Indoor air quality in Porto elderly care centers: the GERIA project answers

Ana Mendes[1], Lívia Aguiar[1], Cristiana Pereira[1], Maria Paula Neves[1], Diana Mendes[1], Rossana Moroni[2], Stefano Bonassi[2], João Paulo Teixeira[1]
[1]Portuguese National Health Institute Dr. Ricardo Jorge, Portugal
[2]IRCCS San Raffaele S.p.A., Italy

ABSTRACT
Indoor environments are often considered to be among the healthiest and safest places, particularly for older individuals who possess unique health needs and environmental sensitivities. It is estimated that people spend 80 to 90% of their day indoors in developed countries, and elderly are likely to spend even more time indoors, thus, indoor air pollutants may have special significance for this age group, even at low concentrations due to long exposure periods. In addition indoor air quality (IAQ) is a key indoor factor that might affect comfort, health and occupants' performance. This study explored the impact of IAQ and buildings assessment in 22 elderly care centers (ECCs) in Porto, Portugal. Indoor environmental parameters were measured twice (winter & summer) in 141 ECCs rooms. These areas were assessed for IAQ chemical and biological contaminants. It was also performed a building and ventilation characterization survey. Our results point out that: (i) Overall $PM_{2.5}$ mean concentration of the 22 ECCs was above the reference levels in both seasons; (ii) TVOC, Bacteria, CO and CO_2 showed significantly higher indoor levels compared to outdoor, in both seasons; (iii) PM_{10}, TVOC, Bacteria and CO_2 presented significant differences between season; (iv) Bacteria and CO_2 showed significant differences between ECC rooms; (v) 4% of fungi samples were positive for *Aspergillus flavus, Aspergillus fumigatus and Aspergillus. niger*. Ongoing analysis is focusing on the interaction between IAQ variables with building and ventilation characteristics.

Keywords: Indoor air quality; Elderly care centers, Building assessment, Ventilation practices, Older people

1. INTRODUCTION
The age of the European population is rising and the percentage of adults aged 65 years and older is projected to increase from 16% in 2000 to 20% in 2020 (Adan O., 2006). It has been estimated that older persons spend about 19-20 hours per day indoor (WHO, 2003). Moreover, elderly care homes have the potential to influence people's lives socially, physically and psychologically (Bradshaw S., 2012). As a result, the study of indoor air quality (IAQ) in the elderly population is becoming an important issue to be addressed by clinical research. In fact, older persons may be particularly at risk of detrimental effects from pollutants, even at low concentrations due to their common reduced immunological defense and multiple underlying chronic diseases. Several health-related effects may be caused (or worsened if already present) by exposure to poor IAQ, including eye irritation, nausea, upper respiratory complications, cognitive impairment, asthma, respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease, and cancer. In this sense it was design the GERIA Project - Geriatric study in Portugal on Health Effects of Air Quality in Elderly Care Centers (www.geria.webnode.com) which will examine 20 elderly care centers (ECCs) chosen among 60 in Porto and Lisbon. This study will provide crucial information about ECCs construction characteristics, indoor environment and prevalence of cardio-respiratory diseases in older persons in Portugal. This paper explore the results of indoor air quality assessment of this ongoing study, analyzing the impact of environmental variables and building characteristics in 22 elderly care centers (ECCs) in Porto urban area, Portugal.

2. MATERIALS AND METHOD
The studied sample (n = 22) was accomplished by convenience where all Porto urban area ECCs were invited to participate (acceptance rate of 39%). Indoor environmental parameters were measured twice, during winter and summer in 141 ECCs rooms within dining rooms, drawing rooms, medical offices and bedrooms including the bedridden subgroup. These areas were assessed for IAQ chemical (CO_2, CO, formaldehyde, TVOC, PM_{10}, $PM_{2.5}$), biological contaminants (bacteria and fungi), as well as temperature and relative humidity (RH). It was also performed a building and ventilation characterization survey and outdoor samples were also collected for comparison.

2.1. Sampling sites
The building characteristics included the following information: type of building construction (concrete or masonry); thermal isolation of the building; characteristics of building envelope (type of windows and doors, presence of weather stripping, etc.); ventilation system (natural, mechanical, or hybrid); types of indoor materials; use of gas burning appliances; evidence of dampness or mold; and ventilation practices (opened windows). The IAQ monitoring phase included daytime air sampling (starting at 10 a.m. and continuing for at least 4 h during normal activities) conducted in a discreet fashion in order not to disturb occupants' normal behavior. Samplers were placed at a height of 0.6–1.5 m above the floor, approximately at the breathing zone level of elderly, and as close as possible to the center of the main area of the room. Sampling points were no closer than 1 m to walls, windows, doors, or an active heating system.

