Determination of Airborne Nanoparticles in Elderly Care Centers

ARTICLE in JOURNAL OF TOXICOLOGY AND ENVIRONMENTAL HEALTH · JULY 2014
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M. Almeida-Silvaab, S. M. Almeidaa, J. F. Gomescd, P. C. Albuquerquee & H. T. Wolterbeekb

a Centro de Ciências e Tecnologias Nucleares, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
b Faculty of Applied Sciences, Department of Radiation, Radionuclides and Reactors, Section RIH (Radiation and Isotopes in Health), Technical University of Delft, Delft, The Netherlands
c ISEL-Instituto Superior de Engenharia de Lisboa, Área Departamental de Engenharia Química, Lisboa, Portugal
d IBB-Instituto de Biotecnologia e Bioengenharia, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
e ESTeSL-Escola Superior de Tecnologia da Saúde de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal

Published online: 29 Jul 2014.


To link to this article: http://dx.doi.org/10.1080/15287394.2014.910157

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DETERMINATION OF AIRBORNE NANOPARTICLES IN ELDERLY CARE CENTERS

M. Almeida-Silva, S. M. Almeida, J. F. Gomes, P. C. Albuquerque, H. T. Wolterbeek

1Centro de Ciências e Tecnologias Nucleares, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
2Faculty of Applied Sciences, Department of Radiation, Radionuclides and Reactors, Section RIH (Radiation and Isotopes in Health), Technical University of Delft, Delft, The Netherlands
3ISEL–Instituto Superior de Engenharia de Lisboa, Área Departamental de Engenharia Química, Lisboa, Portugal
4IBB–Instituto de Biotecnologia e Bioengenharia, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
5ESTeSL–Escola Superior de Tecnologia da Saúde de Lisboa, Instituto Politécnico de Lisboa, Lisboa, Portugal

According to numerous studies, airborne nanoparticles have a potential to produce serious adverse human health effects when deposited into the respiratory tract. The most important parts of the lung are the alveolar regions with their enormous surface areas and potential to transfer nanoparticles into the bloodstream. These effects may be potentiated in case of the elderly, since this population is more susceptible to air pollutants in general and more to nanoparticles than larger particles. The main goal of this investigation was to determine the exposure of institutionalized elders to nanoparticles using Nanoparticle Surface Area Monitor (NSAM) equipment to calculate the deposited surface area (DSA) of nanoparticles into elderly lungs. In total, 193 institutionalized individuals over 65 yr of age were examined in four elderly care centers (ECC). The occupancy daily pattern was achieved by applying a questionnaire, and it was concluded that these subjects spent most of their time indoors, including the bedroom and living room, the indoor microenvironments with higher prevalence of elderly occupancy. The deposited surface area ranged from 10 to 46 $\mu m^2/cm^3$. The living rooms presented significantly higher levels compared with bedrooms. Comparing PM$_{10}$ concentrations with nanoparticles deposited surface area in elderly lungs, it is conceivable that living rooms presented the highest concentration of PM$_{10}$ and were similar to the highest average DSA. The temporal distribution of DSA was also assessed. While data showed a quantitative fluctuation in values in bedrooms, high peaks were detected in living rooms.

Over the last few decades, scientific community interest in indoor air pollution has increased due to changes in lifestyle (Weschler, 2009). In fact, individuals started to spend the majority of their life inside indoor environments and consequently, experienced an increased exposure to indoor air pollutants. Reports regarding buildings with air-related problems have received increasing attention since the 1970s (Spengler and Sexton, 1983). Indoor air pollution originates from a combination of several factors: hazardous substances that are emitted from the outdoors, buildings, construction materials, furnishings, equipment, inadequate ventilation, and indoor human activities (Almeida-Silva et al., 2014; Canha et al., 2011, 2013, 2014; Pegas et al., 2011a, 2011b; Weschler, 2009; Viegas et al., 2010).

