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Effects of Chalk Use on Dust Exposure and Classroom Air Quality

Chi-Chi Lin[1], Mei-Kuei Lee[2], Hsiao-Lin Huang[2*]

[1] *Department of Civil and Environmental Engineering, National University of Kaohsiung, No.700, Kaohsiung University Rd., Nan-Tzu Dist., Kaohsiung 81148, Taiwan*
[2] *Department of Occupational Safety and Health, Chia Nan University of Pharmacy and Science, No.60, Sec. 1, Erren Rd., Rende Dist., Tainan City 71710, Taiwan*

ABSTRACT

This study explores human exposure to harmful dust when antidust chalk is used for teaching, as well as dust particle size distribution and how chalk dust affects indoor air quality. In this study, a classroom with 5 ventilation modes was selected. A dust size analyzer and a scanning mobility particle sizer were employed to measure the mass concentration and particle size distribution of chalk dust based on the frequency of chalk use during classes. The results indicate that antidust chalk can generate considerable quantities of dust particles and substantially increase the mass concentration of dust in the proximity of the chalkboard. Approximately 15% of observed chalk dust particles were respirable and high concentrations of chalk dust deteriorated the indoor air quality. Moreover, chalk dust was the primary source of indoor coarse particles. Mechanical ventilation resuspended the settled chalk dust particles, thereby increasing the mass concentration of airborne dust. Using antidust chalk generates coarse, fine, and ultrafine particles, particularly when cleaning the chalkboard. The best ventilation mode to reduce dust accumulated in the chalk teaching classroom was to open doors and turn on ceiling fans. Wearing face masks and increasing distance between seats and blackboard can also prevent teachers and students from chalk dust hazard. The results of this study should serve as a reference for improving indoor air quality and protecting teachers and students from harmful dust particles in classrooms.

Keywords: Dust; Exposure; School; Indoor air quality; Ventilation.

INTRODUCTION

Numerous tools and instruments have been developed to facilitate teaching, including whiteboards, video materials, interactive whiteboards, and electronic tools. However, the traditional “chalk-and-talk” method remains commonly practiced in schools. Writing with chalk and subsequent cleaning of the chalkboard generates chalk dusts. Various antidust chalks are manufactured to reduce the quantity of chalk dust. Antidust chalk can reduce particulate suspension by increasing the density or particle size of the dust.

No obvious link between chalk dust and human cancer was established. Ohtsuka *et al.* (1995) reported chalk dust in the lungs of school teachers suffering from interstitial pneumonia and multiple bullae; however, the relation between chalk dust and pneumonia requires further research. The potential acute health effects of calcium sulfate or calcium carbonate in chalk dust include irritation to the eyes, skin, respiratory tract, mucous membranes, and digestive tract; the potential chronic health concerns are lung and liver damage resulting from exposure to calcium sulfate and calcium carbonate particles, respectively (Sciencelab.com, 2005a, b). Fine chalk particles could exert oxidative damages in alveolar macrophages and result in cytotoxicity (Zhang *et al.*, 2015a, b). Furthermore, epidemiological studies have suggested that long- and short-term exposure to particulate matter (PM) is associated with adverse health effects, including cardiovascular mortality, histopathologic markers of subclinical chronic inflammatory lung injury, and mortality resulting from cardiovascular illness (Pope and Dockery, 2006; Downs *et al.*, 2007). Therefore, the potential health risks of chalk dust particles cannot be overlooked when using chalk in classrooms.

Few studies have explored the characteristics of chalk dust. Majumdar and William (2009) observed that common chalk generates a higher amount of settled dust (diameters < 4.5 μm and < 11 μm) than does antidust chalk. Jai Devi *et al.* (2009) indicated that students in small classrooms were more affected by the indoor particle source than were those in large classrooms. They determined that antidust chalk is a major source of fine particles. Furthermore, Majumdar *et al.* (2012) showed that Clean Write and Local Gypsum chalks generate the lowest and highest levels of

[*] Corresponding author.
Tel.: +886 6 2664911 ext. 6245; Fax: +886 6 2667320
E-mail address: hlhuang@mail.cnu.edu.tw

PM_1, $PM_{2.5}$, PM_5, and PM_{10} when writing on a chalkboard, respectively. Chalk use has been identified as a primary factor increasing the indoor aerosol concentration (Franchi and Carrer, 2002; Madureira *et al.*, 2009). Stranger *et al.* (2008) analyzed the indoor $PM_{2.5}$ content and observed high concentrations of calcium, suggesting that indoor calcium originates from chalk dust. Almeida *et al.* (2011) argued that $PM_{2.5}$ particles are introduced to classrooms through the infiltration of outdoor air. In addition, high concentrations of coarse $PM_{2.5-10}$ calcium have been attributed to chalk use in the classroom. Based on the high calcium concentrations present in PM, Fromme *et al.* (2008) concluded that chalk is a primary source of indoor PM_{10} and $PM_{2.5}$.

Knowledge regarding how chalk affects airborne PM in classrooms is limited. Teachers using chalk may be exposed to risks resulting from long-term exposure to chalk dust. Because indoor air quality deteriorates during classes, students who remain in the classroom are also at risk of inhaling large quantities of chalk dust. Airborne chalk particles are believed to increase the risk of adverse health effects on teachers and students. Thus, teachers and students must understand the effects of chalk dust particles and how chalk dust affects classroom air quality. Therefore, the objectives of this study are to examine (1) exposure of teachers to chalk dust; (2) dust particle size distributions in the proximity of the chalkboard; and (3) how chalk dust affects the air quality in classrooms that employ various ventilation systems.

MATERIALS AND METHODS

Ventilation Methods and Chalk Types

A windowless classroom was selected in order to assess the chalk dust exposure of teachers and students. Fig. 1 shows the classroom schematic. The dimensions of the classroom were 890 × 837 × 450 cm (length × width × height). Two air conditioners and four ceiling fans were situated inside the classroom. The indoor-outdoor air circulation was primarily through the front and back doors of the classroom. To simulate real classes and examine the levels of chalk dust exposure, the following five ventilation situations were studied: (1) doors closed; (2) doors closed and air conditioning on; (3) doors closed, air conditioning on, and ceiling fans on; (4) doors opened; and (5) doors opened and ceiling fans on. White antidust chalks (calcium sulfate as the primary ingredient) were used to generate aerosols by writing on the chalkboard followed by being wiped off. Only two persons stayed in the classroom during the whole period of experiment. To standardize the amount of chalk used to write on the chalkboard, the number of 126 grids (24 × 22 cm) were drawn by one person on the chalkboard as a substitute for teaching content before being wiped off by a chalk duster. Another person remained in the classroom to measure the experiment results (each experiment lasted for 1 h) and minimize the settlement and resuspension of dust particles by movement.