2.2. Sampling methods
PM_{10} and $PM_{2.5}$ samples were collected using polytetrafluoroethylene (PTFE) filters on each correspondent personal environmental monitors (PEM), Gilian personal pumps, and a sample flow rate of 2 L/min following U.S. Environmental Protection Agency (EPA) Method 10-A, "Determination of Respirable Particulate Matter in Indoor Air Using Size Specific Impaction". Each filter was weighed before and after sampling, under controlled temperature (20 ± 1 °C) and RH (50 ± 5%), using an electronic microbalance. Static charges were eliminated using a non-radioactive ionizing air blower (EXAIR, model number 7907). Concentrations were calculated from the difference in filter weight and sample air volume. TVOC samples were collected by drawing air through a stainless-steel sampling tube containing Tenax TA using a personal air sampling pump (SKC Pocket pump) at a flow rate of 0.05 L /min for a period of 45 min. Analysis of TVOC was performed by automatic thermal desorption coupled with capillary gas chromatography (GC) using a Perkin Elmer ATD 400 and AutoSystem GC fitted with flame ionization detector (FID) and an SE30 column, according to ISO 16000, part 6, as well as an internal method based on ECA Report 1997. Formaldehyde was measured by active sampling using 2,4-dinitrophenylhydrazine- coated glass fiber filters in Millipore Swinnex-13 filter holders, personal pumps (SKC AirChek 2000), and a flow rate of 0.8 L /min. Concentrations were determined by high-performance liquid chromatography (HPLC) using an internal methods based on NIOSH 2016:2003. All the pumps mentioned above, were calibrated and checked prior and after each sample using a Gillian Gilibrator-2 air flow calibrator. CO_2, CO, RH and temperature were determined using a portable IAQ monitor (GasData, model PAQ) during the occupied period. Short term measurements (30 min average) were collected in each room. After the equipment stabilized, measurements were recorded continuously using PCLogger 32 V3.0 software. Microorganism air sampling was conducted following NIOSH 0800:1998, using a microbiological air sampler (Merck air sampler MAS-100), an airflow rate of 100 L /min, and 2 agars, *tryptic soy agar* (TSA) for total bacteria and *malt extract agar* (MEA) for fungi. Both indoor and outdoor samples (250 L) were collected in duplicate with one field blank per culture medium per day. To quantify fungi, samples were incubated at 25 °C. Identification of fungal colonies was based upon phenotypic characteristics and followed standard mycological procedures. Bacteria were incubated at 37 °C. Results were expressed as colony-forming units per cubic meter of air (CFU /m^3).

2.3. Calculation
The IAQ assessment results were compared to international reference levels, since the national reference levels are currently being updated to reflect recent changes. Classical statistical methods were used to estimate means and frequencies (percentages) in order to obtain insight into the ECCs characteristics and environmental monitoring results within and between buildings. The variables were tested for normality with Shapiro-Wilk test revealed a non-normal distribution. Mann-Whitney (U) test and Kruskal-Wallis (H) for independent samples were conducted for seasonal effects assessment, indoor/outdoor and within buildings location differences. A 0.05 level of significance was used for all analyses. All data were analyzed using IBM SPSS 21.0.

3. RESULTS AND DISCUSSION

3.1 Elderly care centers building survey
The 22 ECCs were located in the urban area of Porto, where 79% (n=17) of these buildings were closed to roads with heavy traffic, and housing a total of 716 persons with a range of 7 to 136 occupants per building distributed by an average of 3 floors. Most (66%) of the studied ECCs were adapted of an existing residential building to this role and 40% were also developing activities of day care centers for elderly. ECCs mean age is 111 years with a range of 8 to 313 years, as well as, an average of 7 years for building retrofit. Most of them were built in stone masonry construction (49%) with single pane windows (87%), where only 30% have roof and walls insulation. Moreover, 61% of the sampled buildings presented indoor condensations and infiltrations along walls and roofs. The ceramic tile was the common roof lining (87%) and the indoor floor was typically (48%) cover by Vinyl (PVC). Twelve buildings (53%) provided central heating while the others had only autonomous devices, exception made to 1 ECC that implemented both devices. Concerning the energy sources supply for the heating system, the electricity and gas source had the same individual distribution along the sample (39%) and only 1 ECC had both sources for running the heating system. All ECCs were smoke-free. Regarding the ventilation type, 87% had mixed ventilation (natural ventilation in the rooms along with exhaustion systems in the kitchen and bathrooms) while 13% had only natural ventilation in all the indoor areas.

