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Contributed Paper

Indoor and Outdoor Levels of PM2.5 from Selected Residential and Workplace Buildings in Chiang Mai

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ABSTRACT

Mass concentrations ($\mu g/m^3$) of indoor and outdoor air particulate matter samples (PM2.5) were measured in residential and workplace buildings within the Chiang Mai urban area from June 2004 to May 2005. Twenty-four hour PM2.5 samples were collected each day with Airmetric Minivol® portable air samplers. The monthly averages for indoor PM2.5 mass concentration of residential and workplace buildings ranged from 13.6 to 57.9 $\mu g/m^3$, and 9.9 to 58.5 $\mu g/m^3$, respectively. The corresponding monthly averages for mass concentration of outdoor PM2.5 of two sampling sites ranged from 12.6 to 77.0 $\mu g/m^3$, and 15.1 to 70.0 $\mu g/m^3$. The mass concentrations of indoor and outdoor PM2.5 annual averages in residential buildings (RB) were 29.4 and 36.9 $\mu g/m^3$, and in workplace buildings (WB) were 27.8 and 43.5 $\mu g/m^3$, respectively. Mass concentrations of PM2.5 (24 h average) during February and March 2005 in Chiang Mai were higher than the US Environmental Protection Agency (USEPA), PM2.5, the 24 h standard of 65 $\mu g/m^3$, and the annual PM2.5 of the outdoor and indoor of two sampling sites exceeded the annual standard of 15 $\mu g/m^3$.

Keywords: indoor and outdoor, PM2.5, workplace, residential building.

1. INTRODUCTION

Urban airborne particulate matter contains a large number of genotoxic substances capable of harming humans via inhalation that occur in outdoor and indoor environments [1-3]. Fine particle pollution or PM2.5 describes particulate matter that is 2.5 micrometers in diameter. Fine particle pollution can be emitted directly or formed secondarily in the atmosphere. The chemical composition of particles depends on location, time of year, and weather. The 1997 annual standard was established as a level of 15 micrograms per cubic meter, based on the 3-year average of annual mean PM2.5 concentrations. The 1997 24-hour standard was established as a level of 65 micrograms per cubic meter, determined by the 3-year average of the annual 98th percentile concentrations [4]. Fischer et al. [5] reported higher indoor and outdoor air concentrations

of particulate matters for homes situated near heavy traffic areas than those for homes near lower-traffic areas. The higher indoor concentrations for the homes near higher-traffic areas were primarily influenced by elevated outdoor concentrations. The environmental exposure to many pollutants inferred or estimated through the proximity of residences has been linked to adverse health effects in many epidemiological studies [6]. There have been a number of studies, where indoor air in homes has been characterized and compared with outdoor air [7-10]. The concentration of airborne particles inside a home is governed by the generation of particles within the home, the concentration of particles outside the home, the rate of air exchange and the depositional characteristics of the particles [7, 11].

Chiang Mai is experiencing serious climatic hazards and air pollution due to economic development, increased population, urbanization and its location in a natural basin. It is reported that lung cancers are the most common forms of malignancy and are the primary cause of cancer death in both men and women [12]. The studies on organic extracts of urban particulate matter proved its genotoxicity to reveal a risk for the exposed population in Chiang Mai between December 1998 to March 1999 [13]. Based on these observations, in the present pioneering study, we report the monthly variation of mass concentrations of indoor and outdoor PM2.5 in selected residential and workplace buildings from June 2004 to May 2005.