Sampling Strategy and Methods

A dust monitor (Grimm 1.109, Germany) with a correction factor (C-factor) of 1.0 was employed in the proximity of the chalkboard to continuously measure the levels of inhalable (particulates that can be breathed into the nose or mouth, which corresponding to particles with aerodynamic diameter ≤ 100 µm), thoracic (particulates that can penetrate the head airways and enter the airways of the lung, which is a sub fraction of the inhalable particles and corresponding to particles with aerodynamic diameter ≤ 10 µm), and respirable dust (particulates that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lung, which is a sub fraction of the inhalable particles and corresponding to particles with aerodynamic diameter ≤ 4 µm) (ACGIH, 2005; CEN, 1993), as well as suspended environmental PM_{10} (particles with aerodynamic diameter ≤ 10 µm) and $PM_{2.5}$ (particles with aerodynamic diameter ≤ 2.5 µm) every minute for 1 h. PM_{10} is conceptually the same as thoracic particles. The particle sampling instrument was positioned on the lectern at a height of 1.7 m, representing the approximate breathing zone of a standing teacher. The particle size distribution in the diameter range of 18.1 nm to 30 µm was measured at the same location. The particle size distribution in the diameter range of 18.1 nm to 947.5 nm was measured every 5 min for 1 h by using a scanning mobility particle sizer equipped with an electrostatic classifier (TSI Model 3080, USA) and a condensation particle counter (CPC, TSI Model 3022A, USA). The particle size distribution in the diameter range of 0.25 µm to 30 µm was measured every minute for 1 h by using the aerosol spectrometer Grimm 1.109.

The Grimm dust monitor was used to sample the PM_{10} and $PM_{2.5}$ of the regional environments at 26 locations in the classroom and at two external locations at the front and back door (Fig. 1) for 6 s at each location, and all indoor 26 locations were sampled within 10 min. Two outdoor locations were measured before and after each experiment. Particle sampling was performed at a height of 1.2 m to represent the approximate breathing zone of seated students. The total sampling time was equivalent to one class period (1 h). Before each experiment, the chalkboard, eraser, floor, tables, and chairs were cleaned with a duster. Dust measurements were performed 10 min prior to writing on the chalkboard to estimate the initial concentration. A chalkboard was then used for writing and was cleaned approximately every 10 min until the experiment was completed. The experiment repeated three times.

The Grimm dust monitor operates on the principle of light scattering and its response depends on the particle density, shape and refractive index of the sampled particles (Burkart *et al.*, 2010). All readings from the Grimm dust monitor were calibrated against a beta attenuation monitor (E-Bam, Met One Instruments, Inc, USA). Calibration of PM_{10} and $PM_{2.5}$ were conducted inside and outside of the classroom. The PM_{10} concentrations were measured simultaneously over a 2 h period using the Grimm dust monitor and a beta attenuation monitor with a PM_{10} inlet. The same experiments were performed for $PM_{2.5}$ with a sharp cut $PM_{2.5}$ cyclone over another 2 h period. The following linear regression equations were obtained based on PM_{10} (µg m^{-3}) and $PM_{2.5}$ (µg m^{-3}) measurements by the Grimm dust monitor and a

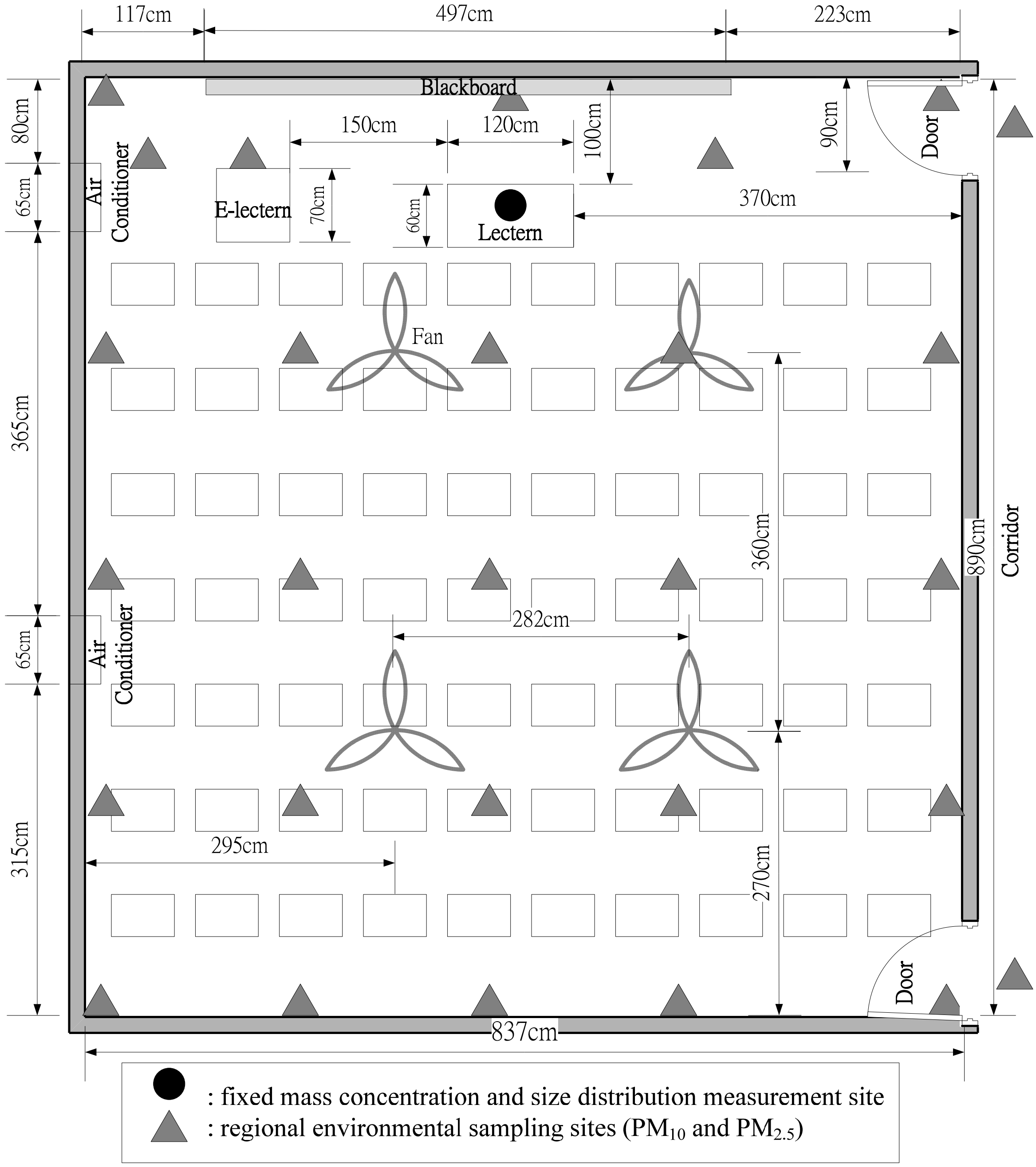


Fig. 1. Layout of classroom and dust monitoring sites in classroom.

