ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 35 no. 4 pp. 45 - 53 2009

PL ISSN 0324-8461

THE INFLUENCE OF AIR-CONDITIONING SYSTEM AND PRESENCE OF STUDENTS ON THE AEROSOL CONCENTRATION IN THE AUDITORIUM

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Keywords: Indoor generated aerosols, air conditioning system, aerosol number concentration, students' health, auditorium.

Abstract: The indoor aerosols that are, among others, generated by air-conditioning systems are especially significant in school facilities. The measurements carried out in the new, air-conditioned auditorium have shown that the aerosol concentrations are strongly dependent on the operation of the air-conditioning system and the presence of students. The aerosol concentration was approximately 5 times higher when the air-conditioning (AC) system was switched on. An increased air movement inside the auditorium and the connected with it resuspention of the particles settled on the indoor surfaces could be responsible for this fact. It could also result from the ineffective operation of the AC filters. The presence of students in the auditorium caused an increase of the coarse aerosol particles irrespectively of the AC system operation. The results of aerosol particle monitoring should be taken into consideration while controlling the AC processes in order to ensure the desired indoor air quality in this type of facilities.

INTRODUCTION

Until the late 1990s aerosols of ambient origin were assumed as the main source of indoor air contamination. However, it has been observed that in many cases the concentrations of indoor generated aerosols are significantly higher than those of infiltrated ambient aerosols [1, 7]. The main sources of indoor generated aerosols are building materials, furnishings, equipment and room occupants [2, 9, 11]. Additionally, when buildings are air-conditioned (AC) the AC systems could also introduce aerosols to the indoor air [8]. The presence of aerosol particles in the indoor air is not desired and is a reason for many nuisances. The naturally occurring gravitational or electrostatic deposition of these particles may in many cases lead to the deterioration of the indoor surfaces and appliances. Aerosol particles present in the indoor air have been also recognized as a significant cause of health problems. It is well established that various respiratory symptoms and diseases are associated with exposures to these particulates [5, 18, 20]. The issue of indoor aerosols has become especially important in school buildings. This is related to the fact that students spend a considerable portion of their time in school facilities and these aerosols may adversely affect their health as well as their academic performance [3, 13, 14]. Particular attention should be paid to school buildings with AC systems, due to the fact that those systems may be responsible for generating additional aerosols [5, 8].

Until very recently most indoor aerosol studies were carried out either for naturally or mechanically ventilated buildings. Ventilation systems were examined to establish how they protect the indoor environment against outdoor particles, or how indoor-generated particles are distributed by these systems. This paper deals with the influence of the AC system operation on the aerosol particle concentration in an occupied and an unoccupied school auditorium. According to the literature, only a few researches have been conducted on the aerosol particle concentrations in air-conditioned classrooms, however, the occupancy of the classrooms has not particularly been taken into account [5, 8, 10]. It seems important to consider the varying classroom occupancy during the measurements as it may have a significant impact on the indoor conditions and the obtained results.

MATERIALS AND METHODS

The particle number concentration measurements were performed in a new air-conditioned auditorium at the Lublin University of Technology (LUT). The auditorium with seats for 186 people (Fig. 1) is located on the first floor of the LUT building and has a volume of approximately 1200 m^3 (average dimensions – 20 x 15 x 4 m). It has 8 double pane air tight windows (2.6 x 3 m) and a carpeted floor. The auditorium was ventilated with a total supply of 1.6 m^3/s of conditioned outdoor air (50%) and recirculated air (50%). The air conditioning system provided mechanical ventilation, cooling or heating and humidity control inside the auditorium and comprised of a supply-exhaust air handling unit with a rotary heat exchanger, a heat pump, a water heater and a humidifier.