Particulate matter (PM) is one of the parameters used to characterize indoor air quality (IAQ), since the majority of national and international guidelines consider PM$_{10}$

Address correspondence to M. Almeida-Silva, URSN, IST/ITN, Instituto Superior Técnico, Universidade Técnica de Lisboa, Estrada Nacional 10, Sacavém 2686-953, Portugal. E-mail: marina@ctn.ist.utl.pt
as a monitored air indoor pollutant, among other chemical and physical pollutants (DL no. 79/2006, 2006; HKEPD, 2003; HN 35:2002, 2002; U.S. Environmental Protection Agency [EPA], 2000). However, there is a special challenge concerning interpretation of the data. Exposure assessment to PM is a difficult task, particularly considering the complexity and diversity of its constitution and size (Almeida-Silva et al., 2014). In fact, the relation between human adverse health effects and characteristics of PM is still not conclusive (Almeida et al., 2014; Morawska et al., 2013).

Investigators started to be concerned with exposure to nanoparticles (NP), which occurs essentially indoors, at home, schools, or at the workplace, and depends on the amount of time that an individual spends in areas with high or low concentrations (Coelho et al., 2005). Therefore, it is expected an increase of exposure to NP as a result of enhanced production and use of engineering nanomaterials (Asbach et al., 2009). Common sources of indoor NP include home cooking and heating systems, but other sources such as tobacco smoke, burning candles, vacuuming, natural gas clothes dryers, and other household activities also contribute to indoor NP levels (Weichenthal et al., 2007). Several studies previously showed that airborne NP possess the potential to produce adverse human health effects when deposited into the respiratory tract (Oberdörster et al., 2005; Zhao and Castranova, 2011). The most important part of the lung is the alveolar region, with an enormous surface area that increases the possibility to transfer NP into the bloodstream and subsequently into all end organs of the body. Other potential consequences of exposure are oxidative stress and cancer, which occur due to typical indoor exposure to NP (Weichenthal et al., 2007; Vinzents et al., 2005; Guo et al., 2012).

All these effects may be potentiated in the case of the elderly, since these individuals are more vulnerable to air pollutants and more susceptible to nanoparticles than to larger particles (Weichenthal et al., 2007; Chow and Watson, 2006; Vigotti et al., 2007). Knowledge regarding elderly exposure to NP is still scarce. Thus, the main goal of this investigation was to determine exposure of institutionalized elders to NP, using Nanoparticle Surface Area Monitor (NSAM) equipment (TSI) to calculate the deposited surface area (DSA) of NP into elderly lungs.

**MATERIALS AND METHODS**

**Sampling Sites and Studied Population**

The current study was carried out in four elderly care centers (ECC) located in Loures, which belongs to the metropolitan area of Lisbon, the capital city of Portugal (Figure 1). In total, 193 institutionalized persons more than 65 yr of age were examined, and their personal characteristics are described in Table 1. Most of the elderly studied were women, with an average age of 86 yr. Elderly care center 4 was the institution with most residents, with a total of 66 elders.

A technical questionnaire was applied in order to characterize the ECC infrastructures.
This questionnaire included questions regarding (1) ventilation systems; (2) types of indoor materials; (3) ventilation and cleaning practices; (4) type of building construction; (5) thermal isolation of the building; and (6) characterization of the building envelope. Table 2 summarizes the obtained results. ECC 1, 2, and 3 are located in a suburban area, whereas ECC 4 is in an urban area. Only ECC 1 has a heating, ventilation, and air conditioning (HVAC) system; however, its utilization is rare. The floor of ECC 2 and ECC 3 is covered with wood in both bedrooms and living rooms. The material of ECC 1 and ECC 4 bedroom floors is vinyl and the floor materials of living rooms are made of epoxy and tile, respectively. For all ECC the windows are made of aluminum with double glass. The cleaning maintenance frequency varied from once a day to once a week for the living rooms, where the indoor microenvironment had the highest frequency of cleanliness. This fact is due to the large number of elders that spend more than 8 h per day in this microenvironment.

### Airborne Nanoparticles Measurement

Determination of airborne NP deposition in alveolar regions of the respiratory system was assessed for elders living in the four elderly care centers. Measurements were performed during the occupied periods in two different indoor microenvironments: bedrooms and living rooms. All of the selected bedrooms were occupied by two elders to keep the occupancy as a constant and because this occupancy reflects the reality of the majority of the bedrooms in the studied elderly care centers. As the physical characteristics of all bedrooms in each ECC were equivalent, it was decided to select only one bedroom per ECC and to perform longer measurements in order to identify temporal patterns. In each elderly care center, measurements in bedrooms were made during the night, varying between 11 and 16 h, depending on ECC routine.