beta attenuation monitor.

$$PM_{10(\text{beta, Indoor})} = 0.90 \times PM_{10(\text{Grimm, Indoor})} - 3.22;\ R^2 = 0.91 \quad (1)$$

$$PM_{2.5(\text{beta, Indoor})} = 0.56 \times PM_{2.5(\text{Grimm, Indoor})} - 1.66;\ R^2 = 0.84 \quad (2)$$

$$PM_{10(\text{beta, Outdoor})} = 2.53 \times PM_{10(\text{Grimm, Outdoor})} - 50.37;\ R^2 = 0.86 \quad (3)$$

$$PM_{2.5(\text{beta, Outdoor})} = 1.42 \times PM_{2.5(\text{Grimm, Outdoor})} - 3.57;\ R^2 = 0.80 \quad (4)$$

RESULTS AND DISCUSSION

Occupational Exposure to Chalk Dust

Table 1 shows the mass concentrations of coarse, thoracic, and respirable fractions of chalk dust measured before and during the experiment in the proximity of the chalkboard. After using chalk, the mass concentration of dust particles was higher than that before the experiment regardless of the test ventilation mode. Moreover, antidust chalks application increased the quantity of airborne dust particles in the proximity of the chalkboard. The results indicate that the chalk-and-talk method exposed teachers to increased quantities of suspended chalk dust particles, as

Table 1. Mass concentrations of inhalable, thoracic and respirable chalk dust in teaching platform area.

Dust	Before teaching					Teaching with chalks				
	doors closed	doors closed + air conditioning	doors closed + air conditioning + ceiling fans	Doors opened	doors opened + ceiling fans	doors closed	doors closed + air conditioning	doors closed + air conditioning + ceiling fans	doors opened	doors opened + ceiling fans
	(N = 30)	(N = 30)	(N = 30)	(N = 30)	(N = 30)	(N = 150)	(N = 150)	(N = 150)	(N = 150)	(N = 150)
Inhalable	17.77	9.19	6.50	31.84	18.43	1227.56	208.76	269.20	758.63	269.07
(µg m^{-3})	(3.54)[a]	(4.60)	(3.58)	(10.90)	(2.14)	(2096.71)	(276.10)	(371.39)	(1637.74)	(444.26)
Thoracic	16.78	6.91	5.38	26.69	17.79	339.63	85.18	94.99	163.19	90.84
(µg m^{-3})	(2.65)	(1.95)	(0.87)	(1.71)	(1.67)	(478.55)	(66.45)	(81.96)	(273.28)	(84.50)
Respirable	11.05	3.76	3.74	18.32	13.21	72.14	22.28	24.19	41.07	28.91
(µg m^{-3})	(1.18)	(0.50)	(0.36)	(0.95)	(0.70)	(70.94)	(18.48)	(10.65)	(38.65)	(11.36)
Coarse fraction	4.85	18.91	8.87	11.42	3.22	51.34	44.49	46.46	51.71	40.61
(%)	(5.10)	(15.87)	(16.9)	(15.58)	(2.90)	(24.59)	(19.28)	(23.66)	(28.39)	(25.48)
Thoracic fraction	95.15	81.09	91.13	88.58	96.78	48.66	55.51	53.54	48.29	59.39
(%)	(5.10)	(15.87)	(16.92)	(15.58)	(2.90)	(24.59)	(19.28)	(23.66)	(28.39)	(25.48)
Respirable fraction	63.27	47.44	64.73	61.58	72.22	17.97	18.48	18.98	23.88	25.64
(%)	(6.41)	(17.42)	(15.46)	(13.31)	(5.48)	(19.77)	(15.44)	(21.29)	(22.80)	(21.62)

[a] Standard deviation; [b] Coarse fraction: (Inhalable-Thoracic)/Inhalable; [c] Thoracic fraction: Thoracic/Inhalable.

well as dermal and eye contact with chalk dusts during teaching (Jai Devi *et al.*, 2009). Comparing the mass concentration distributions of the three dust types shows that the proportions of thoracic and respirable dust before experiment were obviously higher than those during the experiment. However, the proportion of the coarse chalk dust (coarse fraction) was apparently elevated during the experiment relative to that before the experiment. The increase in percentage and high mass concentration of the coarse dust indicates that a substantial quantity of large chalk particles was generated when using antidust chalks during the experiment. Approximately 75–80% of chalk dust particles (the rest of respirable fraction) were observed at the head and tracheoalveolar regions (CEN, 1993). These particles can be eliminated from the body by swallowing, nose wiping, sneezing, and other actions (Lippman, 2001). However, approximately 20–25% of respirable chalk dust can enter the pulmonary alveolus. The clearance rates of these particles from the alveolar region are low. The body cannot easily remove such particles by using natural elimination mechanisms. Although the proportion of respirable chalk dust reduced during the experiment, the mass concentration increased compared with the period before the experiment. Madureira *et al.* (2009) reported similar results, indicating that using chalk dust leads to an increase in respirable particles; furthermore, the upper respiratory problems and mucosal irritation that teachers experienced were substantially related to the concentration of respirable dust. In this study, the mass concentration of respirable chalk dust was below Taiwan's (Taiwan OSHA, 2014) and the Occupational Safety and Health Administration's permissible exposure limit of 5 mg m^{-3} (time-weighted average) over 8 h (29 CFR 1910.100). Adverse respiratory system health effects could be related to long-term exposure to small, randomly shaped particles (Vincent, 1995; Nieboer *et al.*, 2005; Majumdar and William, 2009). Of the five ventilation conditions, the highest mass concentration of chalk dust particles was measured in the teaching platform area when the classroom doors were closed (Table 1). Therefore, with the doors closed, teachers are at exposure risk from chalk dust particles because of the considerable particle distribution in the proximity of the chalkboard. The classroom ventilation is limited with only the front and back doors open. Therefore, the secondly highest mass concentration of chalk dust was recorded with the doors open. Considering that most chalk dust remains near the chalkboard, this could also negatively affect teachers' health. The other three modes of mechanical ventilation demonstrated increased dispersion of the dust particles in the classroom. Therefore, the concentration of chalk dust decreased near the chalkboard.

