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Indoor/outdoor relationships of size-resolved particle concentrations in naturally ventilated school environments

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Abstract

Assessment of indoor air quality in typical classrooms is vital to students' health and their performance. The present study was designed to monitor indoor and outdoor size-resolved particle concentrations in a naturally ventilated classroom and investigate factors influencing their levels and relationships. The experiments were performed, at normal ventilation condition with doors and windows opened, on the top floor of a public school building near a busy commercial area of Chiang Mai, Thailand. The particle number concentrations were measured using an optical counter with four size intervals between 0.3 and 5.0 μm. The dataset was collected during weekdays and weekends with a 24 h sampling period over November and December 2005. It was observed that the median indoor particle number concentrations during daytime for 0.3–0.5, 0.5–1.0, 1.0–2.5, and 2.5–5.0 μm size intervals were about 1.6×10^8, 1.7×10^7, 1.2×10^6, and 4.1×10^5 particles/m^3, respectively. It was also found that concentrations at weekends were slightly higher those measured on weekdays, and at night, appeared to be higher than daytime. Indoor particles were observed to exhibit similar temporal variation pattern with outdoor particles. Results suggested that a significant contribution to indoor particles was from penetration of outdoor particles, whereas indoor sources generated from occupant activity did not show strong evidence. High outdoor particle loading and high air exchange rate were thought to be predominant causes. Ratios of indoor-to-outdoor (I/O) particle concentrations varied in a relatively narrow range from 0.69 to 0.88 with average values well below 1. The I/O ratios were in the range from 0.74 to 0.88 for submicrometer particles and from 0.69 to 0.80 for supermicrometer particles.

Keywords: Classroom; I/O ratios; Natural ventilation; Particle number; Size dependent

1. Introduction

Great consideration has been paid to the indoor environment as most persons spend nearly 90% of their time indoors and just a little over 10% outdoors. For young people, the school environment is where they spend the most considerable portion of the day in, apart from at home [1]. Healthy indoor school environments are, therefore, of utmost importance to reduce health risks and contribute to better student performance. There are approximately 350,000 schoolchildren in about 500 schools in densely populated communities such as the municipality and city areas in Thailand. The majority of these schools are state owned, for which most public school classrooms are naturally ventilated with doors and windows normally kept opened for thermal comfort reasons. External air movement is allowed to penetrate the school buildings. Many reports suggest that the air in schools may be contaminated with various air pollutants, such as particulate matter, toxic gases and compounds, noise, etc. Poor indoor environments in schools may be attributed to two primary causes: (i) schools are likely to have environmental deficiencies from inadequate operation and maintenance of facilities due to shortage of necessary funding; (ii) children of school ages are more susceptible to some environmental pollutants than adults because they breathe higher volumes of air relative to their body weights, and their tissue and organs are growing [2]. The single most important pollutant is identified as airborne particles. Presence of

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airborne particulate matter has become a growing concern for the public after an association between exposure and adverse health effects was demonstrated by a number of epidemiological and clinical studies [3–6]. Evidence has pointed towards fine particles, which usually contain hazardous substances and are able to penetrate deep into the human lung, provoking inflammation. Exposures to particulate contaminants indoors can constitute a potential health hazard. Indoor particle concentrations involves complex combinations of numerous factors, such as sources, ambient conditions, building structure and materials, occupant behavior and activities, ventilation and air exchange rate, which also affect particle size distributions. For indoor environments where there are no specific indoor sources, occupant-related activities may become a major source of particles [7]. It is generally accepted that one of the major factors influencing indoor particle levels is the outdoor source. It is, therefore, of importance to determine the sources of indoor particles and to examine to what degree indoor particles are affected by outdoor pollutant concentrations. There have been a number of studies where indoor particles have been measured and related with outdoor air [8–12].

For measurements in schools, a number of recent reports have been published. Daisey et al. [13] gave a comprehensive review on indoor air quality, ventilation and health symptoms in schools. They reported a wide range of air pollutants in schools that may have negative impact on the health of students, teachers and regular visitors. They also pointed out that inadequate ventilation led to health symptoms. Lee and Chang [14] monitored indoor air pollutants including PM_{10} levels at schools in Hong Kong. Their PM_{10} measurements with photometers appeared to be excessively high and the use of air cleaners to mitigate the problem was suggested. Lee and Chang [15] also investigated indoor and outdoor air quality in five school classrooms, focusing on PM_{10}, CO_2, SO_2, NO, NO_2, formaldehyde, and total bacterial counts. It was reported that average indoor PM_{10} and CO_2 exceeded acceptable standards due to overcrowded rooms and inadequate ventilation. They also cited the influence of high outdoor PM_{10} on indoor PM_{10} level. Similar findings reported that particle mass (PM) loadings were higher in classrooms than in ambient air [16]. Branis et al. [17] studied parameters influencing size-dependent PM concentration in a classroom. They found variations in particle levels associated with workdays and weekends, as well as night and day, influenced by outdoor concentration and indoor human activity. While the focus of previous studies has been on PM, there is limited information available on particle number. It was suggested that particle surface area and surface chemistry may be more important factors than PM. Hence, particle number and size distribution appear to be a significant alternative metric to PM. In a recent study [18], measurements of outdoor and indoor pollution were carried out for eight schools in France. The pollutants include size-resolved particle counts, ozone and nitrogen oxides. Outdoor and indoor concentration levels in school buildings were compared. It was reported that occupancy strongly influenced the indoor particle concentration and the indoor-to-outdoor (I/O) particle number concentration ratios were found to decrease with increasing particle size.

Understanding the relationship of indoor and outdoor number based particles is important in improving exposure estimates and developing efficient control strategies to reduce health risk. This study was undertaken to address some of the issues involving indoor particle number concentrations. The aims of this study were to examine 24 h number concentration levels of several size fractions of particles in a classroom and compare weekday and weekend fluctuations, and thus also to investigate factors influencing the relationships between indoor and outdoor particle concentrations.

2. Methods

2.1. Site description

A public school located on Sri Donchai road in central Chiang Mai was chosen as the experimental site. Chiang Mai is one of the major cities in Thailand and is situated in the Ping river valley and surrounded by the Suthep mountain ranges. The city accommodates government offices, shopping complexes, medical, agricultural and educational institutions, industrial units, and residential areas and has a population of about 400,000 with about 3 million visitors a year. Meteorological conditions are typical of the southeast Asian tropical regimes. A chosen classroom with a capacity of 32 students is of standard dimension (8.2 m long × 7.9 m wide × 3.5 m high) according to the Ministry of Education. The classroom was found on a top floor of a four-storey school building. It was naturally ventilated through four windows and two doors which were permanently left open. Based on wind direction data from local meteorological department surveying over the period of the study, prominent wind direction was found to vary significantly between weekday and weekend, as well as over cycles of day and night. During daytime, west and south were the major directions for weekdays and weekends, respectively. At night, wind blowing between west and northwest was found to exhibit maximum frequency for both weekdays and weekends. It was anticipated that window side and door side would not have significantly different air flows. Air exchange rates were calculated from computational fluid dynamics simulation of flow through the openings and estimated to be around 6.0 and $5.1\,h^{-1}$ for daytime and at night, respectively. There was no forced ventilation or air conditioning system in use. Air change rates found in this investigation were considerably higher than reported in previous studies (see Table 1). The room was equipped with standard school tables and chairs, a blackboard for chalk at the front and a bookshelf at the back. The floor surface covering was made of hard rubber sheet. The building faces