Regarding the living room, only ECC 1 and ECC 2 have 2 living rooms, both with the same characteristics, and therefore only one of them was selected in each ECC. Measurements in living rooms were made during the day and varied between 11 and 13 h. The sampling was...
repeated during three consecutive days and took place between October and December 2012, avoiding extreme temperatures and humidity.

**Measurement Equipment**

Nanoparticles are described to have an increasing surface area with a decreasing particle size for the same amount of mass. Consequently, from the viewpoint of NP toxicity, determination of NP surface area deposited in the human lung is desirable. Therefore, in this study a Nanoparticle Surface Area Monitor (NSAM) (TSI, model 3550, Shoreview, MN) was used to measure the lung-deposited surface area of particles, expressed as square micrometers of lung surface per cubic centimeter of inhaled air ($\mu m^2/cm^3$). This deposition corresponds to the tracheobronchial (TB) or alveolar (A) regions of the human lung, according to the International Commission on Radiological Protection (ICRP) deposition model developed by the American Conference of Governmental Industrial Hygienists (ACGIH) (ICRP, 1994).

This equipment is based on diffusion charging of sampled particles, followed by detection of the charged aerosol using an electrometer. An aerosol sample is drawn into the instrument continuously at a rate of 2.5 L/min. The flow is split, with 1 L/min passing through two filters (a carbon filter and a HEPA filter) and an ionizer and 1.5 L/min of aerosol sample flow. The flow streams are merged in a mixing chamber, where particles in the aerosol flow mix with the ions carried by the filtered clean air. This patented counterflow diffusion charging brings the aerosol particles into a defined, charged state. The separation of particles from direct interaction with the corona needle and/or the strong field near it reduces particle loss and makes the charging process more efficient and reproducible. The charged aerosol then passes through an ion trap to remove excess ions and charged aerosol. The aerosol then moves on to an electrometer for charge measurement. In the electrometer, current is passed from the particles to a conductive filter and measured by a sensitive amplifier, as shown schematically in Figure 2. The charge measured by the electrometer is directly proportional to the surface area of the particles passing through the electrometer. The equipment was set to only alveolar response settings, as this is the most significant metric.

**Sampling of PM$_{10}$**

PM$_{10}$ were collected gravimetrically by one TCR-Tecora sampler operating at a flow rate of 38.3 L/min onto Teflon filters with a diameter of 47 mm. The sampling time ranged from 10 to 15 h, during the occupancy period for each selected indoor microenvironment: bedroom and living room. The selection of each evaluated microenvironment respected the same criteria described previously. The sampling was repeated over three consecutive days. Outdoor measurements were performed in parallel with a Partisol Plus 2025 Sequential Ambient Particulate Sampler, operating at a rate of 16.7 L/min and collecting particles onto Teflon filters with a diameter of 47 mm.

In order to ensure comparability of the PM$_{10}$ results, an intercomparison test was performed between four different devices placed indoors and outdoors: two TCR-Tecora (low volume sampler) and one Partisol Plus 2025 Sequential Ambient Particulate Sampler and one Leckel MVS6 (medium volume sampler), respectively. Figure 3 shows a reliable correlation between outdoor (Partisol and MVS6) and indoor equipment (both Tecora): $r^2 = .9$ and $r^2 = .8$, respectively.