Fig. 2 shows the variations of mass concentration for inhalable, thoracic, and respirable chalk dust in the proximity of the chalkboard before (0–10 min) and during the class (10–50 min) in the following ventilation conditions: (1) doors closed; and (2) doors closed, air conditioning on, and ceiling fans on. Regardless of whether the air conditioning and ceiling fans were operating, large quantities of inhalable and thoracic chalk dust particles were observed when cleaning the chalkboard. After cleaning, the dust

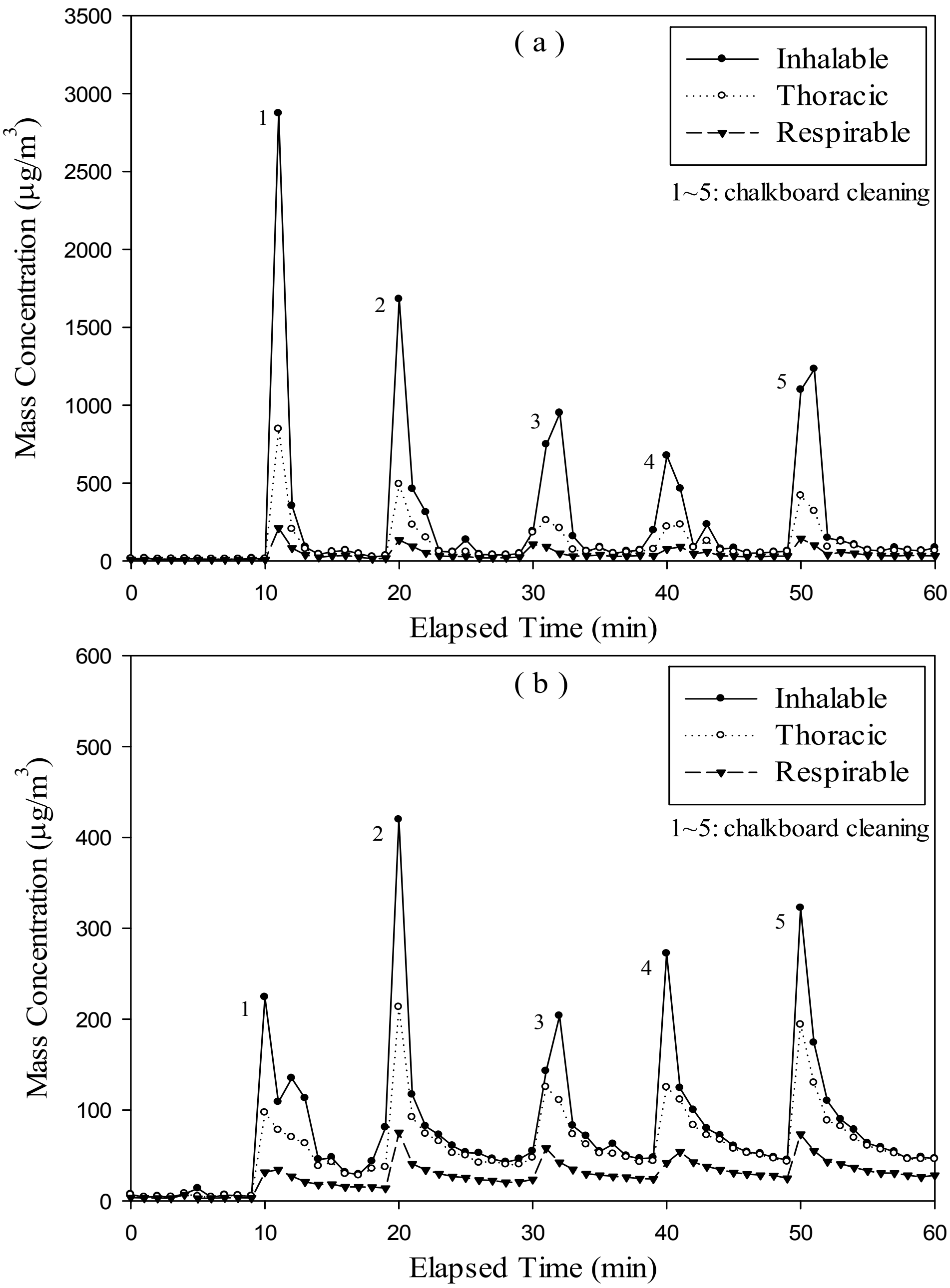


Fig. 2. Mass concentrations for inhalable, thoracic and respirable chalk dust near the chalkboard in the two ventilation modes: (a) doors closed and (b) doors closed, air conditioning on, and ceiling fans on.

concentration decreased. Conversely, the variation of the mass concentration of respirable dust was small. This was due to the much slower deposition rate (or lower settling velocity) of respirable chalk dust particle than large chalk dust particles which have high settling velocity. The remaining three ventilation conditions demonstrated similar profiles of chalk dust concentration in the proximity of the chalkboard. This indicates that cleaning the chalkboard could generate a considerable quantity of large particles. The mass concentration of the chalk dust was smaller when writing on the chalkboard relative to cleaning the chalkboard. Furthermore, compared with the initial classroom dust concentration levels, the findings show that the dust concentration was higher during the experiment. Classroom activities, such as using antidust chalks or cleaning the chalkboard with a chalk duster, were the primary sources of chalk dust that contributed to increased levels of airborne particles near the chalkboard.

Concentration Levels of Chalk Dust

To validate occupational exposure to large dust particles, the mass concentration levels of PM_{10} and $PM_{2.5}$ were measured in the proximity of the chalkboard (Table 2). Similar to the results of the inhalable, thoracic, and respirable chalk dust, the concentration levels of PM_{10} and $PM_{2.5}$ substantially increased after using antidust chalk for teaching

Table 2. Mass concentrations of PM_{10} and $PM_{2.5}$ chalk dust in teaching platform area.

Dust	Before teaching					Teaching with chalks				
	doors closed	doors closed + air conditioning	doors closed + air conditioning + ceiling fans	doors opened	doors opened + ceiling fans	doors closed	doors closed + air conditioning	doors closed + air conditioning + ceiling fans	doors opened	doors opened + ceiling fans
	(N = 30)	(N = 30)	(N = 30)	(N = 30)	(N = 30)	(N = 150)	(N = 150)	(N = 150)	(N = 150)	(N = 150)
PM_{10} (μg m^{-3})	26.66	4.19	6.30	34.62	40.79	174.14	76.30	106.55	126.51	165.24
	(8.57)[a]	(1.39)	(1.53)	(1.15)	(5.09)	(206.05)	(34.81)	(90.29)	(132.78)	(126.04)
$PM_{2.5}$ (μg m^{-3})	4.66	1.44	1.89	14.80	8.73	10.80	10.03	11.91	19.07	15.63
	(0.82)	(0.22)	(0.35)	(0.26)	(0.65)	(5.44)	(3.75)	(5.51)	(4.97)	(2.96)
$PM_{2.5-10}/PM_{10}$ (%)	83.51	63.31	68.98	57.22	78.37	90.94	85.69	86.65	77.62	88.17
	(3.53)	(8.23)	(6.41)	(1.32)	(2.47)	(4.54)	(9.67)	(7.85)	(11.45)	(5.07)
$PM_{2.5}/PM_{10}$ (%)	16.49	36.69	31.02	42.78	21.73	9.06	14.31	13.35	22.38	11.83
	(3.53)	(8.23)	(6.41)	(1.32)	(2.47)	(4.54)	(9.67)	(7.85)	(11.45)	(5.07)

