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Variation in indoor particle number and $PM_{2.5}$ concentrations in a radio station surrounded by busy roads before and after an upgrade of the HVAC system

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Abstract

Indoor particle number and $PM_{2.5}$ concentrations were investigated in a radio station surrounded by busy roads. Two extensive field measurement campaigns were conducted to determine the critical parameters affecting indoor air quality. The results indicated that indoor particle number and $PM_{2.5}$ concentrations were governed by outdoor air, and were significantly affected by the location of air intake and design of HVAC system. Prior to the upgrade of the HVAC system and relocation of the air intake, the indoor median particle number concentration was 7.4×10^3 particles/cm^3 and the median $PM_{2.5}$ concentration was 7 μg/m^3. After the relocation of air intake and the redesign of the HVAC system, the indoor particle number concentration was between 2.3×10^3 and 3.4×10^3 particles/cm^3, with a median value of 2.7×10^3 particles/cm^3, and the indoor $PM_{2.5}$ concentration was in the range of 3–5 μg/m^3, with a median value of 4 μg/m^3. By relocating the air intake of the HVAC, the outdoor particle number and $PM_{2.5}$ concentrations near the air intake were reduced by 35% and 55%, respectively. In addition, with the relocation of air intake and the redesign of the HVAC system, the particle number penetration rate was reduced from 42% to 14%, and the overall filtration efficiency of the HVAC system (relocation of air intake, pre-filter, AHU and particle losses in the air duct) increased from 58% to 86%. For $PM_{2.5}$, the penetration rate after the upgrade was approximately 18% and the overall filtration efficiency was 82%. This study demonstrates that by using a comprehensive approach, including the assessment of outdoor conditions and characterisation of ventilation and filtration parameters, satisfactory indoor air quality can be achieved, even for those indoor environments facing challenging outdoor air conditions.

Keywords: Particle number concentration; $PM_{2.5}$; HVAC; AHU; Penetration rate; Filtration efficiency

1. Introduction

In most urban environments, motor vehicle emissions comprising of a myriad of gaseous and solid or liquid particles constitute the most significant contribution to the urban air pollution. Health effects of this pollution have been known for decades, with a more recent focus on the impacts of particles in the ultrafine size range (<0.1 μm). However, the detrimental impacts of airborne particles are associated not only with health effects but also with adverse effect on materials and instrumentation as a result of surface contamination. The problem may become particularly serious in buildings housing sensitive electronic equipment, such as in the telecommunication and broadcasting industries, and also in office buildings, where computers, servers and other hardware are located. Deposition of particles on the surface of electronic equipment and exposed circuits may lead to a failure of the electronic systems, resulting in a substantial economical cost. For example, in the USA, the cost associated with equipment failure due to particle pollution indoors has been estimated to be of the order of hundreds of million dollars annually [1]. Commercial buildings in an urban environment are often located near busy roads or traffic intersections, which compromises the indoor air quality

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(IAQ) in the buildings and, in turn not only health of its occupants but also the integrity of the equipment.

There are currently no IAQ standards in Australia in relation to particulate pollution indoors (similar situation also exists in other countries), and only limited information is available on the parameters governing particle pollution levels indoors particularly, in mechanically ventilated buildings, including the magnitude of the impact of the outdoor air (OA), the effect of air intakes' location, heating, ventilation and air conditioning (HVAC) effect on particle transport and removal, and indoor/outdoor relationship.

The study reported in this paper investigated the factors affecting IAQ in a building surrounded by busy roads and housing several broadcasting radio stations in the Central Business District (CBD) of an Australian capital city. The study was motivated by complaints about black soot contamination of indoor surfaces and a higher than usual failure rate of the electronic equipment in the radio stations. Two consecutive monitoring campaigns, measuring particle characteristics including particle number (PM) concentration and $PM_{2.5}$, were conducted outside and inside the building with the following objectives: (i) identification of airborne contaminants' sources and pathways of contamination; (ii) characterisation of the HVAC system performance in relation to its filtration efficiency; and (iii) assessment of the HVAC system performance in improving IAQ after an upgrade.