2. MATERIALS AND METHODS

2.1 Sampling Sites

The samplings were carried out in residential (Site RB) and workplace (Site WB) buildings in Chiang Mai's urban areas during the months of June 2004 and May 2005 (Figure 1.). Site RB is located East of Chiang Mai Rajabhat University, and is a residential building situated on the second floor of a six-story building near a street with high traffic intensity. It is about 3.5 km north of the downtown market area. The room is ventilated naturally through open windows which facilitate rapid mixing of indoor and outdoor air masses. The site is directly impacted by local traffic congestion, and by the cooking of meats and other foods inside the building and by the street vendors in this area. Site WB is located on the second floor of a two-story building in the Department of Biochemistry, Faculty of Medicine, at Chiang Mai University. A window-mounted air conditioner cools the room during most of the year and, although the room doors are usually closed, there is considerable pedestrian traffic throughout the day. The site is about 2.5 km west of the downtown market area and about 1.5 km north of the airport but is "sandwiched" between three busy streets which experience heavy year round traffic.

2.2 Sample Collection

Samples were obtained using mini-volume portable air samplers (AIRmetrics MiniVol® portable air samplers, 225 Street 5th, Suite 501, Springfield, OR 97477, USA, www.airmetrics.com) with cut points of 2.5μm, as described in previous research [13]. Inside the buildings, sampling equipment was placed in the living room of site RB and in the Bioassay Research Laboratory of site WB about 1.5 m high to simulate the breathing zone, and at least 1 m away from the adjacent obstacle. The outdoor sampler was placed 1.5–2 m high in the balcony, at least 1 m from the wall of the building, and away from the exhaust ducts and lighting heat sources. The sampling study was performed from morning to morning. Samplers were operated at a flow rate of 5 liters min^{-1}, and the flow rates were checked before and at the end of the study to ensure a constant flow rate throughout the sampling period. Samples were collected on 47 mm fiber-film filters (type T60A20, Pallflex Products Corporation, Putnam, CT, USA). A micrometric balance (Sartorius Ag, Germany), with accuracy of 0.001 mg, was used to weigh

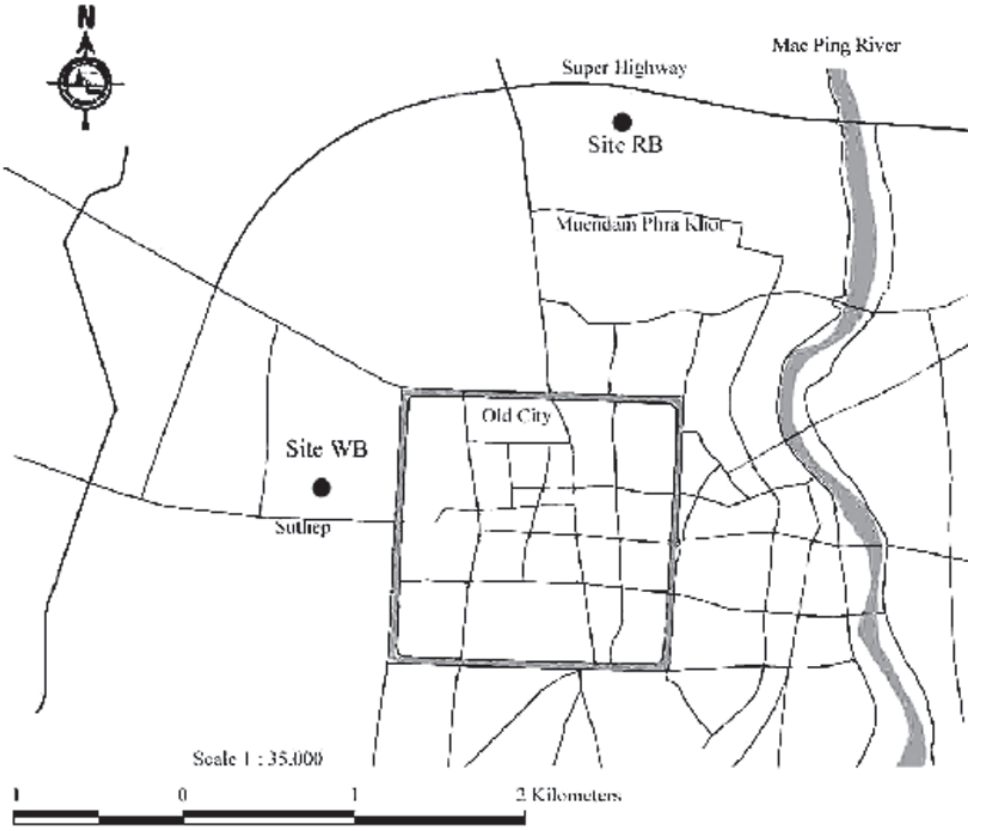

Figure 1. Map of old city, Chiang Mai, Thailand.