**RESULTS AND DISCUSSION**

**Elderly Daily Pattern**

Several studies previously evaluated the daily time used by individuals from different countries (Fisher and Robinson, 2011; Eurostat, 2003, 2005, 2006). However, these studies either excluded the elderly or studied simultaneously all age groups. Therefore, due to the scarcity of investigations focusing on time
occupancy by elders living in elderly care centers, a questionnaire was applied to build a time-budget survey for the studied population. In order to identify the microenvironments where elders spend more time, Figure 4 shows that 7% of elders (22 women and 8 men) were bedridden and thus, time was always spent inside their bedrooms. Although a small percentage of older subjects still went outside to stay in the ECC garden or another indoor place, such as family houses, restaurants, or coffee shops, the majority of elders spent their time principally in bedrooms and living rooms. In all ECC the same pattern was observed: from 8:00 to 20:00 the majority of elders were in the living room, moving to the canteen at the mealtimes and to the bedrooms at 21:00. In the specific case of ECC 4 there were elders who sometimes went to sleep in relatives’ homes. It is also possible to observe that in ECC 3 and
ECC 4 elders spent more time in the living room, since they only went to the canteen three times per day.

**PM<sub>10</sub> Concentrations**

Considering the fact that elders spend most of their time in bedrooms and living rooms, the PM<sub>10</sub> concentration was measured in these two indoor microenvironments.

Table 3 summarizes the indoor PM<sub>10</sub> concentrations obtained in bedroom and living room of the four studied elderly care centers. The average PM<sub>10</sub> concentration in bedroom and living room was 11 µg/m<sup>3</sup> and 19 µg/m<sup>3</sup>, respectively. The living rooms displayed significantly higher PM<sub>10</sub> concentrations compared to bedrooms. There are more individuals standing and walking in living rooms than there are in bedrooms, including support help and elders. The fact that the level of PM is influenced by occupancy might explain high PM<sub>10</sub> concentrations present due to their resuspension (Almeida et al., 2010). PM<sub>10</sub> indoor concentrations did not exceed the limit value of 150 µg/m<sup>3</sup> established by the Portuguese legislation for indoor air (DL no. 79/2006). Living rooms of ECC 4 followed by ECC 3 presented the highest concentration of PM<sub>10</sub>. In bedroom, ECC 1 presented the highest PM<sub>10</sub> levels. A study developed in UK residences noted similar results: PM<sub>10</sub> average concentration measured in living rooms.
TABLE 3. PM$_{10}$ Average Concentration (µg/m$^3$) in Bedroom and Living Room of Studied Elderly Care Centers

<table>
<thead>
<tr>
<th>Microenvironments</th>
<th>Sampling time$^a$ (h)</th>
<th>PM$_{10}$ (µg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECC 1</td>
<td>Bedroom 36</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>13</td>
</tr>
<tr>
<td>ECC 2</td>
<td>Bedroom 36</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>19</td>
</tr>
<tr>
<td>ECC 3</td>
<td>Bedroom 36</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>19</td>
</tr>
<tr>
<td>ECC 4</td>
<td>Bedroom 36</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>24</td>
</tr>
</tbody>
</table>

$^a$Sampling was performed during three consecutive occupied periods.

The deposited surface area in elderly lungs was also determined in both indoor microenvironments, bedrooms and living rooms. Table 4 reports the deposited surface area measured by the NSAM, which ranged from $10 \, \mu m^2/cm^3$ to $46 \, \mu m^2/cm^3$. The application of the Mann–Whitney test showed that living rooms presented significantly higher results compared with the assessed bedrooms, and it was the bedroom (p = 0.00) of ECC 2 that displayed the lowest levels of exposure considering the other assessed bedrooms. In fact, it is important to consider that cleaning of these microenvironments is conducted by dry rather than wet procedures, which might promote resuspension of particles. In ECC 2 the periodicity of cleanliness is only once a week, which may explain the low values of deposited NP. The living room from ECC 3 presented the highest value of deposit per surface area ($46 \, \mu m^2/cm^3$).

Comparing the PM$_{10}$ results with NP deposited surface area in elderly lungs, it was found that living rooms that showed the highest concentration of PM$_{10}$ were similar to the highest average of DSA: ECC 3 and ECC 4. Both living rooms and bedrooms of ECC 1 and 2, respectively, were the two indoor microenvironments that presented lowest results of PM$_{10}$ and also DSA. Figure 5 shows the correlation between PM$_{10}$ and DSA presented as $r^2 = .75$.