2. Experimental

2.1. Building location, traffic and HVAC parameters

The radio station building is located in the centre of the city and is surrounded by several busy roads carrying outbound, inbound and local traffic. There are several traffic lights within approximately 50 m of the building. The HVAC air intake was located on the north side of the building at the 1st level, approximately 10 m above, and 3 m away from a busy road. In the process of the upgrade, the air intake was relocated to the roof of the building, at a distance of approximately 70 m from the nearest busy road. The traffic flow rate during the daytime is moderate to heavy, with a significant increase during the peak hours, between 07:00–09:00 in the morning and 16:00–18:00 in the afternoon. Detailed traffic flow rate and speciation patterns for the roads near the sampling location were reported in another study [2]. The building is equipped with a HVAC system which operated at a constant airflow rate during the day and night. In the plant room, 10% OA, which is ducted directly into the plant room using an inline fan, is mixed with 90% return air (RA), which is delivered from indoors through an open plenum (ceiling space), and passed through an air handling unit (AHU), consisting of a battery of dry media filters, cooling coils and an air fan. RA mixes with OA in the plant room, creating mixed air (MA), which is then drawn into the AHU by a fan. Once the air has passed through the AHU filters, it becomes supply air (SA). The SA is delivered through a ducting system into rooms 1, 2 and 3, and once inside these rooms the air is then termed indoor air (IA).

Room 1 housed the OA air intake, room 2 was a storage room, room 3 was a media control room housing electronic equipment and room 4 was an office. Before the upgrade, the HVAC system in the building did not have a pre-filter located at the OA intake, and the AHU located in the plant room contained a low-efficiency air filter (class G4 Australian Standard). After the upgrade, the air intake was equipped with both air pre-filters (G4 class) and secondary medium efficiency air filters (class F8). Fig. 1 presents a schematic diagram of the rooms and the HVAC system prior to the upgrade.

2.2. Instrumentation and parameters measured

PM concentration and size distribution in the range of 0.017–0.600 μm were measured by a scanning mobility particle sizer (SMPS; TSI model 3071A with condensation particle counters (CPC); TSI models 3010 and 3022). SMPS operates on a principle of particle classification by an electrostatic classifier, according to their electrical mobility, which is a function of their size, followed by particle counting by the CPC, which utilises laser light scattering. The whole process is automated and software controlled. The size distribution scanning time was set to 2 min.

The total PN concentration in the size range from 0.02 to 1 μm was measured by a TSI model 8525 P-Trak ultrafine particle counter (TSI Incorporated, St. Paul, MN, USA), and an aerodynamic particle sizer (APS) (TSI model 3320) was used for the measurement of PN concentrations and size distributions in the size range 0.7–20 μm.

Approximation of $PM_{2.5}$ (mass concentration of particles with aerodynamic diameters smaller than 2.5 μm) was measured by a laser photometer (DustTrak TSI model 8520). The time resolution was set to 1 s. DustTrak is an optical photometer measuring the amount of scattered light, which is proportional to the volume concentration of the aerosol. In order to obtain results closer to gravimetric $PM_{2.5}$ values, an experiment was conducted under laboratory conditions to compare the DustTrak readings with the readings of a TEOM (50 °C R &P 1400a with a URG $PM_{2.5}$ cyclone inlet) [3,4]. The calibration equation obtained was $PM_{2.5(TEOM)} = 0.394\ PM_{2.5(DustTrak)} + 4.450$ ($R^2 = 0.83$), and this equation was used in this work. All the instruments were calibrated in the laboratory and compared before the measurements.

2.3. Air sampling

Two field sampling runs were conducted at the site during weekdays that had similar meteorological conditions, traffic volumes and indoor activities. The first run was from 07:00 on 18 November to 19:00 on 19 November 2003,