the filters. The filters were conditioned in an electronic dessicator, with a temperature of 25°C and relative humidity of 50%, before and after sample collection. The balance was placed on an anti-vibration table, on top of a concrete bench.

3. RESULTS AND DISCUSSION

Indoor and outdoor PM2.5 mass concentrations (μg/m^3) observed at the two sampling sites are shown in Table 1. The indoor PM2.5 concentrations of residential (site RB) and workplace (site WB) buildings ranged from 8 to 90 μg/m^3, and 4 to 99 μg/m^3, respectively. The corresponding outdoor PM2.5 concentration of both sampling sites ranged from 6 to 127 μg/m^3, and 6 to 115 μg/m^3, respectively. Annual averages of indoor and outdoor PM2.5 in residential (RB) were 29.4 and 36.9 μg/m^3, and in workplace (WB) buildings were 27.8 and 43.5 μg/m^3 which exceeded the annual standard of 15 μg/m^3 [13]. The indoor PM2.5 USEPA (65 μg/m^3) of site RB and site WB were exceeded on 10(2.9%) and 14(4.1%) days. Also, outdoor PM2.5 mass concentrations of two sites exceed 65 μg/m^3 on 41(12.8%) and 40(17.3%) days, respectively. Recently, the EPA Office of Air Quality Planning and Standards (OAQPS) has set new National Ambient Air Quality Standards which the annual mean PM2.5 concentrations must not exceed 15.0 μg/m^3 and average of 24-hour concentrations must not exceed 35 μg/m^3 (effective December 17, 2006). Therefore, The indoor PM2.5 USEPA (35 μg/m^3) of site RB and site WB were exceeded on 113(32.8%) and 99(29.2%) days and outdoor PM2.5 mass concentrations of two sites exceed 35 μg/m^3 on 158(49.4%) and 139(60.2%) days. PM 2.5 may have health implications associated

Table 1. Monthly averages of outdoor and indoor PM2.5 mass concentrations at site RB and site WB from June 2004 to May 2005.

Month	PM2.5 mass concentration (μg/m³) of 24 h values							
	Site RB				Site WB			
	Indoor		Outdoor		Indoor		Outdoor	
	Mean ± S.D.	Range of 24 h values	Mean ± S.D.	Range of 24 h values	Mean ± S.D.	Range of 24 h values	Mean ± S.D.	Range of 24 h values
June 2004	16.4 ± 4.9	9 - 29	15.2 ± 4.5	7 - 29	13.1 ± 4.3	4 - 27	N.D.	N.D.
July 2004	13.6 ± 3.3	8 - 21	12.6 ± 3.8	6 - 23	9.9 ± 2.7	6 - 16	N.D.	N.D.
August 2004	16.0 ± 4.7	10 - 28	14.8 ± 5.3	8 - 28	11.6 ± 2.5	8 - 17	15.1 ± 4.5	7 - 28
September 2004	16.8 ± 6.8	9 - 38	16.0 ± 5.7	9 - 35	12.5 ± 5.1	6 - 26	17.1 ± 8.5	6 - 41
October 2004	38.7 ± 10.7	19 - 61	44.0 ± 9.9	23 - 61	31.6 ± 9.8	14 - 55	46.1 ± 12.9	22 - 69
November 2004	24.2 ± 7.3	10 - 41	29.7 ± 9.9	7 - 44	21.6 ± 7.2	5 - 35	30.1 ± 10.1	8 - 43
December 2004	41.5 ± 14.0	11 - 77	48.0 ± 14.4	14 - 76	40.5 ± 17.7	13 - 99	52.9 ± 18.4	19 - 78
January 2005	38.6 ± 8.1	23 - 53	45.9 ± 9.8	26 - 68	44.5 ± 11.2	24 - 74	57.0 ± 13.4	35 - 92
February 2005	57.9 ± 13.6	33 - 90	77.0 ± 20.5	44 - 127	58.5 ± 17.9	27 - 96	70.0 ± 20.9	34 - 114
March 2005	43.3 ± 15.6	13 - 71	64.4 ± 22.1	25 - 104	47.1 ± 15.2	20 - 75	65.3 ± 20.1	32 - 94
April 2005	35.4 ± 13.4	19 - 81	42.6 ± 18.3	19 - 108	27.5 ± 10.3	13 - 63	40.3 ± 17.9	22 - 115
May 2005	17.8 ± 4.4	8 - 27	N.D.	N.D.	15.7 ± 5.2	7 - 26	N.D.	N.D.