[a] Standard deviation.

compared with before the experiment. PM_{10} showed higher substantial increase in mass concentration than $PM_{2.5}$. Higher PM_{10} levels were recorded with the doors open and ceiling fans on relative to with only the doors open, whereas $PM_{2.5}$ exhibited opposite trend. The main reason is that the turbulence caused by the ceiling fan slowed down the settling of coarse particles (thereby increased their atmospheric retention time). Hence the measured PM_{10} concentration was higher than with no ceiling fan. However, $PM_{2.5}$ has much slower settling velocity and much longer retention time. So, even without ceiling fan, $PM_{2.5}$ concentration decreased much more slowly than PM_{10}. With the ceiling fan, $PM_{2.5}$ decreased even slower although the difference was not as much as that for PM_{10}. As a result, $PM_{2.5}$ with ceiling fan was not higher than without ceiling fan. Comparing the contributions of $PM_{2.5-10}$ and $PM_{2.5}$ to that of PM_{10}, the primary dust particle size distribution of mass concentration in the proximity of the chalkboard was coarse dust ($PM_{2.5-10}$). The proportions of $PM_{2.5-10}$ apparently increased during the experiment relative to those before the experiment. Most dust particles were coarse before and after the experiment regardless of the ventilation conditions. The dominant particle sizes for chalk dust in the five ventilation modes were in the diameter range of 2.5–10 μm. The results suggest that chalk dust generated when chalk was used to write on the chalkboard or when chalk was wiped off from the chalkboard, substantially increased the levels of airborne particles, particularly large ones in the proximity of the chalkboard. Therefore, the proportions of mass concentration of fine dust ($PM_{2.5}$) were relatively small. These results comply with those of Majumdar *et al.* (2012) in which chalk was used to write in a closed-door classroom.

Particle Size Distribution of Chalk Dust

Majumdar and William (2009) and Majumdar *et al.* (2012) did not examine the characteristics of particle size distribution in detail; they only measured the volumetric particle size distribution of settled chalk dust near the chalkboard. In the current study, the particle number size distribution of airborne chalk dust was measured at various size ranges (Figs. 3 and 4). Fig. 3 shows the number size distribution of chalk dust in the diameter range of 0.25 to 30 μm. Without ventilation interference (i.e., with doors close), chalk dust less than 7 μm in diameter was generated in the proximity of the chalkboard when writing on or cleaning the chalkboard (Fig. 3(a)). The quantity of submicrometer-sized dust particles was greater than that of the coarse-sized particles. However, the findings demonstrated markedly higher quantity of submicrometer chalk dust particles in the closed-door classroom when air conditioning and ceiling fans were active (Fig. 3(b)). Relatively few coarse particles were observed at the initial stage because they were diluted and dispersed by the air conditioning and ceiling fans. Consequently, coarse particles of chalk dust were not observed near the chalkboard. Fig. 4 shows the particle size distribution of fine dust particles (< 1 μm). A large quantity of nanoparticles (< 100 nm) was observed in the proximity of the chalkboard starting from the 10th minute of the experiment since the doors were closed (Fig. 4(a)).

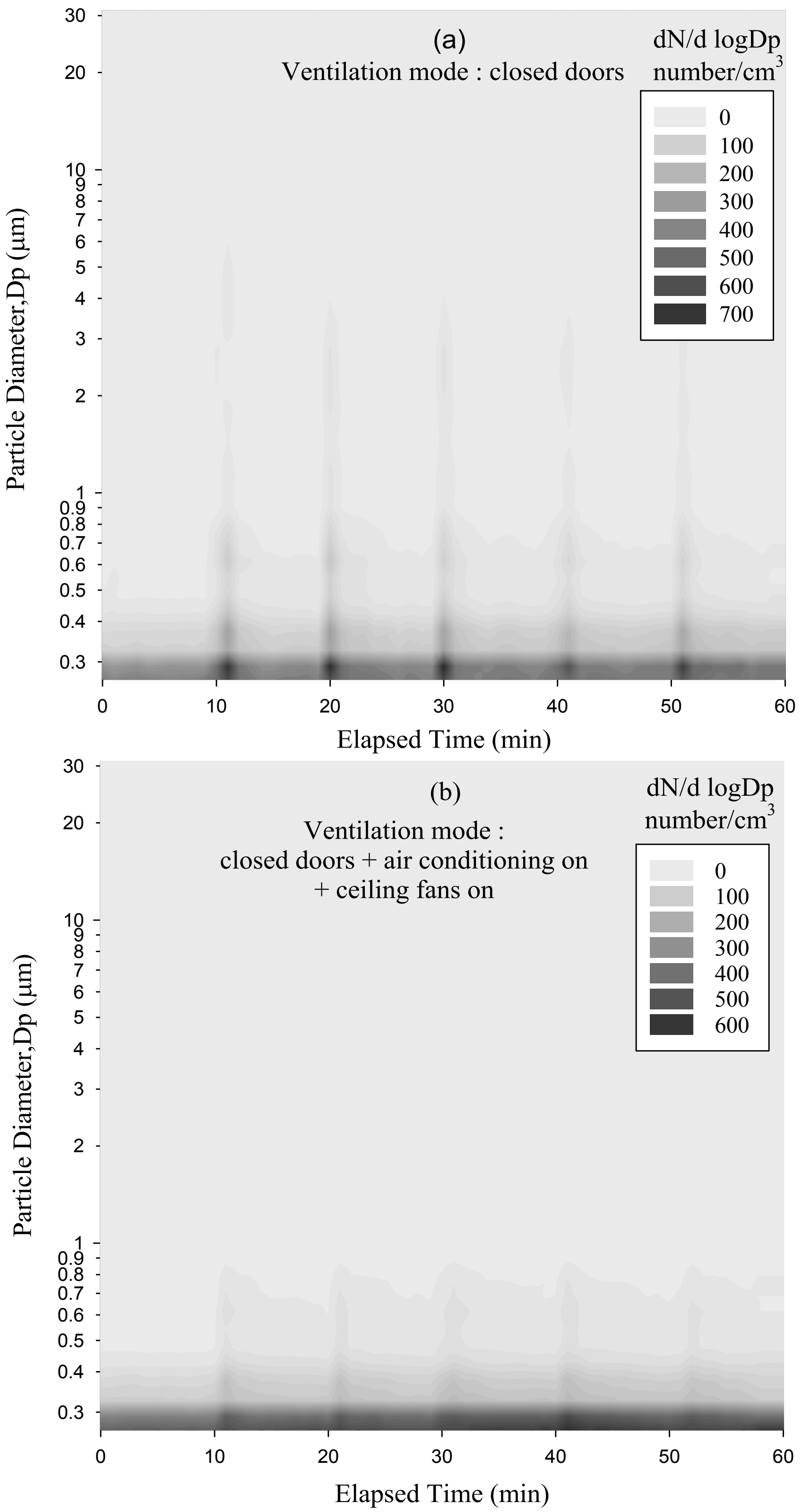


Fig. 3. Particle size distributions in the diameter range of 0.25 to 30 µm in the proximity of the chalkboard.