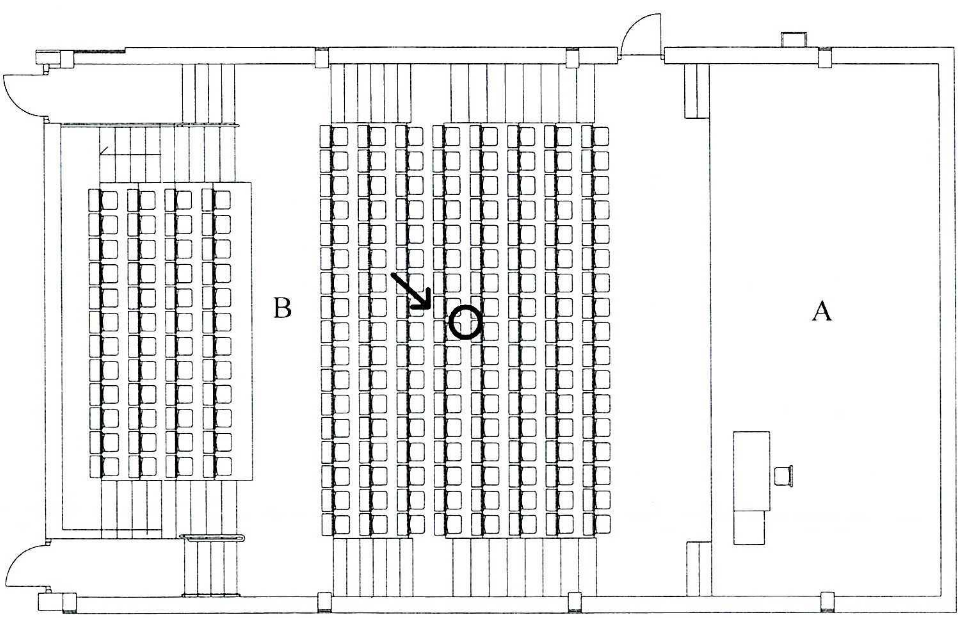

Fig. 1. The scheme of the auditorium with the measurement point
A – scene, B – occupation zone

The auditorium was irregularly occupied from Monday to Friday, usually from 8 a.m. to 8 p.m. according to the schedule of the LUT courses. After each 45 or 90-minute lecture there were 15-minute breaks during which the students moved in and out of the room.

Sizes and concentrations of aerosol particles were determined in the middle of the occupied zone by means of a laser particle counter ROYCO 243A with iso-Diluter D50 (Pacific Scientific Instruments, USA). The samples were collected at 60-second intervals with a 15-minute delay time. The counter categorized the collected particles into four size ranges: 0.3–0.5, 0.5–5, 5–10 and >10 μm. Signal to Noise Ratio was 1.6:1 at maximum sensitivity (0.3 μm). The air temperature and relative humidity were measured using the thermohigrometer LB-701 (LAB-EL, Poland). The inaccuracy of the measured parameters was 0.2°C and 2% respectively.

The experiments were carried out during the lectures for the following conditions established in the auditorium:

- 60 students were present in the auditorium and the AC system was either switched on or switched off,
- 45 or 90 students were present in the auditorium and the AC system was switched on,
- 44 or 84 students were present in the auditorium and the AC system was switched off.

The number of students present in the auditorium varied (max. 90) and the AC system was switched on.

Detailed information on the individual measurement conditions is specified with reported results. The research was conducted for several weeks in the springtime 2008 (March – April).

RESULTS AND DISCUSSION

In order to ascertain how the switched on/off AC system in the auditorium influences the aerosol particle concentrations, the results of measurements from two subsequent days when the AC system was either switched on or off for the entire day were analyzed. During those days the lectures in the auditorium started at 8:15 a.m. and lasted until 8:00 p.m. Table 1 presents the basic statistical information about the measured aerosol number concentrations in both days.

Table 1. Twelve-hour data* for the measured aerosol particle number concentrations, in [particles/m^3]

Particle size [μm]	AC off	AC on	AC on/off means' ratio
0.3–0.5	(1.92/1.77 (1.20-2.78)) × 10^7	(6.47/4.99 (3.58-11.71)) × 10^7	3.37
0.5–5	(8.53/7.37 (5.08-13.25)) × 10^6	(3.12/2.27 (1.38-6.39)) × 10^7	3.66
5–10	(2.65/2.83 (0-8.65)) × 10^4	(1.63/1.50 (0.11-3.14)) × 10^5	6.15
> 10	(3.18/1.77 (0-10.59)) × 10^3	(1.38/1.24 (0-3.18)) × 10^4	4.34