N.D. = not determined, Site RB = Residential Building, Chiang Mai Rajabhat University; Site WB = Workplace Building, Faculty of Medicine, Chiang Mai University

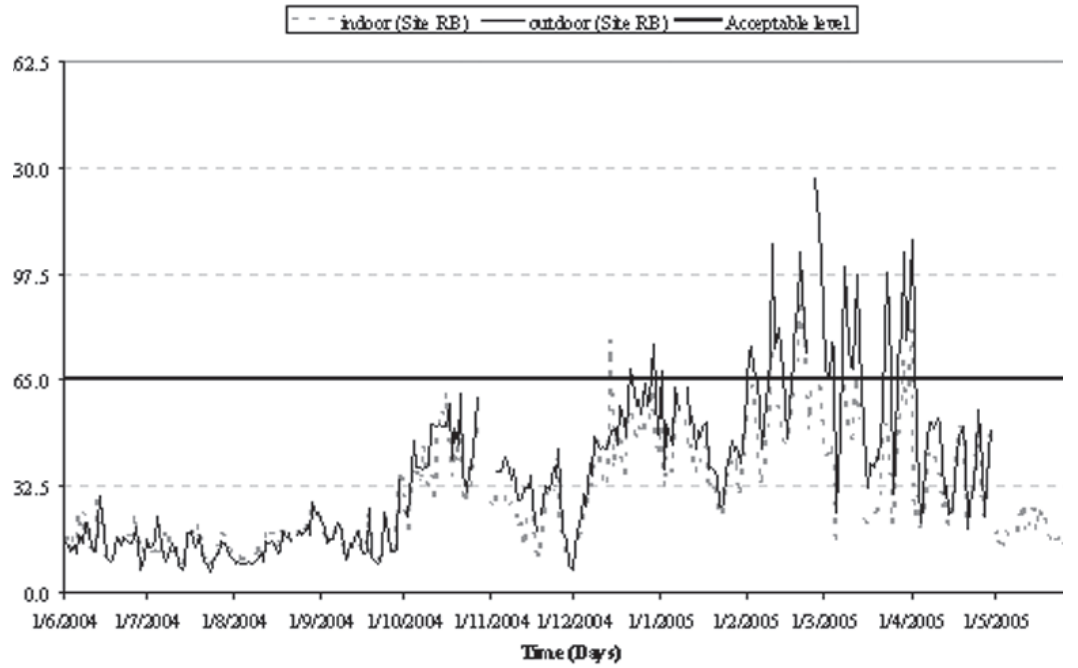

Figure 2. Twenty-four-hour outdoor and indoor PM2.5 mass concentrations at sampling site RB from June 2004 to May 2005.