TABLE 4. Deposited Surface Area (DSA) Into Elderly Lungs by Nanoparticles

<table>
<thead>
<tr>
<th>Microenvironments</th>
<th>Exposure time$^a$ (h)</th>
<th>Average DSA ($\mu m^2/cm^3$)$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECC 1</td>
<td>Bedroom 36</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>19</td>
</tr>
<tr>
<td>ECC 2</td>
<td>Bedroom 24</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>24</td>
</tr>
<tr>
<td>ECC 3</td>
<td>Bedroom 36</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>46</td>
</tr>
<tr>
<td>ECC 4</td>
<td>Bedroom 24</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Living room 36</td>
<td>38</td>
</tr>
</tbody>
</table>

$^a$Exposure time occurs during the period occupied by elderly.  
$^b$Considering an average lung area of $80 \, m^2$. 

Nanoparticles Deposited in Elderly Lungs

ranged from $13 \, \mu g/m^3$ to $22 \, \mu g/m^3$ (Nasir and Colbeck, 2013). In contrast, comparing the current results with the majority of studies developed in different indoor microenvironments it is possible to affirm that PM$_{10}$ concentration evaluated inside ECC was quite low. Indeed, in these indoor microenvironments there is no significant movement since most of the institutionalized elders are semi-autonomous. Consequently, the possibility of resuspension of dust is diminished compared with other crowded indoor environments, such as hospitals, schools, and offices (Almeida et al., 2013; Canha et al., 2012a, 2012b; Pegas et al., 2010). Slezakova et al. (2012) detected in a Portuguese hospital PM$_{10}$ variation of $13 \, \mu g/m^3$ to $59 \, \mu g/m^3$. Zwodziak and coworkers (2013) studied IAQ in schools from Poland and showed a range of PM$_{10}$ average concentration between $43 \, \mu g/m^3$ and $69 \, \mu g/m^3$. Almeida et al. (2010) found in schools higher PM$_{10}$ concentrations than data obtained in this study, where values ranged between $30 \, \mu g/m^3$ and $146 \, \mu g/m^3$. In addition to the low concentrations measured in this study, it is well known that PM$_{10}$ enhances adverse health effects, and it is unclear whether a threshold concentration exists for PM below which no marked effects on health are likely. Further, in this study not only is the elderly population considered more susceptible to air pollutants, but these individuals also live and spend most of their time in these microenvironments.
FIGURE 5. Correlation between PM$_{10}$ and deposited surface area into elderly lungs.

Some factors such as indoor and/or outdoor emission sources, ventilation and/or infiltration rates, and human activities might lead to this discrepancy. Table 5 aimed to compare the deposited surface area measured in this study with results determined by different authors in different environments. Results showed that deposited surface area obtained in the current study was lower compared with the majority of the other studies. Considering only occupational studies, the Avian Base study presented lowest deposited surface area (Buonanno et al., 2012), probably due to the fact that this investigation was performed in outdoor environments. The results related to cooking activities provided similar results among themselves, even considering different types of cooking activities (Bordado et al., 2012; Buonanno et al., 2010). These results were higher compared with the current study, because besides the existence of cooking activities in ECC, cooking is performed in specific and delimited areas where elders are not allowed to enter. Therefore, the distance between cooking activities and exposure points is higher in ECC.

Considering the other susceptible population,—children—it is possible to observe that their deposition surface area was higher compared with data obtained in this study (Buonanno et al., 2013). Both elders and children are considered a susceptible population. Children are more susceptible to environmental pollutants since they breathe more air relative to their body weight and also have a lower capacity to deal with toxic chemicals (Firestone et al., 2008; Selgrade et al., 2008).