* – arithmetic mean/median (range)

The graphs a and b in Figure 2 illustrate the mean concentrations of the measured particles during the lectures which took place between 12:15 p.m. and 2:00 p.m. with 60 students present in the auditorium. The bars denote the standard error of the mean particle concentration values. It follows from the graphs that the concentration of all the measured aerosol fractions was about five times higher when the AC system was switched on. Many reasons may be responsible for this fact. However, due to the fact that the same number of students participated in the lectures, their influence on the measurement results may be excluded. The changes of the indoor air thermal parameters could also be of minor importance. The mean temperature and relative humidity amounted to 23.5°C and 48% when the AC system was switched off and respectively 20°C and 40% when the system was switched on. A significant influence of the changes of outdoor aerosol infiltration into the auditorium may also be excluded. The windows during the measurement periods in question were tightly closed. The outdoor air temperature and relative humidity amounted to respectively approximately 15°C and 50% during both measurement periods. The observed higher concentration of aerosol particles in the auditorium when the AC system was switched on may result from the increased indoor air movement and the connected with it increased resuspension of the particles already deposited on the indoor surfaces, which may be confirmed by the findings of Jamriska *et al.* [12]. Another possible explanation might be that the AC system filters may insufficiently remove aerosols from the air inflowing to the auditorium, as it was stated by Fisk *et al.* [7].

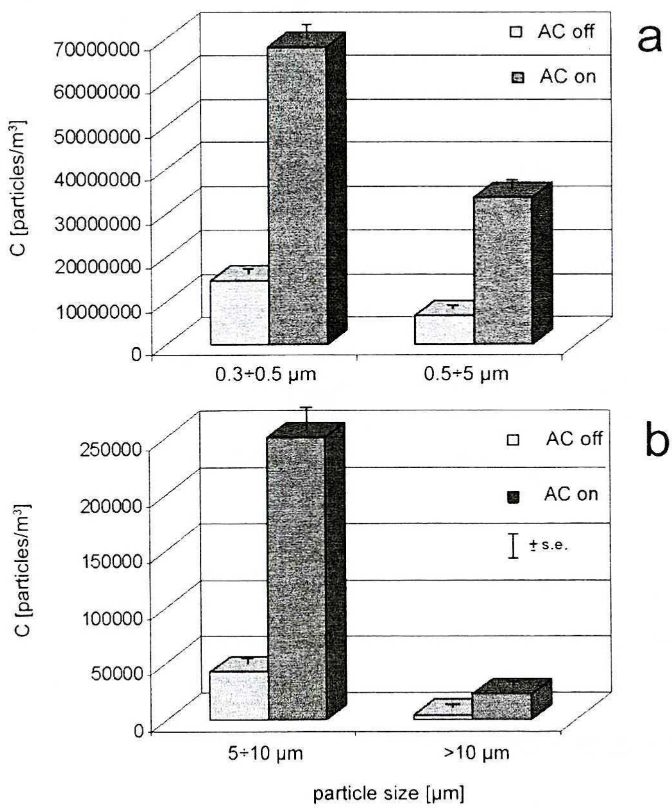

Fig. 2. The mean concentration of aerosol particles during the lectures in the auditorium with 60 students present and with a – switched off AC system (T = 23.5°C, RH = 48%), b – switched on AC system (T = 20°C, RH = 40%)

Graphs in Figure 3 present the concentrations of coarse aerosol particles (5–10 μm and > 10 μm) in the air-conditioned auditorium directly before the 2-hour lectures, during the lectures and just after their end. Graph a presents the concentrations of the aforementioned aerosols when the lecture took place from 10:15 a.m. to 12:00 p.m. and there were 45 students in the auditorium. Graph b refers to the situation in which the lecture lasted from 5:15 p.m. to 6:45 p.m. and there were 90 students in the auditorium. While comparing graphs a and b one can notice similar dependencies between the aerosol particle concentration and the duration of the lectures. The difference consists in the fact that aerosol concentrations are almost three times higher when 90 students are present in the auditorium than when 45 students attend the lecture. The coarse aerosol particle concentration changes inside the auditorium may result from the varied activity of the students. Higher aerosol particle concentration was noted both immediately upon the entrance of the students and after they left the auditorium. During the course of the lectures the concentration of these particles decreased, therefore one can assume that a part of the aerosol particles was removed by the AC system or settled on the indoor surfaces [7, 10, 12]. The accumulation of a certain amount of these particles in the students' respiratory