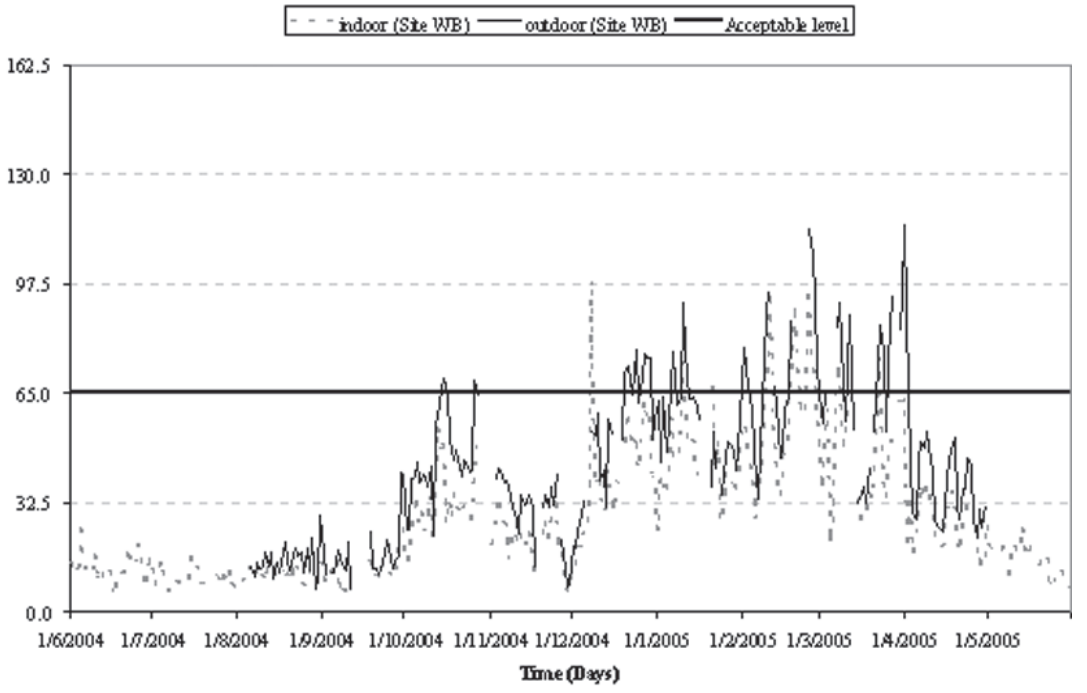

Figure 3. Twenty-four-hour outdoor and indoor PM2.5 mass concentrations at sampling site WB from June 2004 to May 2005.

with these high concentrations which it has been demonstrated that for each 10 μg/m^3 increment in PM2.5 was associated with increased mortality of 4%, 3%, and 2% from pneumonia, chronic obstructive pulmonary disease, and ischemic heart disease, respectively [14].

In February and March 2005, outdoor and indoor PM2.5 mass concentrations of two sites were high, and fell in April 2005 as shown in Figure 2-3. The levels at two sites, both outdoor and indoor, describe a similar pattern of gradual increase during the winter. However, on some occasions, the indoor concentration was higher than that of outdoors. This suggests a contribution of indoor particle sources to the indoor concentrations, as can be found at Sites RB. At Site RB, the monthly average from June 2004 to August 2004 shows higher indoor value than the outdoor value, which could possibly be attributed to particle emission from cigarette burning because, in Thailand, smoking is not forbidden in residential buildings.

The sources responsible for the seasonally high concentrations in the residential (site RB), and the workplace (site WB) building are mainly combustion-related. It is expected that mobile source emissions contribute considerably to the fine particle loading in the Chiang Mai atmosphere during the winter months. It is given that the number of cars and trucks remains relatively constant throughout the year. These emissions will accumulate in the atmosphere under more stagnant air conditions. Industrial processes as well as households activities are additional sources of these emissions. Cooking [15] and tobacco smoking [16] as well as VOC emitting materials employed within the building itself [17] contribute to reduced indoor air quality.