3.2. Indoor air quality assessment
During monitoring, the mean daily ambient air temperatures in Porto were 17°C [11°C – 23°C] with 49% [18% - 80%] RH in the winter and 24°C [17°C – 34°C] with 47% [18% - 76%]. Table 1 presents the overall ECC indoor air analysis. All the parameters mean concentration, with exception of $PM_{2.5}$, are within the reference levels. However there are maximum levels regarding PM_{10}, TVOC, CO_2, bacteria and fungi that exceed the reference levels and might compromise the comfort indoors. Formaldehyde samples also show a winter maximum level 3.2 times above the reference, but this might have happened during *bricolage* activities with the windows closed since the majority of the furniture in the ECCs is antique. Furthermore, 4% of fungi samples were positive for *Aspergillus flavus*, *Aspergillus fumigatus and Aspergillus niger*, which may cause invasive lung infections in susceptible individuals as elderly. Table 1 also shows the significant differences between season and indoor/outdoor, which reveals season significant differences for PM_{10}, TVOC, Bacteria and CO_2 and significantly higher indoor levels compared to outdoor for TVOC.

Bacteria, CO and CO_2 in both seasons. This suggest that indoor pollutants from ECCs activities have an influence in IAQ, especially in the winter season where windows are more closed due to cold weather. The season significant differences may indicate behavior differences regarding opening and closing windows. Ongoing analysis is focusing on the interaction between IAQ variables with building and ventilation characteristics to understand the possible relations between buildings framework, occupant's behavior regarding room's ventilation and indoor air pollutants. Additionally, bacteria (p=0.001) and CO_2 (p=0.007) show significant differences between the indoor analyzed areas.

Table 1. Overall ECCs indoor/outdoor air quality analysis by season

	Indoor		Outdoor			
	N	Mean [Min-Max]	N	Mean [Min-Max]	*p*	References
PM_{10} (mg/m³)						
SUMMER	139	0.066 [0,02 – **1.73**]	24	0.05 [0.02 – 0.25]		
WINTER	138	0.067 [0.02 – **0.43**]	24	0.06 [0.02 – 0.21]	0.006*	0.15 [a)]
$PM_{2.5}$ (mg/m³)						
SUMMER	120	**0.09** [0.02 – **2.12**]	20	0.05 [0.02 – 0.18]		
WINTER	119	**0.06** [0,02 – **0.86**]	20	0.05 [0.02 – 0.29]	-	0.035 [a)]
TVOC (mg/m³)						
SUMMER	129	0.11 [0.01 – **2.53**]	22	0.17 [0.01 – 2,6]		
WINTER	137	0.13 [0.01 – **0.93**]	20	0.04 [0.01 – 0.3]	0.004* / 0.001†	0.2 [b)]
Formaldehyde (mg/m³)						
SUMMER	77	0.002 [0.0002 – 0.06]				
WINTER	84	0.008 [0.0002 – **0.32**]		-	-	0.1 [c)]
CO (mg/m³)						
SUMMER	137	0.7 [0.1 – 7.1]	24	1.3 [0.1 – 7.7]		
WINTER	137	0.6 [0.1 – 3.0]	24	0.9 [0.1 – 3.5]	0.03†	10 [c)]
CO_2 (mg/m³)						
SUMMER	137	786 [538 – **2313**]	24	590 [384 – 893]		
WINTER	137	1125 [541 – **2697**]	24	609 [516 – 879]	0.001* / 0.001†	1300 [e)]
Bacteria (CFU/m³)						
SUMMER	137	329 [6 – **2282**]	23	162 [24 – 616]		
WINTER	133	258 [14 – **996**]	23	89 [8 – 368]	0.01* / 0.001†	below outdoor [until 350 CFU/m³ more] [f)]
Fungi (CFU/m³)						
SUMMER	132	305 [6 – **2224**]	23	531 [20 – 3454]		
WINTER	130	260 [18 – **2812**]	22	208 [62 – 676]	-	500 [g)]

* Significant differences by Season (Summer/Winter); † Significant differences by Indoor/Outdoor; a) EPA, 2012; b) ECA, 1997; c) WHO, 2010; e) FSIAQ by Thade Report, 2004; f) Ordinance 353-A/2013; g) WHO, 2009.

4. CONCLUSIONS

Indoor environmental health risks may depend in complex and subtle ways on factors such as the time pattern of exposure, as well as on the age, gender, genetic heritage, and underlying state of health of the exposed persons. There is a clear need for more studies on indoor pollutants and health in the elderly, with focus on exposure assessment, developing a better understanding of identification and characteristics associated with susceptibility to the adverse effects.

5. ACKNOWLEDGMENTS

This research is supported by GERIA Project: PTDC/SAU-SAP/116563/2010 and a PhD Grant (SFRH/BD/72399/2010) from '*Fundação para a Ciência e Tecnologia*' (FCT).

6. REFERENCES

Adan O., N.-A.-T. J., Hanke W., Sigsgaard T., Hazel P., Wu F. (2006). In Search of a Common European Approach to a Healthy Indoor Environment. *Environmental Health Perspectives, 115*, 983-988.

Bradshaw S., P. E. a. R. A. (2012). Living well in care homes: a systematic review of qualitative studies. *Age and Ageing*. doi: 10.1093/ageing/afs069

World Health Organisation. (2003). Housing and Health: Identifying Priorities - Meeting Report. Bonn, Germany: World Health Organization.