This shows that antichalk dust is composed of coarse and fine particles. More importantly, chalk dust is also source of ultrafine particles in the classroom besides the source of ultrafine secondary organic aerosols formed during art and cleaning activities (Morawska *et al.*, 2009). The level of nanoparticles is not significant in Fig. 4(b) because of the dilution and dispersion effects of mechanical ventilation systems.

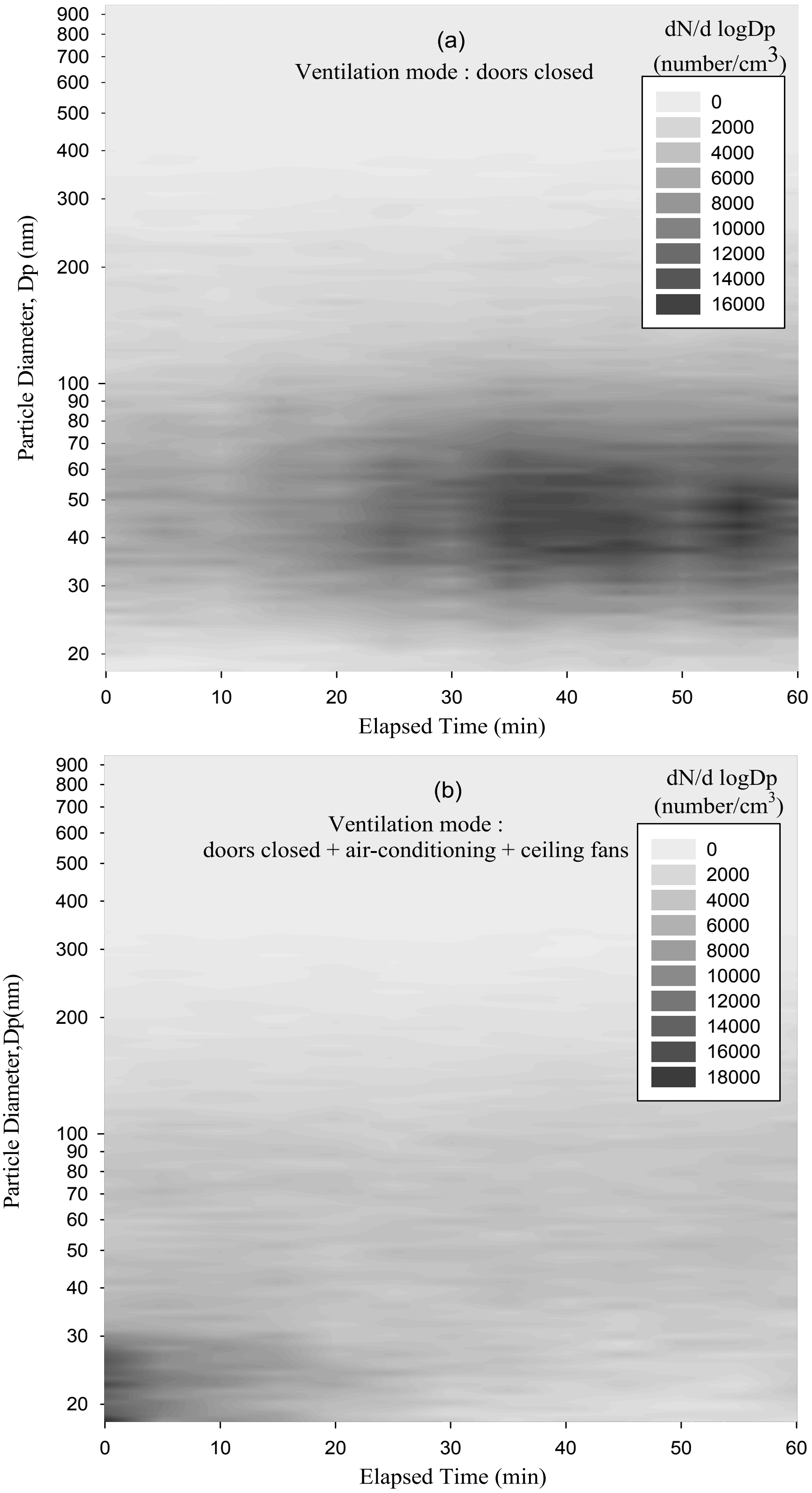


Fig. 4. Particle size distributions in the diameter range of 18.1 to 947.5 nm in the proximity of the chalkboard.

The results indicate that coarse particles were primary contributors to increased mass concentration. The mass concentration of fine and coarse dust particles increased following the experiment, which implies that the quantities of both fine and coarse dust particles increased after classes. Because of the apparent mass differences between small and large particles, the presence of few coarse dust particles can substantially contribute to the mass concentration and affect its distribution. From a health care perspective, the number concentration distribution is critical; this varied depending on the diameter of aerosol particles when chalk was used in the class. Previous studies have demonstrated the health effects of short- or long-term exposure to fine and coarse dust particles (Pope *et al.*, 2004, 200; Pope and Dockery, 2006; Downs *et al.*, 20072; Díaz-Robles *et al.*, 2015). Chalk $PM_{2.5}$ could also stimulate alveolar macrophages to produce reactive oxygen species and cause oxidative stress and cytotoxicity (Zhang *et al.*, 2015a, b). Although the adverse health effects of ultrafine particles remains uncertain, various experimental studies have indicated that human exposure to nanoparticles is related to cardiovascular diseases (Lucking *et al.*, 2008; Langrish *et al.*, 2009; Lundbäck *et al.*, 2009; Samet *et al.*, 2009). According to Figs. 3 and 4, the counts of the fine and ultrafine dust particles that are capable of penetrating the alveoli were greater than those of the coarse dust particles. Higher deposition fraction of nanoparticles occurs at smaller particle size (Patterson *et al.*, 2014). The nanoparticles cause the major health risk due to high deposition efficiency and low clearance rate by the mucociliary escalator (Gorbunov *et al.*, 2013). Therefore, the generation of chalk dust nanoparticles near the teaching platform area is a serious health concern for teachers.