Studies of indoor particulate level in homes have been conducted by many researchers in different countries. A review article by Wallace [18] summarized many key findings of indoor aerosol studies in homes. Neas et al. [19] found that, in 1273 US homes, the annual mean PM2.5 concentration with smoking was 48.5 μg/m^3 while that without smoking was 17.3 μg/m^3. More recently, Haller et al. [20] in the US reported that indoor PM2.5 concentrations were 10.8 μg/m^3. Jones et al. [21] in Birmingham found that indoor PM2.5 concentrations were 7.9 μg/m^3. They also reported the outdoor PM2.5 concentration as 9.1 μg/m^3. In Asia, Nitta et al. [22] found that the mean indoor PM2.5 concentrations in Tokyo in winter and summer were 69.9 and 34.6 μg/m^3. In general, higher indoor particulate concentrations were found in Asian countries [23]. High indoor particulate levels were found in the residential and workplace buildings in Chiang Mai due to the transport of polluted air from outdoor to indoor environment. This is particularly true for those buildings that are located close to heavy traffic [24]. Different living habits among people in Asian versus Western countries can be another factor that leads to higher indoor particulate levels in homes. In Asian homes, the cooking style usually results in the emission of oily fumes from kitchens to living rooms. The common practice of incense burning in some religious families in Asia results in emission of fine-mode particulate matter [25].

4. CONCLUSIONS

This paper presents the results of the first comprehensive outdoor and indoor PM2.5 mass concentrations in selected residential and workplace buildings in Chiang Mai. It was found that the levels at two sites, both outdoor and indoor, expressed a similar pattern of gradual increase during the winter. The indoor PM2.5 levels at the sampling sites were sometimes higher than corresponding outdoor levels, which might result from combustion related activities such as cooking, smoking and incense burning.

Indoor air quality has begun to surface as an important issue that affects the comfort, health and the productivity of residential and office workers. Factors contributing to indoor air pollution include building location, air

intake, building design, building materials, furnishings and indoor activities. Some of the common causes of indoor air problems giving rise to poor air quality are the presence of indoor sources of pollution; poorly designed, maintained or operated air-conditioning and mechanical ventilation systems, use of the building for purposes other than what it was designed for, and renovation. All of these factors should be used to design further studies for assessing the indoor air quality (IAQ) and the relationships with outdoor air quality in Thailand.

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REFERENCES

[1] Kotzias D., Indoor air and human exposure assessment – needs and approaches. Exp. *Toxicol. Pathol.,* 2005; 57 (1): 5-7.

[2] Aunan K. and Pan X., Exposure-response functions for health effects of ambient air pollution applicable for China – a meta-analysis, *Sci. Total Environ.,* 2004; 329: 3-16.

[3] Bernstein J.A., Alexis N., Barnes C., Bernstein I.L., Nel A., Peden D., Diaz-Sanchez D., Tarlo S.M. and Williams P.B., Health effects of air pollution, *J. Allergy Clin. Immunol.,* 2004; 114 (5): 1116-1123.

[4] USEPA. PM2.5 general information, Office of Air Quality Planning and Standards, USEPA, 1998.

[5] Fischer P.H., Hoek G., van Reeuwijk H., Briggs D.J., Lebret E., van Wijnen J.H., Kingham S. and Elliott P.E., Traffic-related differences in outdoor and indoor concentrations of particles and volatile organic compounds in Amsterdam, *Atmos. Environ.*; 2000, 34: 3713–3722.

[6] Huang Y.L. and Batterman S., Residence location as a measure of environmental exposure: a review of air pollution epidemiology studies, *J. Expo. Anal. Environ. Epidemiol.;* 2000; 10: 66–85.

[7] Kamens R., Lee C.-T., Weiner R. and Leith, D., A study to characterize indoor particles in three non-smoking homes, *Atmos. Environ.,* 1991; 25: 939–948.

[8] Clayton C.A., Perritt R.L., Pellizzari E.D., Thomas K.W., Whitmore R.W., Wallace L.A., Ozkaynak H. and Spengler J.D., Particle Total Exposure Assessment Methodology (PTEAM) study: distributions of aerosol and elemental concentrations in personal, indoor and outdoor air samples in a Southern California community. *J. Expo. Anal. Environ. Epidemiol.,* 1993; 3: 227–250.