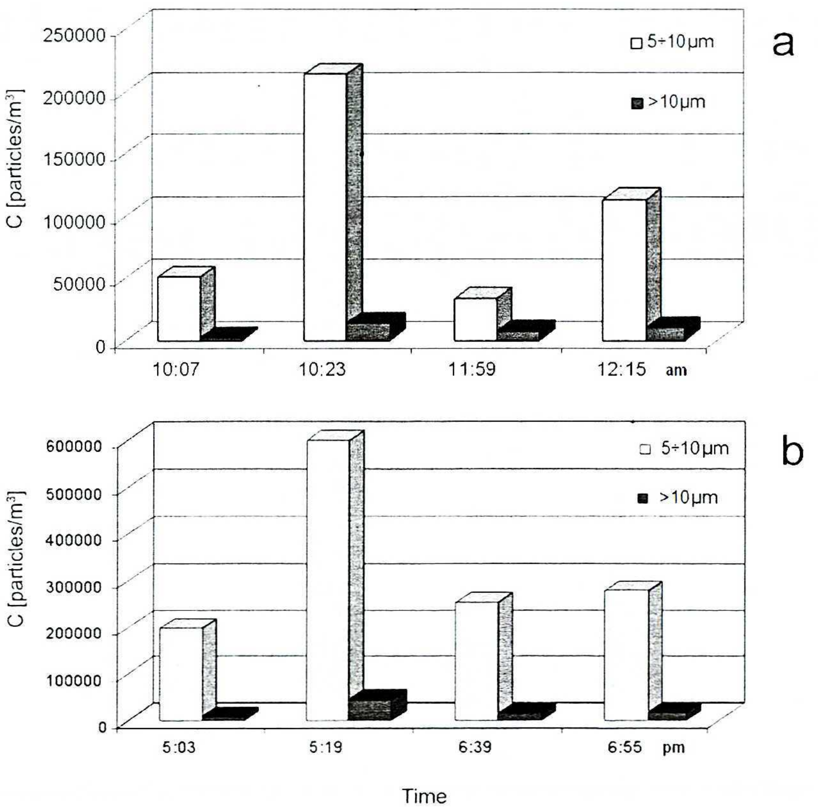

Fig. 3. The concentration of coarse aerosol particles before, during and after the 2-hour lectures with a switched on AC system, a – lecture from 10:15 a.m. to 12:00 a.m., 45 students, b – lecture from 5:15 p.m. to 6:45 p.m., 90 students

tract cannot be ruled out as well [18–20]. It has to be emphasized that the measured values of the particle concentration at the end of the lectures were lower than at the beginning. The observed differences reached more than 50%. As already mentioned, the auditorium ventilation may be responsible for this fact as it may have caused the removal of a certain amount of coarse aerosol particles and the decrease of their concentration in the indoor air. It is also possible that a certain amount of these particles was deposited on indoor surfaces or accumulated in the students' respiratory tract.

The next step of investigation was to eliminate the influence of the AC system on the aerosol particle concentration. In order to do so the changes of the coarse aerosol particle concentration at the beginning and at the end of the two consecutive 45-minute lectures in the auditorium with a switched off AC system were analyzed. Graphs a and b in Figure 4 show the concentration changes of these particles when, respectively, 84 and 44 students were present in the auditorium. The graphs indicate that the coarse aerosol particle concentration was decisively lower at the end of the lectures. This reduction is mainly caused by the deposition of these particles on indoor surfaces during the lectures. An almost double decrease of the number of students during the second lecture (from 11:15 a.m. to 12:00 a.m.) did not translate into a double reduction of the aerosol particle concentration. The reason for this may be an insufficient amount of time (a 15-minute break) between