Mass Concentration Distribution in the Classroom

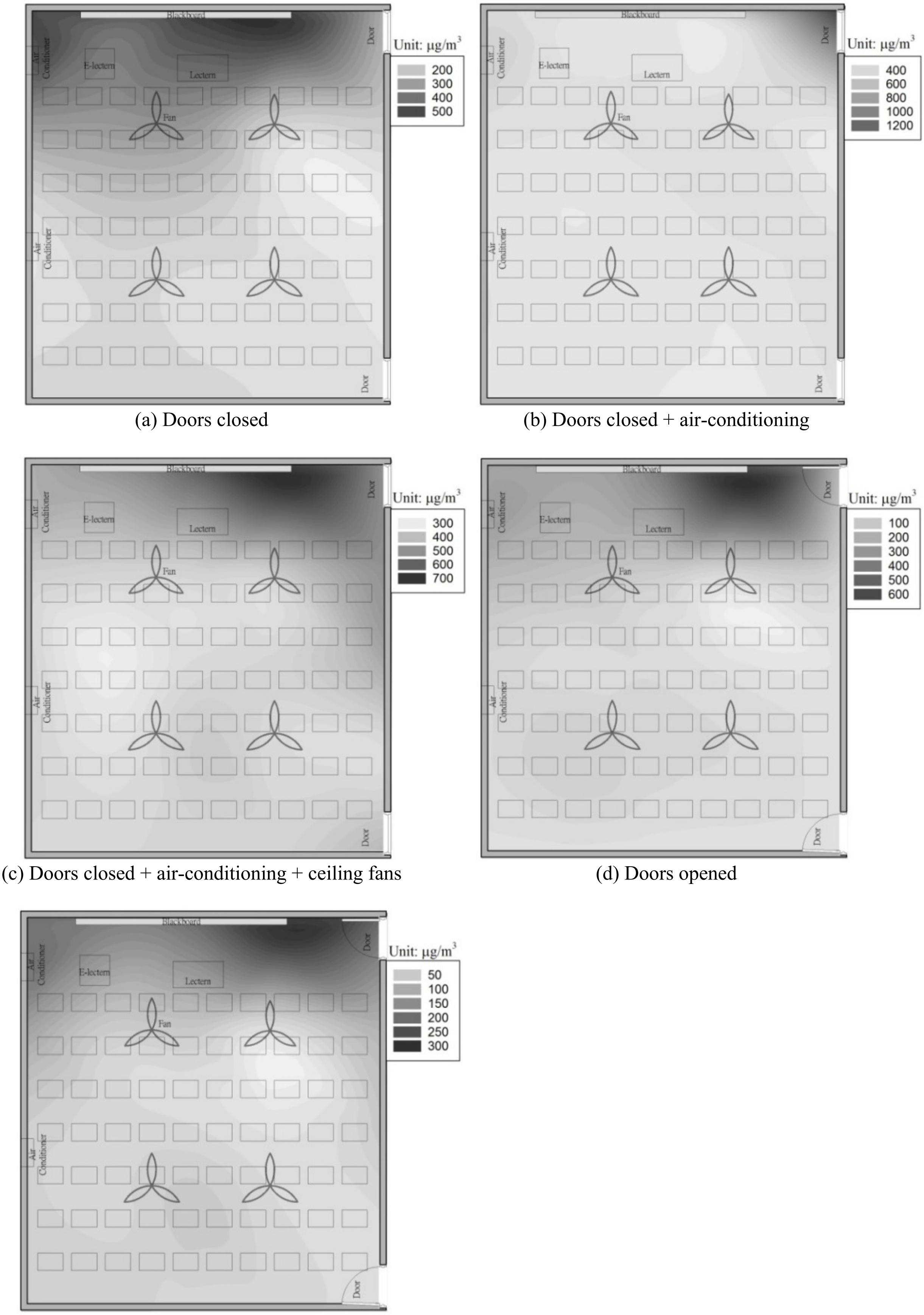
The average mass concentration distribution of chalk dust generated during the experiment was measured at the height of breathing zone to examine how chalk dust particles affect students. Fig. 5(a) shows that PM_{10} chalk dust was primarily distributed in the proximity of the chalkboard when the classroom doors were closed and the mechanical ventilation systems were not operating. Because of the concentration gradient, high concentrations of dust particles slowly dispersed from the chalkboard area toward the student seating area. After turning on the air conditioners (Fig. 5(b)), the chalk dust at the front of the classroom was influenced by the airflow of the air conditioner in the front of the classroom and became concentrated in the corner next to the closed front door. Furthermore, the air curtain effect produced by the air conditioner at the back of the classroom blocked the chalk dust from the front of the classroom and reduced the effects of chalk dust on students seated in that area. After simultaneously turning on the air conditioners and ceiling fans with the doors closed (Fig. 5(c)), the air conditioner carried the chalk dust particles toward the front door. However, the airflow from the ceiling fans confined the dust to the right side of the chalkboard. It also negated the air curtain effect produced by the air conditioner at the back of the classroom. Consequently, the chalk dust proximal to the chalkboard could affect the air quality at the back of the classroom.

With only the front and back doors open (Fig. 5(d)), the chalk dust was primarily distributed in the proximity of the chalkboard because of a lack of enough indoor and outdoor air circulation. However, ceiling fans were used to assist the dilution and dispersion of the chalk dust proximal to the chalkboard (Fig. 5(e)). The mass concentration distribution of $PM_{2.5}$ dust particles in the classroom was similar to that of the PM_{10} particles. The results that chalk dust was primarily located in the proximity of the chalkboard demonstrated that teachers experienced the greatest exposure to chalk dust particles during class. Students (particularly those seated nearby) were also exposed to chalk dust from the chalkboard. According to the results of particle mass concentration distributions and Table 2, teachers and students are recommended to protect themselves from high dust mass concentration exposure by wearing face masks which can filter coarse particles and by sitting started from the front second row chairs during chalk teaching, respectively.