In order to characterize and understand the NP-deposited surface area in alveolar regions of the respiratory system of elders, temporal distribution was determined during the occupied period. Figure 6 shows the temporal variation of deposited surface area into elderly lungs evaluated in bedrooms and living rooms. The temporal distribution of deposited surface area in bedrooms showed a pattern throughout the night campaign characterized by a decrease of DSA. In ECC 1, ECC 2, and ECC 4, peaks associated with the entrance of the ECC supporters were identified. In living rooms, it is possible to observe higher DSA values compared with bedrooms, and this phenomenon is associated with entrance and exit of the elderly in

<table>
<thead>
<tr>
<th>Authors</th>
<th>Type of study</th>
<th>Site</th>
<th>DSA (µm$^2$ cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>Indoor</td>
<td>Bedroom (ECC)</td>
<td>1.8E1</td>
</tr>
<tr>
<td>This study</td>
<td>Indoor</td>
<td>Living room (ECC)</td>
<td>3.2E1</td>
</tr>
<tr>
<td>Buonanno et al., 2012</td>
<td>Occupational</td>
<td>Avian Base</td>
<td>3.6E0</td>
</tr>
<tr>
<td>Wilson et al., 2007</td>
<td>Outdoor</td>
<td>Minneapolis</td>
<td>1.5E1</td>
</tr>
<tr>
<td>Albuquerque et al., 2012</td>
<td>Outdoor</td>
<td>Trailer near traffic road</td>
<td>6.6E1</td>
</tr>
<tr>
<td>Gomes et al., 2012</td>
<td>Occupational</td>
<td>Tungsten inert gas</td>
<td>2.8E2</td>
</tr>
<tr>
<td>Bordado et al., 2012</td>
<td>Indoor</td>
<td>Cooking</td>
<td>3.1E2</td>
</tr>
<tr>
<td>Buonanno et al., 2010</td>
<td>Indoor</td>
<td>Pizzeria</td>
<td>3.6E2</td>
</tr>
<tr>
<td>Gomes et al., 2012</td>
<td>Occupational</td>
<td>Metal active gas</td>
<td>7.7E2</td>
</tr>
<tr>
<td>Buonanno et al., 2013</td>
<td>Indoor + outdoor</td>
<td>Children daily exposure</td>
<td>1.3E3</td>
</tr>
<tr>
<td>Gomes et al., 2012</td>
<td>Occupational</td>
<td>Friction stir welding</td>
<td>1.1E4</td>
</tr>
</tbody>
</table>
FIGURE 6. Temporal distribution of deposited surface area in bedrooms and living rooms of all studied elderly care centers. Results are presented in µm²/cm³.

living rooms, increasing the movement in that indoor microenvironment. ECC 1 presented one high peak at 12 h, which corresponded to lunchtime. This peak may be attributed to two factors: (1) increase of movement by elders and supporters due to movement to the canteen, and (2) transport of NP from cooking activities into the living room. Both reasons may justify the increase of deposited surface area into elderly lungs. In the living room of ECC 3 most elders are dependent and therefore only occupied the living room in the morning between 9 and 10 a.m. and stayed there all day.

CONCLUSIONS

In this study, a time-budget survey was applied to achieve an occupancy daily pattern in an elderly population. In total, 193 institutionalized elders participated in the current study, ranging from 76% females to 24% males with an average age of 86 and 84 yr, respectively. Our survey results showed that elders spent most of their daily time in indoor environments, essentially in bedrooms and living rooms. PM₁₀ concentration was measured in both identified indoor microenvironments in order to characterize indoor contamination with this pollutant. On average, PM₁₀ concentration in bedrooms and living rooms was 11 µg/m³ and 19 µg/m³, respectively, with the concentration in living rooms significantly higher compared to bedrooms. In general, PM₁₀ concentrations assessed in ECC were lower compared with other research studies. It is conceivable that differences in the current investigation might be related to variation in institutional characteristics where older people live and spend most of their time. The deposited surface area ranged from 10 µm²/cm³ to 46 µm²/cm³ and, similar to PM₁₀ concentrations, the living rooms presented significantly higher results than bedrooms. DSA obtained in the current study were lower compared with the majority of other studies. Data indicate the need to develop further studies considering the elderly population and the places where they spend the majority of their time. The higher susceptibility and growing
number of individuals greater than 65 yr of age globally emphasize the need to increase knowledge concerning their exposure to air pollutants.

FUNDING

The study would not be possible without the assistance of the Câmara Municipal de Loures, by Dr. Luzia Sousa and Dr. Beatriz Reis. We gratefully acknowledge Fundação para a Ciência e Tecnologia (FCT) for funding M. Almeida-Silva by a PhD fellowship (SFRH/BD/69700/2010).

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