Environmental Research 126 (2013) 215–220

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Reports from the Field

Particle exposure in a Baroque church during Sunday Masses

Bernard Polednik *

Faculty of Environmental Engineering, Lublin University of Technology, ul. Nadbystrzycka 40B, 20-618 Lublin, Poland

ARTICLE INFO

Article history:
Received 10 March 2013
Received in revised form
26 July 2013
Accepted 29 July 2013
Available online 21 August 2013

Keywords:
Particle concentration
Church
Sunday Masses
Incense burning
Particle exposure

ABSTRACT

Particle concentrations were measured in a Baroque church during five Sunday Masses. The highest particle number and mass concentrations were observed when both candles and the incense were burned. They were respectively 16.8 and 14.3 times higher than outdoors for submicron particles. The exposure to particles experienced by the churchgoers, especially priests and church workers who participated in several Masses on that day, was considerably higher than the exposure experienced at the same time outdoors.

1. Introduction

Combustion processes such as burning candles and the incense are the main source of ultrafine and fine particles in churches (Loupa et al., 2010; Chuang et al., 2012). Such particles may have an adverse effect on the health of the Mass attendees, especially on elderly people who often spend many hours at church (Ho et al., 2005; Kennedy, 2007). What is more, the generated particles also contribute to the deterioration of the works of art inside churches (Salmon et al., 2004). The harmfulness of the particles depends on their size, concentration and chemical composition as well as on the indoor thermal parameters (Pope et al., 2004). The information concerning the particle concentrations in churches and their harmfulness that has been gathered so far is incomplete. Until now only a few studies have been performed in a small number of selected churches, not representative for all architectural styles. Moreover, measurements were conducted only during individual Masses, important holidays or simulated services. On the basis of the measurements carried out in a Gothic Roman Catholic church in Germany, Weber (2006) indicated that the churchgoers' exposure to particles increased several times when the incense was burned in the church. He also stated that burning candles had a relatively minor effect on particle concentrations. The research carried out by Loupa et al. (2010) in two Byzantine Orthodox churches in Cyprus showed that the indoor particle number and mass concentrations increase significantly while the candles and the incense are burned, during the presence of visitors as well as during cleaning activities. In turn, this increase has an impact on the deterioration of the church interior, including the paintings, sculptures and other works of art. The measurements performed by de Kok et al. (2004) in a Romanesque Roman Catholic church in the Netherlands suggested that the products created as a result of the interaction between oxygen free radicals and organic substances present in candle and incense fumes may result in an increased risk of lung cancer or other pulmonary diseases. Chuang et al. (2012) evaluated the risks associated with the combustion particles in an Anglican church in the UK. On the basis of the estimated emissions and the determined oxidative DNA damage caused by the particles generated in the church, the authors stated that the exposure to significant amounts of incense-derived particles can pose an even higher risk than the exposure to tobacco particles.

Burning candles and incense during Masses and other religious services in Catholic churches in Poland is a common practice. Roman Catholicism is a dominant religion in Poland. Ninety-five percent of the population is Roman Catholic (Roman Catholicism in Poland (2012). On average, 18.3 million people participate in Sunday Masses. This number increases to even 28–33 million during major holidays such as Easter and Christmas. Several candles are usually burned at the altars during regular Masses. However, there are also Masses at which the incense is burned and the churchgoers hold lit candles.

The aim of the present study is to report the particle mass and number concentrations and the exposure of the churchgoers in a Baroque Roman Catholic church in eastern Poland on an ordinary Sunday. Five Masses were held on that day. Candles were burned at each Mass, and there was one Mass with the additional burning of the incense. The study also indicates the significance of the

* Fax: +48 81 538 19 97.
E-mail address: b.polednik@wis.pol.lublin.pl

0013-9351/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.envres.2013.07.009

break duration between the Masses and its impact on the particle concentrations as well as the exposure of the churchgoers, the priests and other church workers who participate in several Masses during one day.