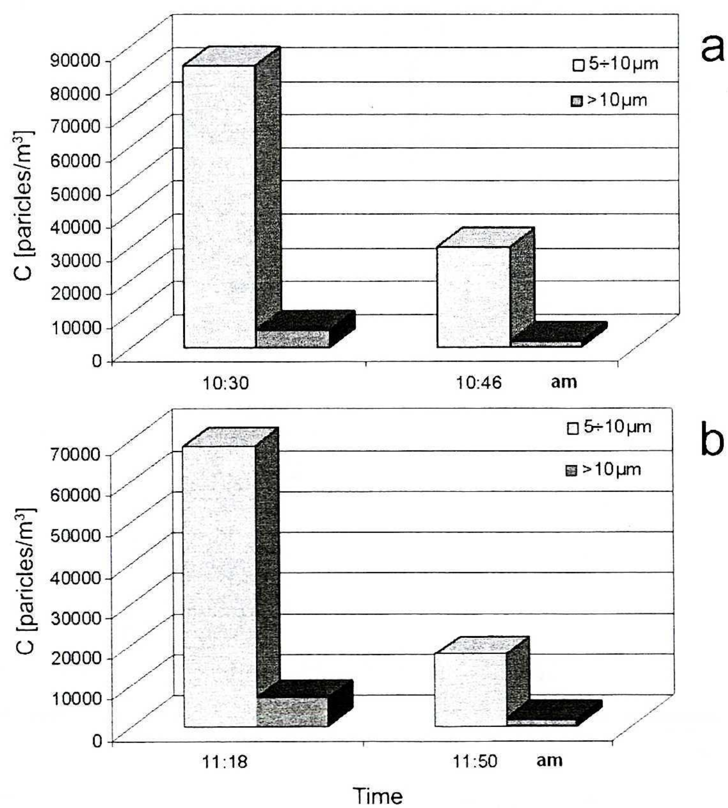

Fig. 4. The concentration of coarse aerosol particles during the lectures with a switched off AC system, a – lecture from 10:15 a.m. to 11:00 a.m., 84 students, b – lecture from 11:15 a.m. to 12:00 a.m., 44 students

the lectures for an effective particle deposition. A greater activity of the smaller group of students as well as their different seat arrangement cannot also be ruled out [4, 6].

Diagrams a and b in Figure 5 present the changes of the coarse aerosol particle concentration with respect to the number of students present in the auditorium. These dependencies indicate that the mean concentrations of these particles increase together with the increase of the number of students. The bars denote the standard deviation of the measured particle concentrations. The values of the correlation coefficients amount to about 0.42, p = 0.05. The instability of the measurement conditions could be responsible for the considerable scattering of the experimental points around the best fit lines. For example, the indoor air thermal parameters as well as the students' seating arrangement inside the auditorium varied during the individual measurement periods. A higher increase of the indoor air temperature and relative humidity was reported when more students were present in the room which resulted, among others, in a higher ventilation rate and therefore a more effective aerosol removal from the auditorium [7, 8]. One could also observe that when fewer students were present they usually took seats at the back of the auditorium, closer to the measurement point. In such cases a higher percentage of students was seated near the measurement point comparing to the situation when more students were present and they were more equally spread around the whole auditorium.

