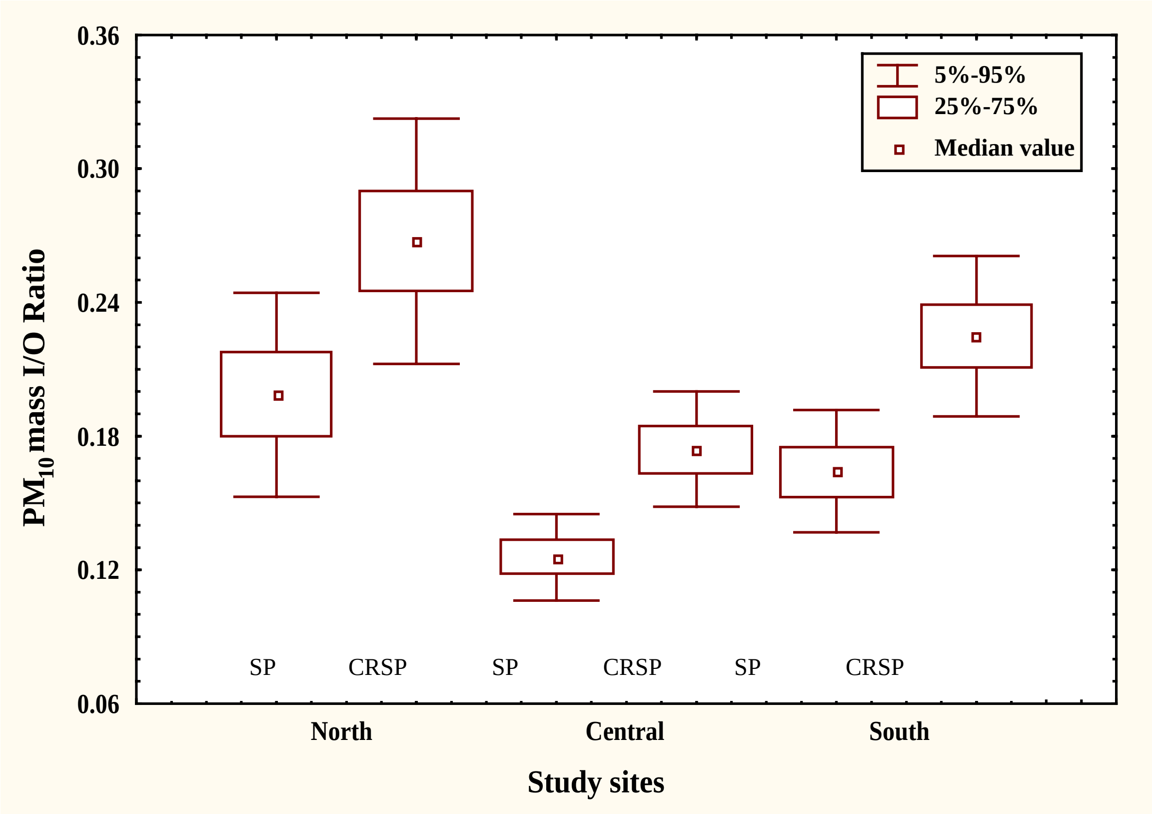


Fig. 1. Calculated PM10 mass indoor/outdoor (I/O) ratio for SP and CRSP type building in the north, central, and south Taiwan region.

Results

The outdoor and indoor PM_{10} mass concentrations for SP and CRSP type buildings are presented in Fig. 1. Box and whisker plots are used to represent the uncertainty in that boxes show 25^{th} and 75^{th} percentiles and whiskers are 5^{th} and 95^{th} percentiles. The relatively lower variability was observed in indoor PM_{10} mass. Median values of measured outdoor PM_{10} mass concentrations were 55.42, 64.06, and 86.94 μg m^{-3}, respectively, in north, central, and south Taiwan region. The CRSP type building has higher calculated indoor PM_{10} mass concentrations (median 11.17 – 19.65 μg m^{-3}) than that of the SP type building (median 8.05 – 14.36 μg m^{-3}). The CRSP type buildings have higher PM_{10} mass I/O ratios (median 0.17 – 0.27) than that of SP type buildings (median 0.13 – 0.20). Strength of the I/O relationships for PM_{10} mass for SP and CRSP type buildings in different Taiwan region is partly explained by the natural ventilation rates of the buildings.

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