2. Materials and methods

2.1. Measurement site

The measurements of the particle mass and number concentrations were conducted in the St. Nicolas Baroque Roman Catholic church in Urzedow (50°59′N, 22°9′E) which is located about 50 km from Lublin, eastern Poland. The parish has 4507 members. The vicinity of the church is suburban with minor vehicle traffic. The monitored three-nave church is made of brick and was built between 1755 and 1784. The church is characterized by all the typical features of the Baroque architecture. It has six stained-glass windows with the size of 1.5×1.2 m. The size of the entrance door is 4×3 m. The church has the floorage of 276 m^2, the total interior volume of approximately 3600 m^3 and the capacity for approximately 600 people. The gravitational ventilation was achieved by means of a small opening in the roof (14 m from the ground) and two small ventilation air-holes next to the entrance door. A small parking lot is located in front of the church.

2.2. Measurement instruments

The particle number concentrations were measured both inside the church and outdoors with the use of the ultrafine particle counters P-Trak model 8525 and the optical spectrometers OPS 3330 (TSI Inc., USA). P-Trak detects and counts aerosol particles with the size ranging from 0.02 to about 1 μm. OPS 3330 allows measuring the concentration and size distribution of particles within the size range from 0.3 to 10 μm in up to 16 channels. The particle mass concentrations were determined using the aerosol monitors DustTrak DRX model 8533 (TSI Inc., USA). The logging interval for the P-Trak counters which were used to measure the number concentrations of submicron particles (PN_1) was 6 min. The number concentrations of particles greater than 0.3 μm ($PN_{0.3-0.5}$, $PN_{0.5-1}$, PN_{1-2}, PN_{2-5}, PN_{5-10} and $PN_{>10}$) were measured by means of the OPS spectrometers at 1-min intervals. DustTrak monitors were used to record approximations of the mass concentrations of PM_1, $PM_{2.5}$, PM_{10}, RESP and TSP (particles with an aerodynamic diameter equal or less than 1, 2.5, 10 μm, respirable and total suspended particles, respectively) at 2-min intervals. These monitors were subject to the standard real-time size correction factor calibration. The approximations of the particle mass concentration values obtained in this study are not actual gravimetric values. For simplification purposes, all the DustTrak results discussed in this paper omit the term "approximation". All instruments were calibrated by their manufacturer before the measurements.

2.3. Indoor and outdoor measurements

Continuous measurements of the particle concentrations inside the church and outdoors were simultaneously conducted on Sunday, May 13th 2012 between 7:00 a.m. and 6:00 p.m.. During that time, five Masses were held which started at 7:30 a.m., 9:00 a.m., 11:30 a.m., 2:30 p.m., and 5:00 p.m.. The Masses lasted for 60, 45, 90, 60 and 50 min, respectively. Due to the fact that the Mass attendees came to the church on average about 10 min before the start of the Mass and left the church on average 5 min after the end of the Mass, it has been assumed that the real duration of each Mass was 15 min longer. The number of people attending the Mass differed depending on the time. The least churchgoers attended the Mass at 7:30 a.m. (80 people). The largest number of churchgoers attended the Masses at 9:00 a.m. (370 people) and 11:30 a.m. (620 people). During each Mass three candles were lit at the main altar. The incense was used during the Mass which started at 2:30 p.m. and it was burned in the main altar area for about 20 min, in the first half of the Mass.

Indoor measurements were performed by means of the instruments set up in the left altar (about 1.3 m above the floor and 6.5 m from the main altar). Outdoor measurements were performed by the instruments set up outside one of the front windows (approximately 5 m above the ground level). All church windows were closed during the sampling period. The measurement day was cloudy, without rainfall and the outdoor air temperature ranged between 16 and 19 °C.