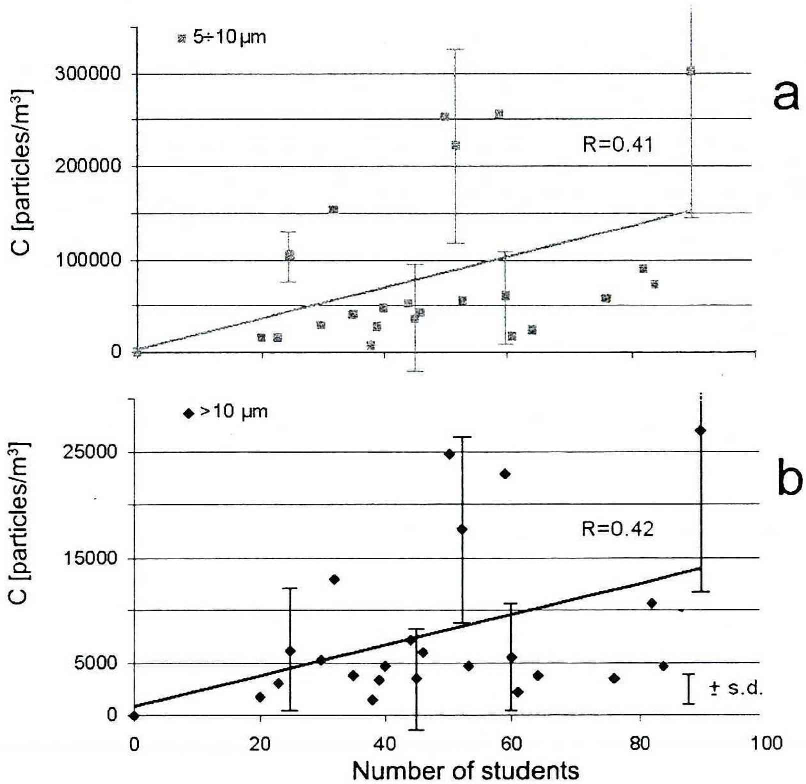

Fig. 5. The mean concentration of coarse aerosol particles during the lectures vs. the number of students, a – for particle size fraction 5–10 μm, b – for particle size fraction >10 μm

Summarizing, the above presented measurement results show the substantial influence of the operating AC system and the presence of students in the auditorium on the indoor aerosol concentrations. The results of a more detailed research could help to improve the indoor environment conditions in the investigated auditorium and other school facilities with AC systems. They could be used for effective control of AC processes connected with e.g. the application of the so-called adaptive demand-controlled ventilation [15–17], which could respond to the actual occupation and aerosol concentration changes. This would ensure constantly low aerosol particle concentrations which would positively influence the indoor air quality in this type of facilities.

CONCLUSIONS

The results of the performed measurements allow to conclude the following:

1. There is a high variability of aerosol particle concentrations inside the auditorium which is mainly caused by the AC system and the presence of the students.
2. The aerosol particle concentrations are higher when the AC system is switched on. This may be caused by the increased air movement in the auditorium and consequently the resuspension of the settled particles.
3. The concentrations of coarse aerosol particles increase with the increase of the number of students inside the auditorium irrespectively of the operation of the AC system.
4. The presented results of this preliminary study may be of universal significance in terms of monitoring and control processes carried out in order to improve the indoor air quality in school facilities with AC systems.

Acknowledgements

This study has been supported by the scientific grant No. 4955/B/T02/2008/34 from the Ministry of Science and Higher Education, Poland.

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Received: April 7, 2009; accepted: August 2, 2009.

WPŁYW KLIMATYZACJI I OBECNOŚCI STUDENTÓW NA KONCENTRACJĘ AEROZOLI W AULI

Aerozole wewnątrz pomieszczeń generowane między innymi przez systemy klimatyzacyjne są szczególnie istotne w szkołach. Pomiary prowadzone w nowym, klimatyzowanym audytorium pokazały, że koncentracja aerozoli w bardzo dużym stopniu zależy od działania klimatyzacji i obecności studentów. Uzyskane wyniki pokazały, że w klimatyzowanej auli koncentracja aerozoli była około pięciokrotnie wyższa w porównaniu z sytuacją, gdy aula nie była klimatyzowana. Wynikać to może z faktu zwiększonej cyrkulacji powietrza i związanej z tym resuspensji cząstek aerozolowych osiadłych na powierzchniach wewnętrznych. Może to również wskazywać na nieefektywność działania systemu filtrującego powietrze. Obecność studentów w auli powodowała wzrost koncentracji grubych cząstek aerozolowych niezależnie od działania systemu klimatyzacyjnego. Dla zapewnienia pożądanej jakości powietrza wewnętrznego wyniki monitoringu cząstek aerozolowych powinny być brane pod uwagę przy sterowaniu procesami klimatyzacji w tego typu pomieszczeniach.