Classroom Indoor Air Quality

Table 3 shows the average mass concentration of PM_{10} and $PM_{2.5}$ observed at 26 locations in the classroom before and during the experiment. The measured 1 h average PM_{10} concentrations in various ventilation modes (excepting that the mode with doors open and ceiling fans on) exceeded the limits stated in the indoor air quality standards of the Taiwan Environmental Protection Administration (Taiwan EPA) (PM_{10}: 75 µg m^{-3} per 24 h) (Taiwan EPA, 2012). Although the 1 h average results were not suitable for direct comparisons with the 24 h PM_{10} standard in Taiwan, they suggested that indoor PM_{10} could potentially increase because of lacking appropriate indoor-outdoor air circulation in a closed classroom. Indoor PM_{10} concentrations considerably increased after turning on the air conditioner, ceiling fans, or both. This was because the consequent airflow delays the settling of chalk dust particles, causing the dust particles to remain suspended longer than typical particles with the only gravitational deposition. With the doors open, the concentration of PM_{10} was approximately 90 µg m^{-3} because of the slight exchange between indoor and outdoor air. The presence of vigorous air exchange diluted and markedly reduced indoor PM_{10} concentration to approximately 60 µg m^{-3} with doors open and the ceiling fans on; this mode was speculated to have the highest air exchange rate (AER) among the five ventilation modes studied in this study. The effect of the mechanism by discharging to outdoor through ventilation was obviously higher than that of by gravitational deposition. Therefore, indoor PM_{10} concentration can be apparently reduced by increasing AER through activing mechanical or natural ventilation system. Guo *et al.* (2008) observed a similar phenomenon, noting that the indoor particle number concentrations decreased as the AER increased. Regarding the three ventilation modes with air conditioners off, the $PM_{2.5}$ concentrations in the classroom after dispersion were below the standard value ($PM_{2.5}$: 35 µg m^{-3}-24 h) set by the Taiwan EPA. Because the small particles resuspended, an increased $PM_{2.5}$ concentration was observed only when the mechanical ventilation systems were operating in a closed classroom.

Table 3 shows that the $PM_{2.5}/PM_{10}$ ratio decreased from 33.36% before the experiment (initial stage) to between 12.43% and 23.26% during the experiment. The results indicate that coarse particles ($PM_{2.5–10}$) are the primary elements that increase the particle mass concentration of dust when chalk is used during teaching. The relation between



(a) Doors closed

(b) Doors closed + air-conditioning

(c) Doors closed + air-conditioning + ceiling fans

(d) Doors opened

(e) Doors opened + ceiling fans

Fig. 5. PM_{10} mass concentration distributions of chalk dust in the classroom at different ventilation modes.

Table 3. Average mass concentrations, $PM_{2.5}/PM_{10}$ and I/O ratio in the classroom.

Dust N = 450	background	doors closed	doors closed + air conditioning	doors closed + air conditioning + ceiling fans	doors opened	doors opened + ceiling fans
PM_{10} (μg m^{-3})	28.21 (10.46) [a]	138.66 (139.80)	220.72 (237.84)	211.20 (185.64)	89.80 (148.28)	61.60 (60.95)
$PM_{2.5}$ (μg m^{-3})	8.89 (1.97)	11.02 (5.11)	43.95 (45.83)	35.58 (31.67)	14.25 (9.21)	9.88 (4.18)
$PM_{2.5}/PM_{10}$ (%)	33.36 (7.67)	12.43 (6.71)	20.21 (2.80)	15.47 (8.97)	23.26 (8.58)	16.01 (0.99)
PM_{10} I/O Ratio	1.01 (0.39)	3.48 (2.45)	4.23 (0.59)	2.70 (1.38)	2.41 (1.50)	3.28 (1.29)
$PM_{2.5}$ I/O Ratio	0.29 (0.08)	0.28 (0.05)	0.87 (0.36)	0.78 (0.46)	0.38 (0.10)	0.35 (0.07)

[a] ( ): standard deviation.

indoor and outdoor particle concentrations is often expressed as the indoor/outdoor (I/O) ratio (Chen and Zhao, 2011). The I/O ratios of PM_{10} in the five tested ventilation modes were considerably higher than those during the initial stage. Compared with other ventilation modes, the I/O ratios of PM_{10} were lower with doors open since the indoor PM_{10} concentration was affected by the penetration of outdoor air. Regardless of the ventilation method, the I/O ratios of PM_{10} were greater than 1, indicating that chalk dust substantially contributed to indoor particle concentrations. Antidust chalks were the primary source of PM_{10} in the classroom. The I/O ratios of $PM_{2.5}$ during the class in the initial stage and five ventilation conditions were lower than 1. Because mechanical ventilation systems prompted the resuspension of fine chalk dust particles, the I/O ratio of $PM_{2.5}$ obviously increased. The PM_{10} and $PM_{2.5}$ concentrations increased significantly when chalks were used during the experiment, compared with the initial stage. Thus, chalk dust particles affect indoor air quality and are the primary source of indoor aerosols in the classroom. Other studies have reported similar findings (Fromme *et al.*, 2008; Stranger *et al.*, 2008; Jai Devi *et al.*, 2009).

According to the results of PM_{10} and $PM_{2.5}$ in the classroom under different ventilation modes, mechanical ventilation can slow down aerosol gravitational deposition and increase their retention time in the air because of turbulent airflow. However, chalk particles can also be enhanced to discharge to outdoor by increasing AER through opening doors. Therefore, the best ventilation mode to reduce dust exposure for teachers and students during chalk teaching was to keep doors open and ceiling fans on. Furthermore, past studies (Holmberg *et al.*, 2003; Braniš *et al.*, 2005; Fromme *et al.*, 2007; Lin and Peng, 2010; Alves *et al.*, 2013; Alves *et al.*, 2014) have indicated that human activity can resuspend sediment particles and increase the indoor mass concentrations of coarse particles. Therefore, frequent cleaning during non lecture time is recommended to reduce respension of settled chalk dusts.

CONCLUSIONS

Scarce studies have evaluated the airborne chalk dust particles resulting from the use of chalk in classrooms. This study is the first to explore mass concentrations and characteristics of chalk aerosols generated while chalk being used for teaching under five test ventilation modes. Detailed dust exposure information and chalk dust size distributions in the nanometer to micrometer ranges were measured in a classroom under various ventilation conditions. The results demonstrate that antidust chalk can generate substantial quantities of chalk dust particles in the proximity of the chalkboard during chalk teaching. The largest quantity of chalk dust was produced when the chalk was wiped off from the blackboard with a chalk duster. The findings also indicate that ventilation affects chalk dust distribution in the classroom. A high concentration of chalk dust was primarily distributed in the proximity of the chalkboard. Furthermore, chalk dust can substantially increase the PM_{10} and $PM_{2.5}$ concentration levels, causing deterioration of indoor air quality. Although using chalkboards in the classroom is a traditional and effective teaching method, chalk generates a large amount of airborne dust, and particularly submicrometer dust and nanoparticles that can penetrate into the respiratory system. Among the five ventilation modes, doors open and ceiling fans on are the best ventilation mode to reduce chalk dust particles accumulated in the classroom while chalk teaching. Wearing face masks for teachers and keeping an appropriate distance from chalkboard for students during chalk teaching is highly recommended. Because using chalk can increase the mass concentration of dust particles in the proximity of the chalkboard and deteriorate air quality, other teaching methods, such as slides, video, digital whiteboards, and electronic tools, may be better alternatives in the classroom. The findings of this research will be applicable to other classrooms with similar indoor settings and ventilation systems.

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