2.4. Data analysis

A simple mass balance model presented by Evans et al. (2008) was applied to determine the time-integrated particle exposure. The amount of particles (in number of particles or μg) inhaled by the churchgoers during each Mass, which for simplicity purposes is referred to as the dose, was calculated with the use of the following formula:

$$D = B \int \frac{P}{\lambda}(1-e^{-\lambda t})dt \quad (1)$$

where B is the breathing frequency (the assumed average amounts to 12×10^3 cm^3/min—Layton (1993)), P is the particle concentration increase rate (particles (pt)/cm^3 min or μg/m^3 min), λ is the particle decrease rate constant (min^{-1}), and t is the time elapsed during the Mass (min).

The particle concentration increase rates and decrease rate constants were determined separately for each Mass. The background values that were assumed as

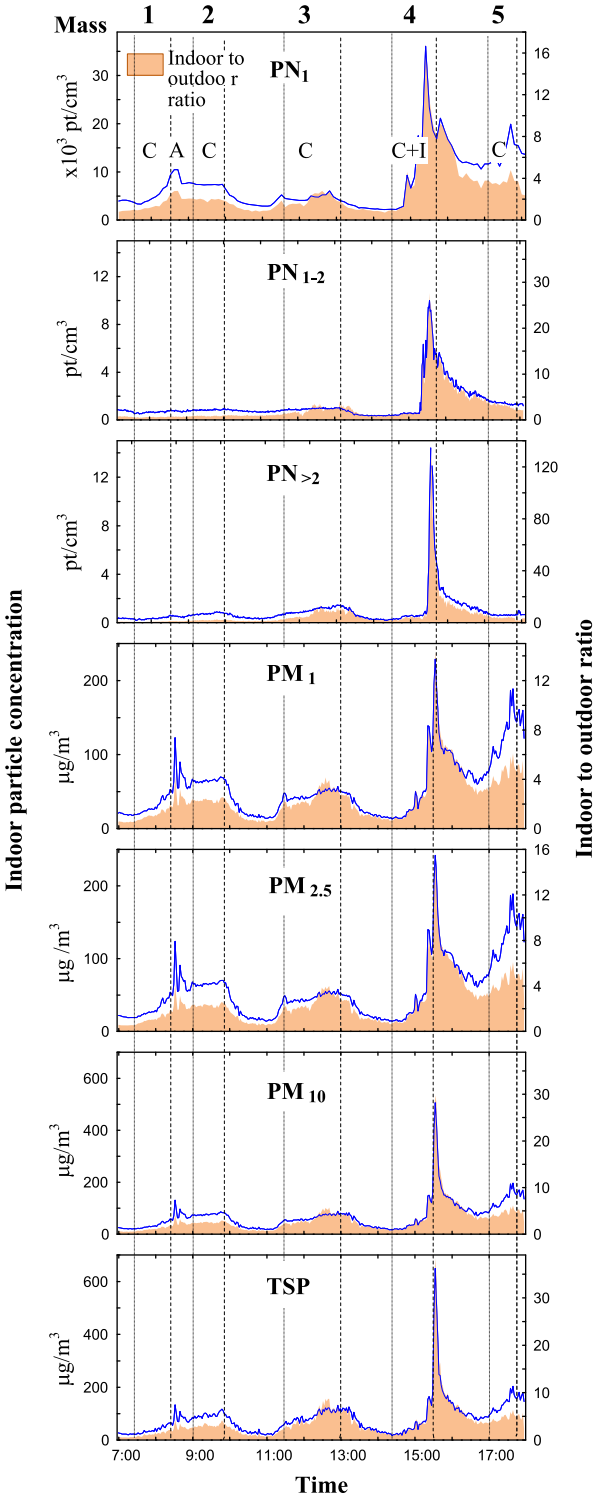

Fig. 1. Time series of the indoor particle number and mass concentrations and the indoor to outdoor particle concentration ratios during the subsequently held Sunday Masses and the breaks between the Masses. PN—particle number, PM—particle mass; the indices represent the particle size fractions, TSP—total suspended particles. C—candle burning, C+I—candle and incense burning, A—additional altar activity.