[9] Miguel A.H., Neto F.R.De A., Cardoso J.N., Vasconcellos P.De C., Pereir, A.S. and Marquez K.S.G., Characterization of indoor air quality in the cities of Sao Paulo and Rio de Janeiro, Brazil. *Environ. Sci. Tech.,* 1995; 29: 338–345.

[10] Chao Y.H., Tung C.W. and Burnett J., Influence of different indoor activities on the indoor particulate levels in residential buildings, *J. Indoor Built Environ.,* 1998; 7: 110–121.

[11] Thatcher T.L. and Layton D.W., Deposition, re-suspension and penetration of particles within a residence, *Atmos. Environ.,* 1995; 29: 1487–1497.

[12] Heepchantree W., Paratasilpin T. and Kangwanpong D., A comparative biomonitoring study of populations residing in regions with low and high risk of lung cancer using the chromosome aberration and the micronucleus tests, *Mutat. Res.,* 2005; 587(1-2): 134-139.

[13] Vinitketkumnuen U., Kalayanamitra K., Chewonarin T. and Kamens R.M., Particulate matter, PM 10 & PM2.5 levels, and airborne mutagenicity in Chiang Mai, Thailand, *Mutat. Res.,* 2002; 519: 121-131.

[14] Neas L.M., Fine particulate matter and cardiovascular disease, *Fuel Process. Tech.,* 2000; 65-66 : 55-67.

[15] Lee S.C., Li W.-M. and Chan L.Y., Indoor air quality at restaurants with different styles of cooking in metropolitan Hong Kong, *Sci. Total Environ.,* 2001; 279 (1-3): 181-193.

[16] Bi X., Sheng G., Feng Y., Fu J. and Xie J., Gas- and particulate-phase specific tracer and toxic organic compounds in environmental tobacco smoke, *Chemosphere,* 2005; 61(10): 1512-1522.

[17] Zuraimi M.S., Roulet C.-A., Tham K.W., Sekhar S.C., David Cheong K.W., Wong N.H. and Lee K.H., A comparative study of VOCs in Singapore and European office buildings, *Building Environ.,* 2006; 41(3): 316-329.

[18] Wallace L., Indoor particles: a review, *J. Air Waste Manage. Assoc.*,1996; 46: 98–126.

[19] Neas L.M., Dockery D.W., Ware J.H., Spengler J.D., Ferris Jr. B.G. and Spizer F.E., Concentration of indoor particulate matter as a determinant of respiratory health in children, *Am. J. Epidemiol.,* 1994; 139: 1088–1099.

[20] Haller L., Claiborn C., Larson T., Koenig J., Norris G. and Edgar R., Airborne particulate matter size distributions in an arid urban area, *J. Air Waste Manage. Assoc.,* 1999; 49: 161–168.

[21] Jones N.C., Thornton C.A., Mark D. and Harrison R.M., Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations, *Atmos. Res.,* 2000; 34: 2603–2612.

[22] Nitta H., Ichikawa M., Sato M., Konishi S. and Ono M., A new approach based on a covariance structure model to source apportionment of indoor fine particles in Tokyo, *Atmos. Res.,* 1994; 28: 631–636.

[23] Tung C.W., Chao Y.H., Burnett J., Pang S.W. and Lee Y.M., A territory wide survey on indoor particulate level in Hong Kong, *Build. Environ.,* 1999; 34: 213–220.

[24] Chen C.-C., Lint J.J. and Tsai J.-H., Characterization for particles in the indoor and outdoor ambient air near a traffic road, *J. Aerosol Sci.,* 1998; 29 (1-2): 245.

[25] Chao Y.H., Tung C.W. and Burnett J., Influence of different indoor activities on the indoor particulate levels in residential buildings, *J. Indoor Built Environ.,* 1998; 7: 110–121.